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Agent-based model and Geographic Information System (GIS):
an integrated approach to test sustainable policies and urban transformation scenarios

By

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Declaration

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…….....
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Abstract

When dealing with the city and the processes that characterize it, we face an extremely complex system, in which multi-dimensional aspects, multi-scalar, and multi-temporal perspectives are strongly relevant. Within this context, the increasing awareness of the fundamental role of sustainability issues and the necessity of long-term perspectives in urban transformation and planning urgently require the identification and evaluation of the environmental, economic, and social impacts of alternative policies and strategies.

The research aims to support decision-making processes for the development of sustainable policies and long-term strategies in urban contexts by proposing an integrated evaluation approach, strongly focused on individuals, stakeholders, and their decision-making processes. In this perspective, sustainability development is proposed as an inherently anthropocentric view around the success or failure of strategies, policies, and urban transformations in a long-term sustainable view. The analysis of alternative policies and urban transformation scenarios is conducted in a holistic way through the application of an integrated approach, able to consider the complexity of urban phenomena, their performances, and consequences over time in a real-world context, starting from the analysis of the system from a bottom-up approach. This implies that the evaluation is grounded in people (i.e., individuals and/or stakeholders), their behaviours, and interactions, capturing and analysing emergent phenomena over time.

The final objective is to identify the key drivers and key effects that guide these processes and connect them to the specificities of a place and its population.

To achieve the goal, the research integrates an agent-based model (ABM) with the potential of GIS, to combine the attitudes and behaviours of the stakeholders in a temporal and dynamic perspective with the consideration of the spatial dimension of the urban complex problems. Also, Multicriteria Analysis (Analytic Hierarchic Process and Best-worst Method), the Choice Experiment method, the Hedonic Price Model, and specific surveys are implemented to include in the model more intangible data related to the social attitudes of the population, their decision rules, and the level of importance of the aspects considered.

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Abbreviations

AHP	Analytic Hierarchy Process
ABM	Agent-based model
ANP	Analytic Network Process
BAU	Business-as-usual
BWM	Best-Worst Method
BWS	Best-to-Worst Scaling
CA	Cellular Automata
CE	Choice Experiment
CIE	Community Impact Evaluation
CBA	Cost-Benefit Analysis
CBD	Central Business District
CVM	Contingent Valuation Method
DCF	Discounted Cash Flow
DRSA	Dominance-based rough set approach
EC	European Commission
ELECTRE	ÉLimination et Choix Traduisant la REalité ELimination Et Choice Translating REality
EU	European Union
DM	Decision-maker
GIS	Geographic Information System
GSE	Gestore Servizi Energetici
GUI	Green Urban Infrastructures
HPM	Hedonic Price Method
KGUV	Kelvin Grove Urban Village
LISA	Local Indicators of Spatial Association
LVM	Lotka-Volterra Model
LUCC	Land-use and land-cover change
MAS	Multi-agent system
MAVT	Multiattribute Value Theory
MCDA	Multicriteria Analysis
MNL	Multinomial Logit Model
MSM	Microsimulation Simulation Model
NAIADE	Novel Approach to Imprecise Assessment and Decision Environments
ODD	Overview, Design concepts, and Details

OLS	Ordinary Least Square
PM	Policymaker
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PV	Photovoltaic
QUT	Queensland University of Technology
RA	Relative Agreement
RP	Revealed Preferences
RPL	Random Parameters Logit
RUM	Random Utility Model
SA	Stakeholder Analysis
SAR	Spatial Autoregressive model
SA1	Statistical area 1
SEM	Spatial Error Model
SDGs	Sustainable Development Goals
SDM	System Dynamic Model
SNA	Social Network Analysis
SP	Stated Preferences
SROI	Social Return on Investment
SWN	Small World Network
TCM	Travel Cost Method
TEV	Total Economic Value
TPB	Theory of Planned Behavior
WTA	Willingness To Accept
WTP	Willingness To Pay

OVERVIEW

Chapter 1

Introduction to the thesis

a. Research Topic

The present research aims to investigate the potential of a recent approach in urban empirical studies called agent-based model (ABM) or multi-agent system (MAS)[1]. Starting from the analysis of the state of the art of ABM/MAS research contributions, with particular reference to the ones concerning urban studies, the main topic is to understand the role of ABM/MAS in this field. More specifically, the research focus is on the potential capabilities of ABM/MAS as a tool for direct empirical research, both to evaluate urban transformation scenarios and to test sustainable policies. Attention is paid to its integration with Geographic Information System (GIS) to analyse the consequences of sustainable policies and transformations in a real-world environment. Different applications are implemented to understand the flexibility of this simulation model where agents (i.e., individuals and stakeholders) with their objectives, expectations, and interactions have a central role as catalysts in the diffusion or inhibition of sustainable processes in urban contexts. Critical reflections are also included to highlight the pros and cons of this simulation model, with a strong focus on the analysis of the results of the case studies developed. The research provides a methodological perspective and a framework for analysing different urban problems based on the integration of ABM/MAS with GIS and more traditional evaluation models.

[1] Some publications refer to MAS rather than ABM. However, the literature does not agree with the similarities and differences between ABM and MAS. In many cases, the use of one term or another depends on the field of research in which they are applied, but, in some cases, MAS is used to define a sort of separation of logical components of intelligent systems (Hinker et al., 2017). This PhD thesis generally uses the two terms as synonyms. Nevertheless, the author prefers the use of ABM when referring to the simulation of individual behaviours, whereas MAS is used for stakeholder behaviours.

b. Keywords

Agent-based model, Multi-agent system, Policy scenario, Scenario building, Decision-making process, Policymaking, Geographic Information System (GIS), Simulation model, Dynamic model, Urban transformation, Urban regeneration, Urban planning.

c. Research questions

- *Why evaluation methods in urban and regional development? And why ABM/MAS?*

The first question intends to understand the role of evaluation methods in urban and regional development and why they have become a fundamental instrument to study urban phenomena and test different development strategies.

The analysis starts with a classification and overview of these evaluation methods. In particular, their strengths and weaknesses are highlighted with reference to their inclusion of individual and stakeholder behaviours and preferences. Then, the dissertation goes deep into the investigation of a specific simulation model called ABM/MAS.

- *What aspects of urban transformations could ABM/MAS study?*

The second question, connected to the previous one, aims to highlight the characteristics and potential of ABM/MAS compared to other evaluation methods. Starting from ABM/MAS evolution over time, particular interest is given to the analysis of the literature related to this model and its application for studying urban phenomena. Past and present contributions provide information to assist in the preparation of the PhD thesis applications, as well as to understand the fields of analysis that have not been explored yet or have not been fully examined.

- *How does ABM/MAS support policymakers (PMs) and decision-makers (DMs) in the definition of future sustainable policies and sustainable urban transformations?*

This question represents the core question of the entire research thesis. Answering means reaching the objective of this PhD research. More insights are needed in the exploration of ABM/MAS to evaluate urban transformations, planning scenarios, and sustainable policies with a long-term perspective and from a bottom-up approach. In particular, the adoption of this approach in its empirical term and integration with spatially explicit data has partially been explored in that

context.

The different applications developed, and the following insights, provide an overview of ABM/MAS capability, usefulness, but also limitations within this context.

1.1 Context of study and aims of the research

The adoption of evaluation methods in urban and territorial decision-making and policy-making processes has become increasingly important due to the new urgent questions and needs of a turnaround in the past (but also present) paradigm of development of our cities. The European Union (EU) has recently adopted many directives aimed at promoting energy redevelopment, the diffusion of zero-energy buildings, and the shift from the vision of efficient single buildings to larger scales with a view to post-carbon cities. However, the achievement of sustainable growth, the reduction of greenhouse gases, and energy consumption are not enough. A wide range of dimensions must be investigated and considered in a decision-making process, such as social, territorial, economic, and environmental aspects, in particular in their variable spatial configuration. Moreover, the transition from the analysis of single buildings to districts or urban scales inevitably requires *ad hoc* tools and approaches able to manage various urban data sets.

In that context, the ability of evaluation methods to structure decision-making processes and of GIS to collect, store, retrieve, transform, and display spatial data is fundamental to effectively supporting real-world problems. However, traditional evaluation methods, both spatial and non-spatial, still fail in the consideration of the evolving dynamics of urban phenomena. At the same time, they are not able to include the effects caused by the relations and interrelations among different stakeholders over time. This gap inevitably requires, firstly, the adoption of dynamic models able to include time in the analysis; secondly, the consideration of the spatial information of people and places; and thirdly, the integration of different approaches able to take into account all the dimensions involved and the role of individuals and stakeholders.

The present PhD research is perfectly in line with these considerations, proposing the use of an innovative mixed method that combines various traditional models and methodologies (such as Hedonic Price (HPM), Choice Experiment (CE), Multicriteria Analysis (MCDA), and surveys) with ABM/MAS and GIS. The idea is to move forward from traditional evaluation approaches by adopting an integrated approach that combines the multi-dimensional perspective of urban complex problems with their inherent spatial, temporal, and dynamic dimensions. These latter aspects, combined with the bottom-up structure of ABM/MAS, are extremely relevant in the definition and analysis of future sustainable policies and actions in a long-term perspective.

Therefore, the aims that guide this PhD research are twofold and connected.

The first one is related to the investigation of the role and potential of ABM/MAS in the assessment of urban phenomena. In particular, ABM/MAS is used in this thesis to evaluate alternative sustainable policies and scenarios. The second one is based on the willingness to bridge the gap between theory and practice in a view of sustainable development in urban contexts from a bottom-up perspective. Starting from some theoretical insights concerning sustainable development in urban contexts, the aim is to identify the fundamental issues and gaps to be applied in the study of sustainable policies and scenarios in real-world case studies.

Within this context, the choice to have ABM/MAS, as a common assessment method for all case study applications, is not random. Due to this complex nature, the evaluation of long-term policies and long-term effects of urban transformations based on a sustainable perspective seems to be particularly feasible only with a mathematical or computer-based model (Boulanger & Bréchet, 2005). However, this broad group of models contains a variety of approaches to choose from, but ABM/MAS represents a suitable tool to study and manage the urban systems affected by countless factors, including economic, social, and environmental factors, which are notoriously difficult to simulate (Torrens, 2000). Moreover, the bottom-up structure and individual/stakeholder decision perspective give an adequate representation of micro and macro-relationships. This leads to the simulation of the real impact and effectiveness of different proposed strategies and scenarios, guiding PMs and DMs through the evaluation of different solutions.

The chosen approach and the motivations to apply it arise essentially from some (partially) unanswered questions:

- how to design in an environment characterized by multi-actor interactions and pressures?
- how to understand in advance the best strategies and scenarios in a context of limited efficacy displayed by statutes and market incentives?
- which variables influence the diffusion or adoption of sustainable strategies and actions in a specific environment?

All these questions have strongly shown the need to develop evaluation methods and, in particular, to apply models able to consider the multi-dimensional aspects, multi-temporal perspectives, and multi-actors involved in the development of sustainable policies and actions, and to predict effects and impacts from a long-term perspective.

1.2 Contribution and development of the research

The contribution and innovation of this PhD research thesis are related both to the model (ABM/MAS also in its mixed form) and its empirical applications.

ABM is a relatively new approach in modelling. It has become widely used in many disciplines in the last 15-20 years (Heppenstall et al., 2012), but its role in

urban system research is quite recent. Moreover, its contribution to this field of research is strongly anchored in the development of urban land-use models based on classical theories (beginning with those based on Schelling-style residential segregation and Von-Thünen-Alonso location theory) and the study of urbanization processes (urban growth, urban sprawl, and gentrification) (Huang et al., 2014). However, the real challenge is related to its application, driven by empirical data, to replicate details of specific case studies as a tool for policy and planning analysis. In fact, this kind of model has only recently been proposed to support PM decisions, essentially, in the energy transition (Chappin et al., 2012). More insights and applications are needed to understand its real contribution in supporting policy design and planning processes. Despite the limited development, this approach offers a flexible architecture able to realize a detailed representation of complex systems, including the behaviour of agents, their social interactions, and the environments that surround them (Khansari et al., 2017). Moreover, as mentioned before, the use of ABM to verify the adoption and diffusion of sustainable policies and evaluate the decision-making process in urban transformation is particularly useful thanks to its ability to build the evaluation from a bottom-up approach. There is an increasing need for exploratory tools and techniques that explicitly take into account and integrate the whole range of relevant social phenomena and the interactions among them (Galán et al., 2009). In that context, ABM/MAS represents one of the most promising methodologies to do this (Downing et al., 2001; Moss, 2002).

However, many ABM/MAS applications, also in policymaking, consider the environment (anything outside the agent) as an abstract space. However, an error is to give insufficient consideration to situational and spatial factors. For that reason, testing policies and strategies in the real-world system plays a pivotal role in their effectiveness and efficiency. To do this, the integration of real data from GIS is starting to assume growing interest, providing the ability to have agents that are related to actual geographic locations (Crooks, 2012; Crooks et al., 2019) and, from that, can also acquire and share information.

Apart from ABM/MAS and GIS integration, the present thesis additionally proposes a mix of methods. This is essentially because ABM/MAS requires a large amount of data for its correct implementation and validation. The simulation of individual and/or stakeholder behaviour is not a simple task and cannot rely on too many assumptions and hypotheses. Methods, such as MCDA, CE, and HPM, essentially bridge this gap, helping, for example, with problem structuring, the elicitation of preferences and relative weights, as well as the verification of the model rules.

Moreover, these thesis applications of the ABM/MAS-based mixed approach are also innovative in the sense that they explore urban policies, phenomena, and scenarios in empirical and spatial terms, as rarely happens in ABM/MAS literature. Among the different software to implement ABM/MAS, this PhD thesis adopts Netlogo. Netlogo is a free downloadable tool, characterized by its intuitive

interface, effective graphic support, ease of use – also in code writing -, and the potential to integrate GIS maps (Chen, 2012; Tisue & Wilensky, 2004).

Three case studies have been developed to test the applicability and usefulness of ABM/MAS in different urban contexts and for various purposes. Specifically, the three case studies are chosen to cover the main topics of sustainable development in urban contexts: (i) socio-energetic topic; (ii) socio-economic topic; and (iii) socio-environmental topic.

The first case study tests the effectiveness and efficiency of existing and new policy mixes in the adoption of sustainable energy technologies, in particular the photovoltaic system (PV). The simulation is developed at the district scale, taking into account contextual factors and individual dynamics. The San Salvario neighbourhood in Turin (Italy) is used as an exemplary case study for the increase in PV adoptions. The results support PMs in effectively designing policy mixes in the specific context under investigation.

The second case study simulates and analyses the gentrification dynamics eventually resulting from market price variation in the districts of Kelvin-Grove and Herston in the city of Brisbane (Australia). Gentrification phenomena and price increases in houses could occur after the realization of a new urban park in proximity to these two districts. The results of the analysis provide PMs with information about the possible effects of this transformation, considering household preferences, house features, and city market trends.

The third case study guides the development of sustainable urban transformation scenarios in consolidated areas, considering the different preferences and behaviours of the various stakeholders involved. The simulation scenario building is applied to the case study of Basse di Stura in Turin (Italy), where a new urban park is expected to be implemented. The simulations provide a set of scenarios that consider, at the same time, the overall sustainable development of the area and the satisfaction of the stakeholders.

In the three cases, the development of a model, strongly based on a bottom-up approach in the evaluation of different strategies and scenarios, gives the opportunity to create an alternative perspective on these complex problems, like those DMs and PMs have to face. However, more than developing an instrument able to give definitive answers on these topics, the final objective is to identify the key drivers and key effects that guide these processes and connect them to the specificities of a place and of its population, and to give a methodology perspective in the study of various problems and processes that specifically characterize the urban dimension.

1.3 Target subjects

When referring to the assessment of urban transformations and sustainable policies, DMs and PMs are the main interested parties in this investigation. Local

administrators and city governments make direct decisions on these actions and policies. So, looking at the existing regulations and proposing more effective options and scenarios should be of interest to them.

At the same time, inhabitants could play an important role in this context, and they could be interested in the way their decisions can modify and shift the current conditions. For example, their actions can improve air quality by reducing CO_2 emissions and energy, water, and waste consumption; they can affect real-estate price variations and the creation of gentrification phenomena; or, even, they can be involved in the participatory planning of urban areas.

Also, providers, companies, or developers with their own decisions could affect government choices and vice-versa.

Since it would be ambitious to assume that the previous figures mentioned were all interested, this PhD research thesis is probably more directed at researchers for the quite innovative contribution of this work, and, in particular, for those interested in predictive and simulation models, as an alternative way to approach urban studies, urban policy scenarios, and planning analysis.

The domain of interest that emerges is quite broad and the number of stakeholders involved and interested is varied and numerous. In fact, it represents quite well the real environment in which PMs and DMs must make decisions. This environment is dominated by a number of components – often conflicting – that must be taken into account, such as social, economic, and environmental aspects, which give rise to an extremely complex context.

1.4 Plan and overview of the thesis

The PhD thesis is structured into nine chapters, as it is also shown in Figure 1.1.

After this introductive chapter (Chapter 1) about the main contents, aims, and contributions of the thesis, Chapter 2 reflects on some theoretical insights concerning sustainable development in urban contexts, with a special focus on the role of people in its achievement.

Chapter 3 presents an overview of the different evaluation methods that support the decision-making and policymaking processes. The focus here is on the differences between static and dynamic models and their ability to include human behaviour in the evaluation of urban transformation scenarios and alternative policies.

Chapter 4 proposes a reflection on the complexity issue and its strong relation with urban studies and the sustainable concept. An introduction to the role of evaluation models is proposed with a focus on ABM/MAS. A literature review of ABM/MAS applications in urban contexts is also included in this chapter.

Chapter 5 contains the methodological part of ABM/MAS. This part gives

more insights into the main elements that characterize ABM/MAS.

Chapters 6, 7 and 8 present the three applications. Each of them applied the mixed-method approach based on ABM/MAS to assess different decision-making problems in urban contexts. Specifically, the three case studies were chosen to explore different pillars of sustainability in urban contexts. Chapter 6 presents a socio-energetic problem, Chapter 7 investigates a socio-economic problem, and Chapter 8 examines a socio-environmental problem.

Chapter 9 summarizes the pros and cons of ABM/MAS based on the results of the three different applications. Starting from these considerations, this chapter provides a general framework and methodological perspective for future research.

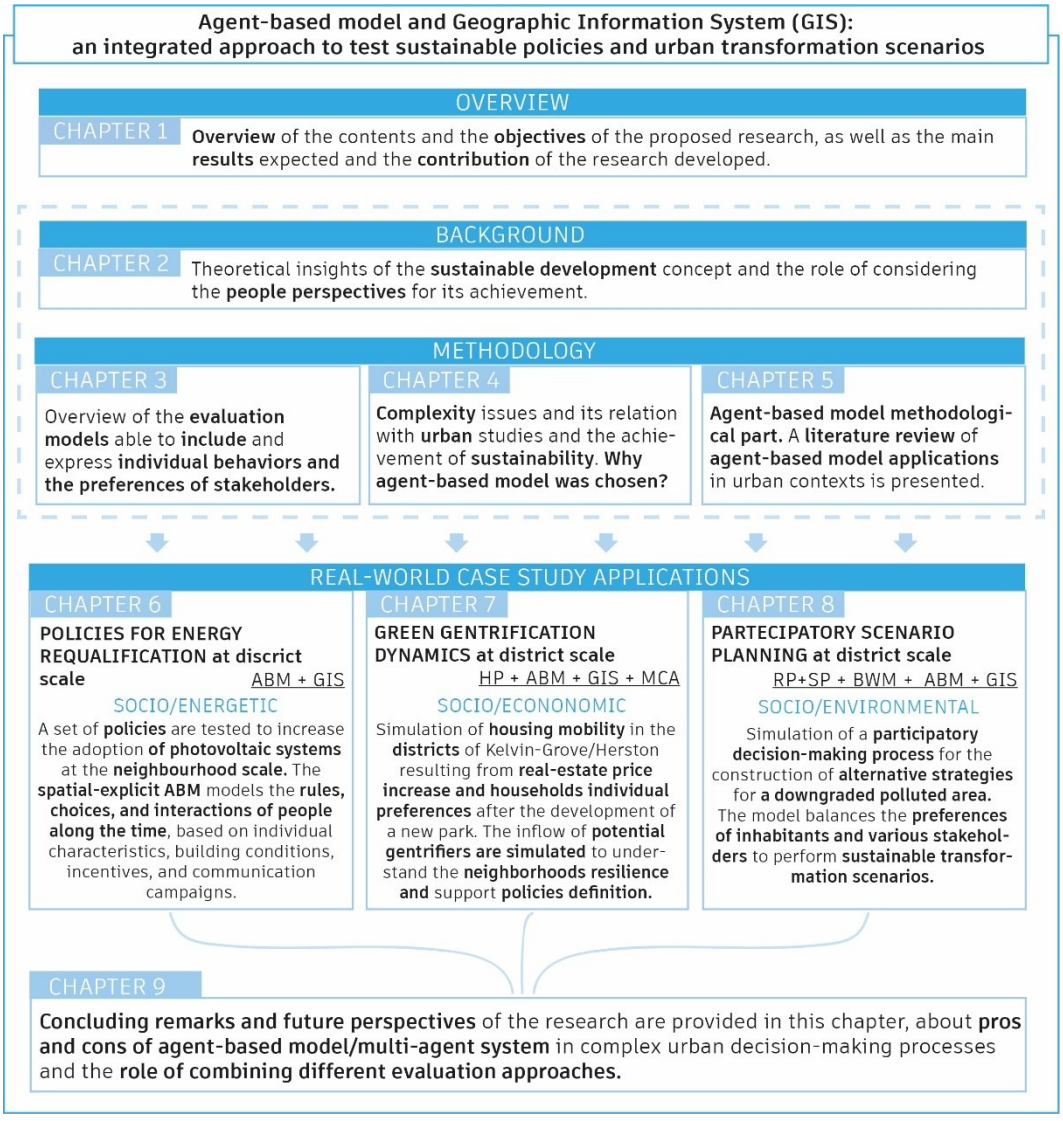


Figure 1.1. Overview of the thesis

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BACKGROUND

Chapter 2

Sustainable development from the people perspective[2]

2.1 Sustainability and sustainable development concepts: what/who is missing?

The concepts of sustainability and sustainable development have been widely explored over time. Many authors have already tried to review these two terms and give a comprehensive vision of their meanings (e.g., Barbosa et al., 2014; Blewitt, 2008; Yolles & Fink, 2014), but, as a result, they showed the variety and, in some cases, conflicting perspectives and meanings connected to these two concepts. This is also the reason why part of academia has expressed some scepticism about these two concepts. They, for example, contest the meaninglessness (O'Riordan, 1988), the randomness between individual preferences and worldviews (Giddings et al., 2002; Jacobs, 1991), the vagueness and fragmentation (Stafford-Smith, 2014; Stokstad, 2015) and commenting as an oxymoron (Daly & Townsend, 1992) or insufficient for guiding policy (Hopwood et al., 2005). While it is true that the sustainable development concept is hard to define and to be operational, it tries to capture and incorporate the essence of today's problems concerning environmental protection and socio-economic development (Holden et al., 2017). For the widespread literature on this theme, more insights are not needed, particularly in this work for its specific purpose. Indeed, the most frequently quoted and accepted definition of sustainable development, proposed by the Brundtland Commission (Brundtland, 1987), is enough to put into light a very relevant and, probably, the

[2] Part of this chapter has been developed in the following paper:

- Bottero, M., Caprioli, C., Cotella, G., & Santangelo, M. (2019). Sustainable Cities: A Reflection on Potentialities and Limits based on Existing Eco-Districts in Europe. *Sustainability*, *11*(20), 5794. https://doi.org/10.3390/su11205794

most critical aspect of the sustainability objective, i.e., people's needs. In some ways, the present research takes the first steps forward from this (critical) element, proposing not a resolution but an attempt to investigate sustainability and sustainable development from the people perspective. In fact, the transition from the sustainability concept to sustainable development goes exactly through the comprehension of the interrelations between more technical aspects and sustainability objectives to the satisfaction of human needs and actions. This latter aspect represents a relevant key driver for supporting an effective transition to a sustainable perspective, particularly in the built environment, which is crucial in this thesis.

As Brandon and Lombardi (2010) pointed out more than 20 years ago, *"the subject of sustainable development is one of the key research and policy issues"*. And this is becoming even more important and urgent in order to support a post-pandemic strategy capable of promoting sustainable development (Barbier & Burgess, 2020). It can happen only through a *"coordinated, decisive, and innovative policy action from the world's leading economies"*, as proposed in the UN Secretary General's report, *Shared Responsibility, Global Solidarity*. Despite the difficult task, the need for a transition of our cities into a sustainable perspective has become a primary aim and an urgent call for current and future urban strategies. City living is both an attractive place (the United Nations predicts that over 60% of the world population will live in urban areas by 2030 (Division, 2018)) and the highest consumer of total final energy (Grubler et al., 2012). At the same time, cities represent a flourishing environment for technological, economic, and socio-cultural development (Kourtit & Nijkamp, 2018).

For all these reasons, the last few decades have seen a succession of programmes and frameworks to achieve this issue: spanning from the very first steps with the definition of sustainable development and the beginning of the major efforts in this line during the Stockholm Conference on Human Environment in the early 1970s and the related report *Our Common Future*, presented by the World Commission on Environment and Development headed by Gro Harlem Brundtland, to the most recent steps with the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) and the 169 targets adopted in 2015, as well as the work of the Inter-Agency Expert Group on SDGs in developing the 232 indicators. The fact that the world community has finally agreed upon common sustainable development goals and worked together to implement them is a great success.

Nevertheless, there is still a need to work on the SDGs (Holden et al., 2017), and the COVID-19 pandemic exacerbates this demand (Heggen et al., 2020). It is even more true when looking at the adoption and implementation of sustainable policies and strategies on a local scale. There is an evident lack of attention to the role of stakeholders and individuals during the development of sustainable actions. However, individual decision-making strongly involves many barriers, spanning from non-economic motivations to the relevance of situational factors. Failure to

consider these aspects can compromise the sustainability of actions and strategies in real-world contexts (Friege, 2016). According to Müller-Eie and Bjørnø (2017) four areas of conflict can help to explain the slow and reluctant process of implementing sustainability: (i) a non-conclusive relationship between global goal and local realisation; (ii) a non-communicative relationship between institutions and individuals; (iii) a non-compatible relationship between strategic/normative changes and individual desirability; and (iv) a non-commutive relationship between individual attitudes and behaviours. Nevertheless, a sustainable development view involves both the provision of sustainable infrastructure and policy by institutions and the spreading of collective and individual sustainable behaviour (Müller-Eie & Bjørnø, 2014). Individual characteristics do play a role in choice and behaviour, but so does the social and cultural environment: price, social networks, awareness, commitment, moral obligation, routines, cultural norms, comfort, fashion, and convenience all have an impact on individual behaviour (Owens & Driffill, 2008).

Since the main core of this PhD research is to support, in an alternative way, and in particular from a people perspective, the development of sustainable policies and strategies in a real-world environment, those considerations represent the natural and needed baseline. These considerations allow to propose a step forward on the role and potential of evaluation approaches in supporting sustainable development for the development of future cities beyond the triple-bottom-line approach (Sala et al., 2015).

2.2 Sustainable development and the local perspective: the district scale policies

The previous paragraph has highlighted the vagueness around sustainability and sustainable development terms. This vagueness is surely related to the broad range of concepts, strategies, and aspects to be considered. All these components are then diverse at the different scales at which the sustainability concept is expressed and operationalized. For that reason, it is strictly important to analyse and distinguish the term when it refers to a broader or smaller scale. Globally, sustainability should guide, in terms of aims and objectives, the capacity to commonly reduce negative impacts on the global environment and on the social and economic conditions of the world population. Locally, instead, it should strategically provide the coordination between formal and functional strategies in a specific environment (Müller-Eie & Bjørnø, 2017). Over-simplifying, the sustainability concept can be seen as having two sides: once, the goals (common aims and objectives of sustainability) and the other, the concrete implementation (in terms of strategies, actions, and effects) (Müller-Eie & Bjørnø, 2017).

Without ignoring the larger scale and the common strategic goals of sustainability and sustainable development, this research focuses primarily on the second context, the local, and in particular on a specific local, i.e., the

district/neighbourhood scale. This scale is recognized as the appropriate one where institutions are more active and social networks are stimulated, offering several opportunities for participation in collective decisions (Lützkendorf & Balouktsi, 2017). The district is in fact defined as a "meso" level between the buildings and the city, which offers the appropriate scale of analysis for implementing sustainable policies and strategies in urban contexts. In particular, districts are considered a suitable test-bed area for good practices and their upgrading to achieve overall city sustainability.

Concerning this role of districts, in the last two decades, some episodes of change and innovation started to be implemented and referred to under the terms of "eco-district" and "sustainable neighbourhood". It is not within the scope of this research to explore eco-districts and sustainable neighbourhood either in their theoretical meanings or practical experiences around the world (for an in-depth analysis of this, look at Bottero et al. 2019a), but to highlight the centrality of this specific urban scale. This simply explains why, in recent years, many actions have been proposed for district areas and transformation processes have affected a district/neighbourhood.

Recently, with the spread of the COVID-19 pandemic, this "meso" level has assumed greater importance for the definition of policies in urban contexts, since this scale allows people to reach essential services on foot or by bicycle and enjoy new open spaces for recreation and socializing. The COVID-19 epidemic and the restriction measures adopted at national and international levels have shown the need to discuss policies and actions that are truly capable of improving the quality of life of the environment, of people and of the city as a whole. On one hand, experiences and models all over the world—among them the Paris en Commun concept, also known as the "city of 15 minutes", and the "Superblocks" of Barcelona—have assumed even more importance. Reaching workplaces and basic services on foot or by bicycle, according to the French model, or providing new open spaces for pedestrians, cyclists, and children, moving between cycle paths, pedestrian paths, trees, street furniture, leisure and play equipment following the Superblocks model, seems strategic in a post-COVID era (Camerin, 2021).

Nevertheless, examining the numerous experiences of "eco-districts" and "sustainable neighbourhood" around the world (see for example Holden et al. (2015), Bottero et al. (2019a), Medved (2016)) the characteristics and strategies adopted are not homogeneous and follow specific paths. This is also due to intrinsic variability in the meaning of sustainability and neighbourhood, as well as in the role it plays within the urban areas in which it is located. The complex meaning of district/neighbourhood is a critical point that will not be addressed by this work for its scope, but it requires clarification. As pointed out by Choguill (2008) (p. 42), there is not a specific population size or a universal civic function that a district/neighbourhood must fulfil. A neighbourhood/district is not simply an administrative sub-division of a city or urban area. People who live there, as well as their relationships and interactions, play a relevant role in the formation of

identity, a sense of place, and recognition. At the same time, the district/neighbourhood and its relations with the city/urban area are not simply a matter of being a part of the whole, but the interlinkages deserve attention. This is also particularly true in terms of upscaling, side-scaling, and/or transferability of policies (Cassen et al., 2018; Cotella et al., 2015). A policy that fits well in one place could have completely different effects in another or on a broader scale, thus requiring more than a simple imitation of good practices. The specificity of a place and its contextual factors, such as stakeholders, environmental and technical characteristics, social and cultural aspects, types of institutions or innovation, and policy diffusion, must be strongly taken into consideration.

The local scale has also been part of the many proposals implemented at the political level. Indeed, preliminary research-oriented considerations are consistent with several recent policy-oriented directives and plans, particularly those provided by the EU to promote energy efficiency and emissions reductions (see for instance the EU SET-Plan (European Commission, 2017b) or 2050 long-term strategy (European Commission, 2018)). In urban contexts, the vision has shifted from efficient single buildings to larger scales with a view to post-carbon cities. This explains (together with the Clean Energy Package (European Commission, 2017a)) also the increasing interest in the creation of energy communities where members are able to collectively produce, distribute, supply, consume, share, accumulate, and sell their self-produced energy. And in the energy sector, the EU has made its major efforts. However, this purely technologically driven European policy has been widely criticized in the literature, necessitating a more broad focus on urban outcomes by taking technology issues into account alongside other factors such as culture, governance, and metabolism (Allam & Newman, 2018).

2.3 Sustainable development and sustainable policy: the people perspective

This work starts from the idea of concretely considering the people perspective within the sustainable development view and real-world decision-making processes. Real decision-making processes are strongly characterized by interaction dynamics between individuals and different stakeholders, whose preferences and needs are often conflicting. However, these relations and interrelations are not fully explored in the research and in political debates to support the definition of long-term sustainable strategies in urban contexts, as mentioned in Section 2.1. It is not the purpose of this section to discuss behavioural theories and their applications in literature contributions for supporting urban planning, transformation processes, and policymaking. Specific sections are properly devoted to this objective (see, Chapter 4, Section 4.4 and Chapter 5, Section 5.5). Literature review: agent-based model in urban studies). However, it is useful to underline that individual behaviour, also in their upscaling to entire

population behaviours, are often considered simply as direct and linear effects connected to the provision or not of services, incentives, technologies, infrastructures, and so on (Müller-Eie, 2012). The idea that sustainable development agendas are a matter of nations and governments and do not concern individuals is the very first limit of this view. In the subsets of components that characterize cities and urban areas, people represent one of the most relevant forces.

Many phenomena in urban contexts are born from individual behaviour but manifest as a collective behaviour (Findeli, 2008). Individual travel preferences, for example, emerge in travel patterns, i.e. in collective mobility behaviour (Handy, 1996). Many studies have examined collective behaviour and its consequences, but there is a significant gap in the study of individual behaviours and the factors that cause them for policymaking purposes. These aspects are considered immensely important in this thesis since the success or failure of sustainable development in urban contexts passes exactly through them. Many authors point out how education can help in altering lifestyles (Jenks & Dempsey, 2006; Pratt & Larkham, 1996). Others investigate the role of environmental consciousness as *"a function of knowledge of environmental problems"* (Boztepe, 2012). Then, particular importance was given to the influence of values on pro-environmental behaviours (Stern et al., 1999; Thøgersen, 2000), whereas others (e.g. Laroche, Bergeron, & Barbaro-Forleo, 2001; Roberts, 1996) discussed and analysed the correlation of this pro-environmental behaviour with socio-demographic characteristics. Then, environmentally significant behaviours are connected with routine actions (Jackson, 2004). More recent contributions between 2000 and nowadays focus on four main areas of investigation: cognitive barriers, economic incentives and nudges, individual self-identity, social influence and social norms (Trudel, 2018). These simply represent a limited range of examples of how complex but fundamental it is to understand the factors and rules that generate behaviours for promoting sustainable actions.

Another aspect that deserves attention is related to the role of social interaction among people. This topic was briefly touched before on the role of social influence and social norms in individual decision-making processes. In essence, it means that exist a social order, particularly at the local scale (such as at neighbourhood scale), where social interactions and networks among residents are stimulated and prevail (Dempsey et al., 2011). This manifestation assumes the sense of "community", characterized by social networks, norms of reciprocity, and other features of social organization, resulting in social behaviour (Dempsey, 2008). The community achieves relative stability in terms of both resident-migration balances and socio-demographic composition, as well as collective institution participation or a sense of place and trust among residents (Dempsey et al., 2011). Apart from the difficulties of perfectly framing and defining the term "community," as previously mentioned for "neighbourhood" and "district," it is clear that community, like neighbourhood and district, has an inherent and interconnected socio-spatial characteristic. More specifically, the (sustainable) community and (sustainable)

neighbourhood (discussed in the preceding section) must take into account the interdependence of territorial dimension, physical setting, social interactions, and social activity (Gehl, 1987; Mistry, 2008). These interconnected dimensions are further touched upon in this section, in order to clarify the role of individual behaviour and collective aspects of everyday life, which are crucially associated with the features of the built environment (Bramley & Power, 2009). On one hand, the topic of social capital is pivotal in this discourse since it exactly represents the networks of relationships among people who live and work in a particular society (Oxford Dictionary, n.d.). It incorporates interpersonal relationships, shared values and norms, cooperation, trust, and a sense of identity (Borgonovi & Andrieu, 2020; Pennington & Rydin, 2000). All together, these features facilitate cooperation and reciprocal actions. The quality and extent of social capital directly influence social cohesion, i.e. the collective behaviour of residents in a given neighbourhood (Borgonovi & Andrieu, 2020; Dempsey et al., 2011). It is therefore clear how social networks and social interaction are essential and integral components of social capital (Forrest & Kearns, 2001). However, its meaning puts into light the inherent role of contextual factors. In fact, social capital exists at the crossroads of both tangible and intangible aspects and their values: on the one hand, public spaces, services, infrastructures, and private properties; on the other, actors, people, and human capital. At the local level, we can appreciate the formation of ties or weak networks. This is how the neighbourhood is recognized in urban sociology literature as a site of social activity. On the other hand, as highlighted by Jenks & Dempsey (2006), the right plan of urban morphology, buildings, and infrastructure represent the baseline context for setting a sustainable development, but behaviour, lifestyles, and people's aspirations are the engines for its achievement. This is why supporting policymaking and behavioural change requires taking into account all factors in play, spanning physical shape, socio-economic and cultural aspects, their impact on current behaviours and how they are interrelated.

Behaviour is in fact determined by hedonic reasons and pleasure, money and gain, moral and normative reasons (Lindenberg & Steg, 2007), meaning that people surely follow personal reasons, but also sociocultural and economic motivations. And more specifically, policymakers need to recognize that people make different choices in different situations based on their differences. This implies admitting and working with the complexity of human behaviour (Amir et al., 2005). Contextually, these individual components need to be considered with and within situational and contextual factors such as financial constraints, goods and product availability, and diversification. Jackson (2005) calls this overestimation of individual-related factors (i.e., attitudes and beliefs) over situational factors the *"fundamental attribution error"*. In fact, situational factors can encourage or discourage some behaviours, activating individual goals that create meaning and motivation for behavioural change (Bergquist et al., 2017; Kostadinova, 2016).

The analysis of individual or group behaviours in their local context can really support policymaking in anticipating the effects and predicting potential outcomes.

In the context of incentive instruments, environmental protection, energy policy, and social justice, the investigation of attitudes, social norms, and social interaction could have a significant impact on their efficiency and efficacy.

In the next section, more insights are given about how the EU is trying to incorporate behavioural studies and research into its policy cycle.

2.4 Sustainable policy and the people perspective in EU contexts

It has been previously pointed out how people's behaviours, their daily routines, and decisions are directly inherent in complex urban problems and affect their related policies. Public policies for promoting sustainable development generally follow three different types of approaches: regulatory instruments, information campaigns, and market-based instruments (Simões, 2016). Each of them requires, in one form or another, the contribution of individuals to its compliance. The first group imposes limitations and/or restrictions that people are expected to comply with. Sometimes, regulations fail to understand the adverse individual behaviours. The second group requires the direct involvement of people through public initiatives and information campaigns to raise awareness of the environmental impacts of individual decisions and behaviours. The third group promotes changing people's behaviour through economic incentives. These instruments are often beneficial for a short time with visible results, but fail in the long term. This happens mainly because people are not rational and are often pushed by uncontrolled, irrational, and time-inconsistent motivations rather than by the simple assessment of the costs and benefits of their decisions.

For that reason, and to predict the possible outcomes of people's behaviours, the role of behavioural sciences[3] has been increasing in recent years to support urban decision-making processes and the design of policies.

There is also a lot of evidence on the functioning and efficiency of behavioural teams around the world, but less information about their applicability within the European Commission (EC) (Baggio et al., 2021). Some countries, such as the UK and USA, have started to create specific units to assist in these processes (see, for instance, the Behavior Insights Team[4]). It is not surprising that, mainly in these two English-speaking countries, these studies have been integrated into policymaking since, here, behavioural studies have a long history and application. Some international non-governmental organizations, such as the OECD and the World Bank, have recommended several initiatives in the context of behavioural findings (Lunn, 2014; Shogren, 2012; World Bank, 2014), as well as agencies of the United

[3] At the moment, the work of the team has yet to start, but the intention is quite clear and in line with the present research. The expectation is to provide evidence-based behavioural policy advice by conducting more anticipatory research on relevant topics

[4] https://www.bi.team/

Nations, notably the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF) (Baggio et al., 2021).

Also, the EU has gradually incorporated behavioural sciences in some policy fields[5]. For example, in 2010, there was established a Framework Contract for the Provision of Behavioral Studies to support the integration of this research in EU policymaking (Simões, 2016). Then, in 2013, the EC created a policy brief dedicated to showing the role of applying behavioural sciences to EU policymaking (Bavel et al., 2013). The outcomes of these interventions are visible, for example, in the collaboration with the joint research centre, called Behavioral Studies for Urban Policies (BESTEP), and the general Directorate for Health and Consumers, as well as in three reports that touch on a range of policy areas: the first one on the implications of consumer and health behaviour, the second on consumer decision-making in retail service investments, and the third, a more complete contribution, on the variety of areas where these studies can give support for policy implementation (Simões, 2016). More recently, the EC embraced this trend more systematically in order to help the impact assessment process and all phases of the EU policy cycle (spanning from preparation, adaptation, implementation, and application) by gathering and analysing evidence about the likely impacts of a planned policy[6]. The main action provided by the EC to achieve this objective is the creation in 2019 of a dedicated team at the Joint Research Centre (JRC, the EC's science and knowledge service), called the Competence Centre on Behavioural Insights, with the aim of supporting EU policymaking with evidence about human behaviour. More specifically, the team aims to (a) use behavioural insights to help design better policies, (b) bridge the gap between policymakers and behavioural researchers, and (c) increase the use of behavioural insights for policy[7] through research activities, expert assistance, training modules, and workshops. At the moment, the work of the team has yet to start, but the intention is quite clear and in line with the present research. The expectation is to provide evidence-based behavioural policy advice by conducting more anticipatory research on relevant topics (Baggio et al., 2021).

[5] This section will provide a brief synthesis of the main steps of this process. For an in-depth explanation see (Baggio et al., 2021)

[6] https://knowledge4policy.ec.europa.eu/behavioural-insights/about-behavioural-insights_en

[7] https://knowledge4policy.ec.europa.eu/behavioural-insights/about_en#ourteam

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METHODOLOGY

Chapter 3

From traditional to innovative evaluation models in urban contexts[8]

3.1 Solving complex problems in decision-making and policymaking: the role of evaluation

The definition of policies and strategies can be defined as a decision-making activity in which knowledge and evaluation go hand in hand. In particular, policy-making and scenario-making for sustainable development constitute very special

[8] Part of this chapter has been developed in the following papers:

- Bottero, M., Assumma, V., Caprioli, C., Dell'Ovo, M., 2021a. Decision making in urban development: The application of a hybrid evaluation method for a critical area in the city of Turin (Italy). Sustain. Cities Soc. 72, 103028. https://doi.org/10.1016/j.scs.2021.103028
- Bottero, M., Caprioli, C., Berta, M., 2020. Urban Problems and Patterns of Change: The Analysis of a Downgraded Industrial Area in Turin, in: Values and Functions for Future Cities. Springer, Cham, pp. 385–401. https://doi.org/10.1007/978-3-030-23786-8_22
- Caprioli, C., Bottero, M., 2021. Addressing complex challenges in transformations and planning: A fuzzy spatial multicriteria analysis for identifying suitable locations for urban infrastructures. Land use policy 102, 105147. https://doi.org/10.1016/j.landusepol.2020.105147
- Bottero, M., Bravi, M., Caprioli, C., Dell'Anna, F., Dell'Ovo, M., Oppio, A., 2021b. New Housing Preferences in the COVID-19 Era: A Best-to-Worst Scaling Experiment, in: Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). https://doi.org/10.1007/978-3-030-86979-3_9
- Bottero, M., Bravi, M., Caprioli, C., Dell'Anna, F., 2022a. Using Revealed and Stated Preferences to design a new urban park in a metropolitan area of North-Western Italy (under review)
- Bottero, M., Caprioli, C., Foth, M., Mitchell, P., Rittenbruch, M., Santangelo, M., 2022b. Exploring the effects of urban green space on property values: an application of the Spatial Hedonic Model in the city of Brisbane. (under review)

kinds of decision-making where many interrelations and conflicting aspects characterize them (Boulanger & Bréchet, 2005). Different objectives, a plurality of decision-makers, and the costs and benefits of sustainability issues make it hard to work effectively. In particular, the latter aspects highlight the need to consider the existence of multi-spatial and multi-temporal externalities, the presence of long-term and/or unexpected externalities, uncertainties, and the interplay between human beings and natural or technological systems (Boulanger & Bréchet, 2005). As the dissertation has often underlined, these interrelations and the conflicts generated by human practices and objectives are intrinsically insightful in sustainable development. In that context, the need for a different approach to transition policies and sustainable actions seems relevant.

Since the 1950s, many different evaluation approaches have been proposed to support the decision-making process of plans, programmes, projects, and policies, although with less awareness than today about the complexity and multi-dimensionality, multi-scalarity, multi-temporality, and multi-perspective of decision-making problems. It is possible to distinguish evaluation methods, according to (i) the input data required (qualitative vs quantitative), (ii) the outputs produced (monetary vs non-monetary), (iii) the time when they can be used for assessing the decision-making problem (*ex-ante, in-itinere, ex-post*), (iv) the temporal perspective of evaluation (static or dynamic), or (v) the point of view of the analysis (top-down vs bottom-up) (Figure 3.1).

(i) The first classification makes possible the selection of suitable evaluation approaches based on the data required, if quantitative or qualitative, for conducting the assessment procedure. Among the others, Revealed and Stated Preference methods (RP and SP) and Cost-Benefit Analysis (CBA) fall into the quantitative ones. Conversely, the group of qualitative assessments includes SWOT, Stakeholder Analysis (SA), Focus groups and Community Impact Evaluation (CIE).

(ii) The second classification distinguishes between those methods that provide financial/monetary outputs, i.e., translating all values into a direct monetary quantification (EURO, USD, etc.), and those methods that use different units of measurements to assess the values in play, without providing final monetary outcomes. Non-monetary methods can also use qualitative scales to provide the assessment results. MCDA, ABM, SWOT, SA, and CIE are non-monetary methods, whereas RP, SP, and CBA fall into monetary ones.

(iii) The third classification allows them to be selected depending on the time frame in which the problem needs to be assessed (Bezzi, 1998). The *ex-ante* evaluation makes possible the estimation of the future effects of what is investigated. In that context, it could also be interesting to compare different alternatives to find an optimal/suitable solution. The *in-itinere* evaluation is conducted with the ongoing development of the element under investigation. It monitors the suitable trajectory of the plan, program, project, or policy according to the initial objective, eventually supporting the definition of corrective measures.

The *ex-post* evaluation gives a clear picture of the results performed. It is therefore useful for understanding how much the element being investigated has complied with the initial objective and their expected results.

(iv) The fourth classification divides methods between static and dynamic ones. The first ones are mainly based on static variables that remain fixed for the entire evaluation. The second ones have a set of equations or rules that allow state variables to change over time as a function of their past and current values. Examples of dynamic models are ABM/MAS, System Dynamic Models (SDM) and Lotka-Volterra Models (LVM).

(v) The fifth classification refers to the direction of the assessment procedure. Top-down approaches go from the general to the specific, while bottom-up approaches start from the specific and go to the general. The bottom-up approach generally models micro-attributes and detailed characteristics of an individual asset. Top-down analysis generally uses a comprehensive set of factors for solving the decision-making process. The top-down approach splits up the overall objective into its smaller components, guiding to the final aim. Conversely, the bottom-up approaches look at and model every single element and its related rules and characteristics. Global behaviour is often unpredictable by simply summing the single elements. Bottom-up approaches are associated with the molecular self-assembly phenomenon, where the single pieces of a system are modelled to give rise to more complex systems and emergent phenomena. ABM/MAS is one of the few evaluation methods that fall into the bottom-up group.

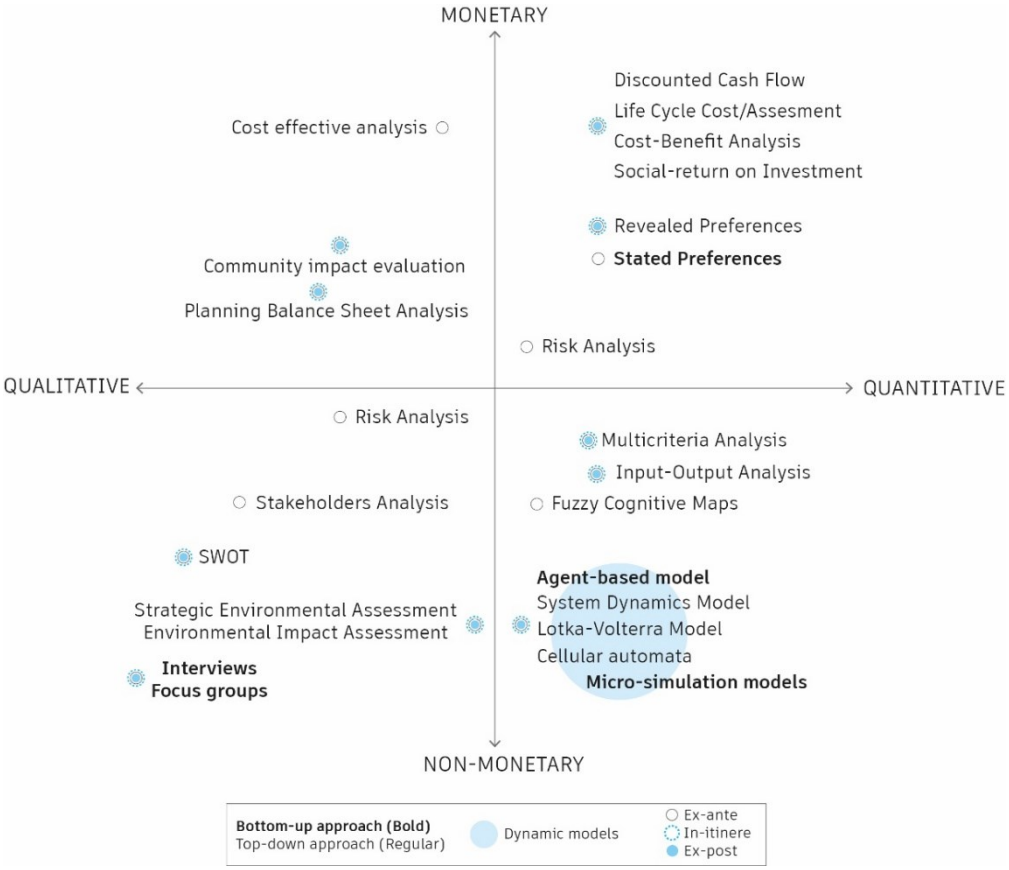


Figure 3.1. Taxonomy of evaluation methods in urban contexts

In different ways, all these methods are useful in decision-making contexts to solve specific problems or parts of them. For example, SWOT and SA are widely used approaches in preliminary context analysis, helping to qualitatively frame the state of the art and the main drivers of the process under analysis, as well as the stakeholders involved and interested. MCDA is a family of non-monetary evaluation methods that make possible the consideration of different aspects, often conflicting, in the same assessment procedures, and the comparison among various alternatives. The econometric analysis provided by the RP and SP methods is conducted to observe individuals' decisions on a certain asset, good, or service in a real or simulated market. SDM or LVM are dynamic models able to support medium-to-long-term trajectories of scenarios. Finally, ABM/MAS is a bottom-up model, able to approach socio-related studies from a different perspective, mainly capturing emergent phenomena by modelling individuals/stakeholders and their relationships with the surrounding environment.

However, two problems can be detectable in some of these evaluation methods when urban phenomena and their related strategies are studied and assessed: (i) the lack of analysis on individuals/stakeholders' decision-making processes, and (ii) the static perspective of real-world problems. Those aspects are strengthened when the definition of policies and strategies – not only, but in particular at urban scales – and the comprehension of their effectiveness and effects are the main objectives. As underlined in the work of Friege (2016), three points are strongly underestimated in the analysis of policies and strategies for sustainable development. Firstly, quoting Weiss et al. (2012) arguments, the little success of policy instruments depends on the improper consideration of the barriers in individuals' decision-making. Secondly, considering Friege and Chappin (2014) insights, non-economic motivations are fundamental in individuals' decision-making. Thirdly, situational factors—such as building characteristics and income levels—are the main reasons that determine the efficiency of sustainable actions and strategies.

To better consider together the effects of non-economic components, situational factors, and the social interaction influence of individual choice, the study of urban sustainable strategies and policies in a long-term perspective requires the use of simulation models, in particular, based on empirical research (Friege, 2016). In fact, because of their ability to predict performance and consequences in the real world, simulation models appear to be a good way to approach these questions. Although traditional decision analysis has been enormously useful in enabling the systematic application of simulation models to support decision-making, it often fails under conditions of deep uncertainty. At the same time, not all simulation models are capable of directly considering interactive individuals and/or stakeholders. The distinctive strengths of ABM/MAS are mainly related to its ability to predict in conditions of such deep uncertainty (Lempert, 2002), i.e., where multiple and heterogeneous observers with different perspectives on reality behave and interact asynchronously, operating with path dependencies

(i.e., historical conditions) (Borrill & Tesfatsion, 2010), specific objectives and situational factors, and data acquired by various surrounding environments.

Nevertheless, ABM/MAS often requires a lot of data for its accurate implementation. Therefore, its combination with other evaluation methods seems necessary and promising.

The following section will present the different evaluation methods mentioned earlier, with particular reference to how individual behaviours and preferences are included in their procedures. This section is preliminary to the following ones, where the methods integrated with ABM/MAS in the three case studies are deeply illustrated.

3.2 Human perspectives and behaviours in evaluation models

Some of the evaluation methods previously mentioned make possible the inclusion of individual or group/stakeholders' preferences and behaviours in their assessment procedures. It is possible to distinguish between (i) methodologies able to support the identification, classification, and relationships of the stakeholders involved in a decision-making process; (ii) evaluation approaches that consider opinions and preferences of experts or stakeholders for conducting a more structured and accurate procedure; and (iii) assessed methods that directly work with the individual behaviours and decisions.

Belonging to the first group (i), SA is the most common tool, applied for anticipating conflicts and reactions, identifying alliances among stakeholders, as well as the complexity of the decision-making process based on the type, power, and resources, among others, provided by each stakeholder (Dente, 2014).

In the second group (ii), it is possible to list MCDA, Social Return on Investment (SROI), CIE, SWOT Analysis, Risk Analysis, focus groups, and interviews. Generally, focus groups and interviews are used in plenty of case studies, also very different from each other and in integration with other methods to directly involve inhabitants, experts, and stakeholders. SWOT can be applied in two different ways based on the degree of inclusion of experts and stakeholders in the identification of strengths, weaknesses, opportunities, and threats of a given problem, project, or plan. In the desktop modality, the analyst collects data and adopts an "expert knowledge" position to list all drivers neutrally. The participatory modality uses focus groups to identify S, W, O, and T through a joint analysis between experts/stakeholders and the analyst. Similarly, Risk Analysis can be conducted in cooperation with stakeholders and experts to assess all the risks or anticipate them by a direct survey. Then, the monetary-based approaches, such as CIE and SROI, can involve stakeholders for a better collection of all objectives and values creation, respectively. MCDA, as a class of methods, contains differences in the execution and implementation of the evaluation procedures. However, some

common steps can be identified in most MCDA techniques, where stakeholders and/or experts are involved to ameliorate the quality and transparency of the decision-making process: selection of the set of criteria, standardization of the performance indicators/construction of the value function, and the weighting phase. In all these steps, experts and stakeholders are more or less involved. For a detailed explanation of how MCDA includes preferences and opinions, see Section 3.4.

RP, SP, and ABM/MAS fall into the third group (iii). The first two methods (RP and SP) belong to the family of econometric analysis and take into account individual preferences in different ways. RP uses a top-down approach since it estimates the value of a good from the observation of individuals' decisions in real markets. Conversely, SP adopts a bottom-up approach since it collects the preferences of individuals directly through targeted answers based on their Willingness To Pay (WTP) or Willingness To Accept (WTA) for using or losing a certain good, respectively, or through experiments with the Choice Experiment methods (CE). As with SP, ABM/MAS and Microsimulation Models (MSM) also use a bottom-up approach. The latter model depicts individual behaviours adopting stochastic processes parameterized by real data. Instead, ABM/MAS models opinions, preferences, behaviours, and interactions of individuals or stakeholders to analyse the system as a whole or specific dynamics.

The following sections illustrate these classes of evaluation methods, highlighting their pros and cons, as well as their methodologies. For practical reasons, only some of them are described in-depth. The methods were selected based on their adoption in integration with ABM/MAS in the case study applications contained in Chapter 6, Chapter 7, and Chapter 8.

3.3 Preliminary context analysis with stakeholders: SWOT and Stakeholder Analysis

The SWOT Analysis is a well-known technique developed during the '60s (Humphrey, 2005) to analyse the strengths (S), the weaknesses (W), the opportunities (O), and the threats (T) of a complex problem. The SWOT Analysis is a 4-quadrant matrix that allows DMs to divide a given problem according to existing endogenous factors (i.e., strengths and weaknesses) and exogenous factors that could occur in the future (i.e., opportunities and threats). The SWOT analysis supports the interpretation of the state of the art and the identification of the drivers able to empower strengths and opportunities and to minimize weaknesses and threats. The SWOT Analysis was used in the fields of marketing and economics, and, since the '80s, it has been employed in the public sector for evaluating alternative scenarios and public policies. Today, SWOT Analysis is applied to both public and private sectors, such as in the assessment of plans, programs, and projects, or territorial analysis for localization of new interventions (Bottero et al., 2021).

Stakeholder Analysis (SA) is a widespread tool in urban transformation and planning, able to support the identification of the stakeholders involved and interested in the process under analysis and, consequently, to highlight their capacity to affect the diffusion or inhibition of strategies (Yang, 2014). Single or groups of actors can have a significant impact on decision-making outcomes, both in terms of satisfaction of individual interests and objectives based on their values and preferences, and in terms of their relationships with other stakeholders (Dente, 2014). As far as the decision-making process is concerned in strategic planning and sustainability assessment procedures, the identification and classification of the stakeholders are fundamental to highlight the conflicting interests among them at an early stage of the process and to avoid negative effects in the next one (Gill et al., 2013).

From a practical point of view, the first step in the development of a SA is related to the identification of some characteristics of each actor: their level of intervention (national, regional, local), the category of actors to which they belong (political, bureaucratic, special interest, general interest, experts), and the resources that they carry out (political, economic, legal, cognitive), as well as their roles and expectations (Dente, 2014).

Different methods support the development of SA. Among the well-known, there are the Power Interest Matrix (Johnson & Scholes, 1999; Mendelow, 1981) and the Social Network Analysis (Marin & Mayntz, 1991; Rhodes, 1997). The Power Interest Matrix classifies on a 4-quadrant matrix, the power and interest of each stakeholder (Figure 3.2) regarding the specific decision-making process under analysis (Mendelow, 1991).

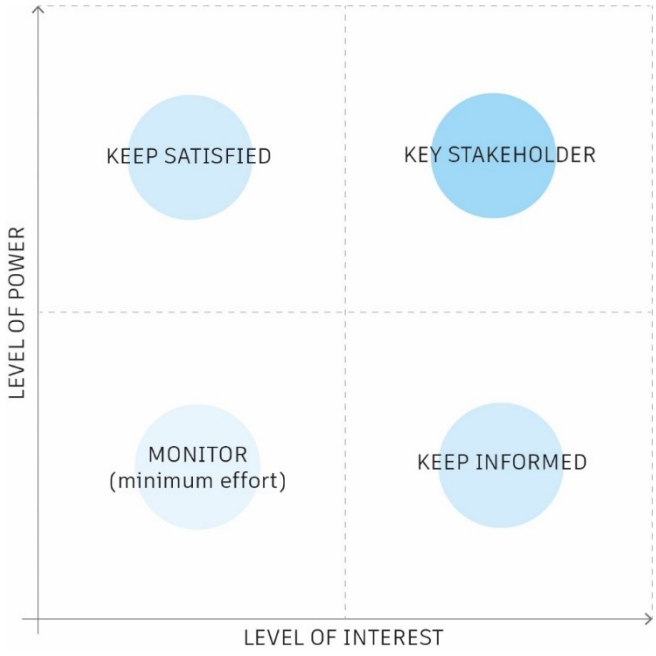


Figure 3.2. Power-interest matrix

The Social Network Analysis (SNA) maps the relationships and exchange of resources among the stakeholders. According to this approach, it is possible to

visually understand the size and form of the network, as well as the coalitions and key actors in the decision-making context (Bottero et al., 2020). According to this latter method, it is possible to obtain specific indexes able to understand some dynamics in the network (Berta et al., 2018): the density index, the complexity index, and the centrality of the network index. The density index underlines the intensity of relations between actors in a decision-making process, as represented in the following equation 3.1:

$$D = \frac{\sum K_i}{(n^2 - n)} \qquad (3.1)$$

where *D* is the density index varying between 0 and 1, *n* is the number of actors, and *Ki* is the number of all relations. The complexity index measures the variety of stakeholders that participate in the discussion: high complexity indicates that the competence levels of the actors are very different (from the international level to the local), as well as the types of stakeholders they are (from politician to expert, from bureaucrat to special interest). The complexity index is given by the sum of all cells filled with at least one stakeholder per each category of intervention (national, regional, local) and competence (politician, expert, bureaucrat, general or special interests). Finally, the centrality index underlines how much each stakeholder is connected to the others through the following equation 3.2:

$$C = \frac{k_i}{\sum K_i} \qquad (3.2)$$

where *C* is the centrality index that varies between 0 and 1, and *Ki* is the number of relations of each stakeholder. Every time SNA is performed, the relationships among the stakeholders produce a certain form of the network. It is possible to classify networks in four different ways, as represented in Figure 3.3: a star network (top left), a linear network (top right), a nested network (bottom left), and a total interaction network (bottom right).

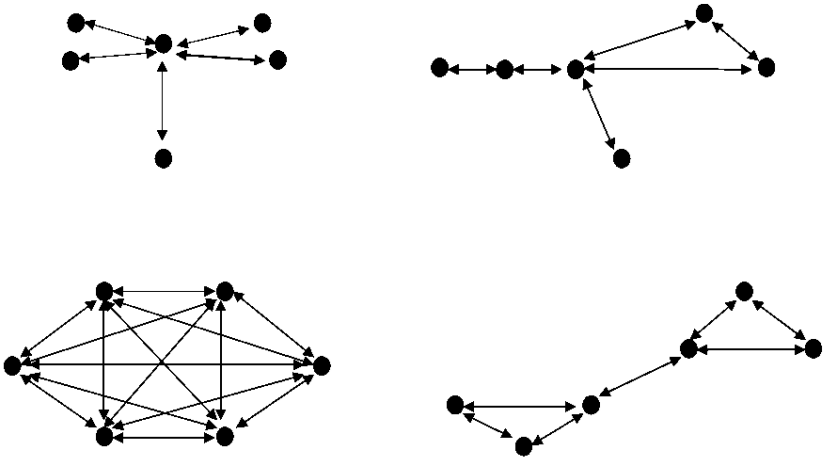


Figure 3.3. Network forms (Dente, 2014)

3.4 Multicriteria Decision Analysis (MCDA) and stakeholders' preferences

Multicriteria Decision Analysis (MCDA) is a class of methods able to make a comparative assessment of alternatives or heterogeneous measures (Figueira et al., 2005; Roy & Bouyssou, 1995). MCDA allows the consideration of the full range of aspects that characterize a complex decision-making process. In fact, MCDA makes possible the inclusion in the same evaluation procedure of both economic and extra-economic values (Caprioli & Bottero, 2021; Cinelli et al., 2014; Roy, 1985), such as environmental, social, and economic aspects. Furthermore, MCDA evaluations are frequently characterized by strong interactions between DMs and stakeholders at various stages. This helps with the considerations of all the perspectives of the stakeholders involved in the decision-making process, as well as the enrichment of the assessment as a whole.

Many MCDA methods have been proposed (for a complete survey, it is possible to refer to Figueira et al., 2005). Common classification of MCDA techniques is based on their level of compensation:

- compensatory methods like Multiattribute Value Theory (MAVT), Analytic Hierarchy Process (AHP), or Analytic Network Process (ANP);
- partially compensatory methods, such as PROMETHEE, NAIADE, ELECTRE, and REGIME;
- non-compensatory methods, such as the Rough set approach and the Dominance-based rough set approach (DRSA).

In MCDA, the participation of stakeholders, with their values, objectives, and opinions, and experts, with their knowledge, can be part of different stages of MCDA implementation. From the beginning, it can be useful to understand and list all the stakeholders involved or interested in the decision-making process under investigation. This stage is necessary in order to include in the assessment all the points of view and perspectives for the analysis of the problem. Once they are identified, the organization of a focus group with them or/and with experts allows the analyst to conduct a more transparent process and really take into account these conflicting and various positions. Generally, stakeholders and experts are involved in the evaluation procedure in different phases according to the MCDA approach selected.

For compensatory methods, i.e., MAVT, AHP and ANP, the stakeholders and experts are mainly involved in the weighting phase, when it is assigned a relative importance to each criterion for the achievement of the final objective of the evaluation. However, in ANP (Saaty, 1996), the consultation of a panel of experts or stakeholders can also support the structuring of the network between clusters and their related elements. Additionally, in MAVT, the participation of stakeholders and experts is strongly required in the composition of the value function. According

to the MAVT methodology (Keeney & Raiffa, 1976), the elicitation procedure starts with the definition of the value function for each indicator, in order to scale between 0 and 1, and then aggregate all of them. The value function is, in fact, a mathematical representation of human judgements, offering an analytic description of the individual value system about the alternatives (Beinat, 1997). Value functions translate alternatives performances into value scores, which indicate how much a decision objective (or multiple decision objectives) is achieved. To determine the value functions, different techniques are available: Direct rating technique, Curve fitting, Bisection, Standard difference, Parametric estimation, and Semantic judgments (Ferretti et al., 2014).

It is required a distinction in the way stakeholders and experts are involved, instead, among partially compensatory methods. NAIADE (Novel Approach to Imprecise Assessment and Decision Environments) (Munda, 1995), with the equity analysis[9], performs the ranking of the alternatives starting from the qualitative judgment (i.e., linguistic variables spanning from extremely bad to perfect) assigned by each stakeholder to all the alternatives. The judgements are used to fill the equity matrix, which is composed, in the row, by the names of the stakeholders and, in the column, by the alternatives. Specifically, from the direct completion of the equity matrix, the similarity matrix is obtained. Then, through a mathematical reduction algorithm performed by the Naiade software[10], it is possible to obtain the dendrogram of coalitions. This dendrogram shows the possible coalition formation, as well as the level of conflict among the interest groups. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), developed by Brans (1982) and further extended by Vinckle and Brans (1985), is an outranking method for a finite set of alternative actions. In PROMETHEE, the two main phases in which stakeholders or experts are involved are (i) the definition of the preference function and (ii) the weighting phase, as for all the other MCDA methods. (i) The preference function expresses the difference between alternative *a* over alternative *b*, based on their performances. The identification of the type of preference functions (among the six different shapes: Usual, U-shape, V-shape, Level, Linear, and Gaussian (Brans & Mareschal, 2005)) and the degree of preference (according to the indifferent and preference threshold) is the task of the analyst, or the experts/stakeholders involved. (ii) The weighting phase, as for the other MCDA methods, always requires the participation of stakeholders or experts for a more transparent evaluation. In PROMETHEE, the SRF weighting approach is commonly used. Proposed by Simos-Roy-Figueira (Figueira & Roy, 2002), the

[9] Conversely, if NAIADE is used following the impact analysis, the stakeholders – but more often the experts – are involved in the definition of preference relations. In fact, for each criterion, it must be defined if fuzzy, stochastic, qualitative, or quantitative, as well as its parameters (measurement units, maximisation or minimization, and the crossover points of its preference relations). Generally, this last part can be supported by the consultation of experts. More details about the impact analysis and equity analysis of NAIADE can be found in Munda (1995) and the software manual

[10] http://www.start.org/Projects/AIACC_Project/meetings/Trieste_02/trieste_cd/Software/NAIADE/naiade.PDF

method uses a set of cards to indirectly determine numerical values for weights. Finally, in all the ELECTRE (ÉLimination et Choix Traduisant la REalité ELimination Et Choice Translating REality) methods (Roy, 1968), the involvement of stakeholders and experts mainly concerns the elicitation of the intrinsic weights, i.e., the relative importance of the different criteria. In the ELECTRE III extension (Figueira et al., 2009), stakeholders and experts are also involved in another phase, precisely in the definition of the type of interactions among the criteria (mutual strengthening, mutual weakening, or antagonistic). This latter procedure requires the assignment of numerical values and indetermination margins to the parameters (Bottero et al., 2015).

For non-compensatory methods such as rough set approach, stakeholders and experts are involved in the exploitation of the preferences in terms of decision rules. The rules are expressed through examples of decisions that are based on preferential information provided by stakeholders or experts. These examples of decisions are a subset of objects $B \subseteq A$, called reference objects, where A is a finite set of objects. The examples can refer to decision classes, in the case of sorting problem, or pairwise comparisons of reference objects, for choice and ranking problems (Greco et al., 2001).

The following section will be focused on AHP and Best-Worst Method (BWM) techniques, that were adopted in integration with ABM for the case studies illustrated in Chapters 7 and 8, respectively.

3.4.1 Analytic Hierarchy Process (AHP)

AHP was developed by Saaty between 1977 and 1996 (Saaty, 1987, 1980, 1990), as a flexible method to prioritize alternatives based on their performance arising from one or more criteria (Boroushaki & Malczewski, 2008). The term "hierarchy" refers to the hierarchical relationships among the different elements that compose the evaluation framework: the objective, the criteria, the sub-criteria, and the alternatives (Caprioli & Bottero, 2021).

Six parts generally compose the AHP procedure (Saaty, 2008) plus the check of the results with sensitivity analysis:

- defining the evaluation objective and outcomes;
- dividing the complex problem into different decision levels with a hierarchical structure: the criteria, the sub-criteria, and the alternatives;
- developing pairwise comparisons among elements to obtain the comparison matrices through the eigenvalue method;
- determining the relative importance of decision elements
- validating the consistency of the matrices (less than 0.1) for judgment accuracy;
- combining the weighted decision elements to produce an overall rating for the alternatives;
- examining the results, and eventually conducting sensitivity analysis to

verify the robustness of the model under the variation of scores or weights.

Two aspects mainly distinguish AHP from other MCDA methods: the structure of the decision-making process and the weighting phase. As the name suggests, AHP uses a hierarchical structure to organize the decision problem and its components (criteria, sub-criteria, and alternatives), as it is possible to see in Figure 3.4.

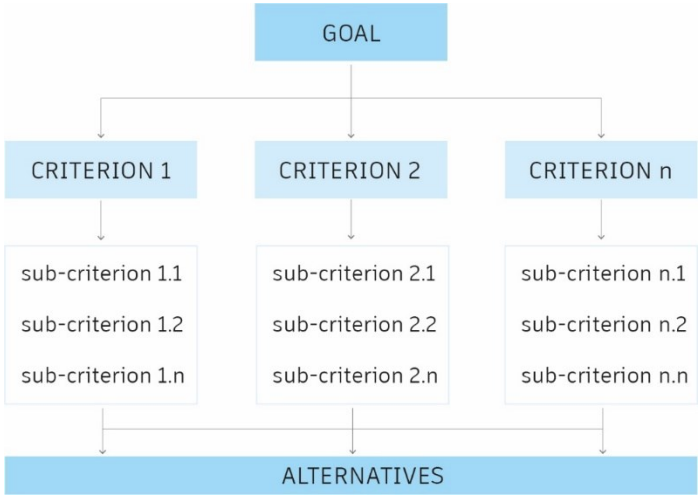


Figure 3.4. Hierarchical structure of AHP

In AHP, the weighting phase is carried out by a pairwise comparison, where judgements are expressed by preference degree. The pairwise comparison method was developed by Saaty, which defined a measurement scale for comparing the level of contribution of criterion X over criterion Y in achieving the specific goal of the evaluation. The fundamental scale of Saaty follows a numerical scale from 1 to 9, where 1 indicates that the two aspects contribute equally to the achievement of the goal, while 9 indicates that one aspect is extremely preferred over the other. In Table 3.1, the Saaty fundamental scale is reported with its levels of value and importance.

Table 3.1. The fundamental scale of Saaty (adapted from Saaty, 1980)

Value	Importance	Description
1	Equally preferred	The two aspects contribute equally to achieving the goal
3	Moderately preferred	One aspect is moderately preferred than the other
5	Preferred	One aspect is preferred over the other
7	Strongly preferred	One aspect is strongly preferred over the other
9	Extremely preferred	One aspect is extremely preferred than the other
2,4,6,8	Intermediate value	Compromise among judgements

The numerical values constitute square matrices of pairwise comparisons of the elements, at each level of the hierarchy, as shown in Figure 3.5.

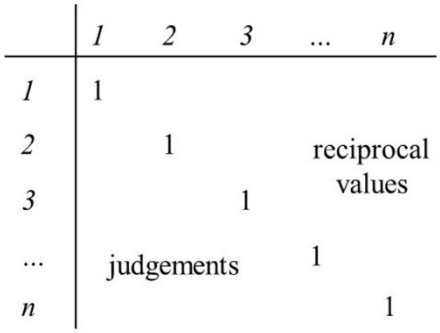


Figure 3.5. AHP comparison matrix

To extract the priority scale (or weights) from the matrix of pairwise comparisons, the main eigenvector has to be solved, as well as its normalization. The eigenvector is weighed with the priority of the element with respect to which the comparison was made (Saaty, 1987). The sum of all weighted eigenvectors gives the weight of each alternative.

The assignment of pairwise values by DMs can result in some inconsistencies due to the conditions of limited rationality. Therefore, the set of weights needs to be checked before its use. The consistency of the results is calculated as the ratio of the C, as follow (equation 3.3):

$$CR = \frac{CI}{RI} \qquad (3.3)$$

Where CR is the Consistency Ratio, which has to be lower than 0.1. RI is the value of consistency of a randomly generated reciprocal matrix. CI is consistency index calculated as the following equation 3.4:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (3.4)$$

Where λ_{max} is the maximum value of the eigenvector of the pairwise comparison.

3.4.2 Best-worst method (BWM)

The best-worst method (BWM) is a recent multi-criteria decision-making method developed in 2015 by Rezaei. The idea behind this method derives from combining the main advantages of MCDA (particularly, AHP)[11] and the Best-to-

[11] Refer to Section 3.2.2.1 for MCDA pros.

Worst Scaling (BWS)[12], a well-known econometric method proposed by Finn and Louviere (1992).

BWM is a comparison-based method that uses two vectors of pairwise comparisons to determine the criteria weights (Rezaei, 2016). The DM first chooses the best (i.e., most desirable, most important) and worst (i.e., least desirable, least important) criteria, and then compares the best criterion to the other criteria, and the other criteria to the worst criterion (Rezaei, 2016). The weights are identified using a non-linear minmax model which minimizes the highest absolute difference between the weight ratios and their related comparisons.

Two approaches can be used with BWM, which can give two different solutions. On one hand, it may result in multiple optimal solutions, meaning that solving the problem results in several sets of weights for the criteria. On the other hand, BWM can simply produce a unique solution. BWM results in a unique solution when the problem is composed of two or three criteria, or alternatively when all the comparisons are fully consistent for any number of criteria (for details about consistency, see below Step 5). Conversely, multiple optimal solutions result when more than three criteria are not fully consistent, giving weights as intervals (Rezaei, 2016). In this latter case, the centre of the intervals is used to rank the criteria. Multiple-optimal solutions can be more useful in some cases, such as in political contexts when debiting plays an important role in the decision-making process, since it provides more information about the optimal solution (Rezaei, 2016). However, in other cases, the unique solution is enough, or rather preferable.

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[12] It is presented here a brief description of BWS (Finn and Louviere, 1992). Based on the random utility theory, BWS collects a great amount of information by simply collecting the "best" and the "worst" choices of respondents in market research. The BWS approach is founded on the assumption that individuals make more reliable choices when they evaluate the upper and lower objects/elements among a set of three or more of them, rather ranking the entire list (Bottero et al., 2021). What is certain is that BWS requires less time and effort when conducting real experiments with individuals. Identifying the best and worst alternatives is easier than classifying the entire list, particularly middle objects/elements. In contrast, the information gathered is lower than that obtained through ranking methods because the distance between the best and worst choices, as well as those between them and the middle ones, is unknown. Moreover, BWS does not allow the respondent to select more than one best or worst choice, meaning that it is not possible to give the same importance to two or more objects/elements.
Many procedures are available for the estimation of the best-worst score. Among the simple procedures for the calculation of MaxDiff scores, the Analytical Best-Worst Score (ABW) (Lipovetsky & Conklin, 2014)) is one of the most efficient. For example, it has a lower error in the estimation of latent values of elements compared to Best Minus Worst Scoring (Finn and Louviere, 1992). Additionally, ABW is more computationally efficient than multinomial logit models (Marley et al., 2016).

ABW is calculated as the following equation 3.5: $ABW = ln\left(\frac{1+NBW}{1-NBW}\right)$ (3.5)

where NBW is the best-worst score normalized, calculated as follow (eq. 3.6):

$$NBW = \frac{\#Bests - \#Worsts}{Total\ times\ shown} \quad (3.6)$$

where *#Bests* and *#Worsts* are the number of times an item is selected as best and worst respectively, divided by the number of times the item is presented to the sample.

The advantages of BWM regard the less effort and time of the interviewee in the comparison of criteria, as well as the reduction of inconsistency that characterizes the other MCDA methods. Moreover, the structure of BWM and its advantages allow the comparison of alternative actions/strategies in complex urban transformations and planning. In fact, when many stakeholders with different opinions are involved in a transformation process and there are no predefined alternatives to be assessed, the investigation of the priorities in the implementation of strategies can be more useful and efficient.

Five steps are required in BWM to derive the weights (Rezaei, 2015).

Step 1. Define a set of decision criteria.

DM identifies *n* criteria $\{c_1, c_2, \dots, c_n\}$ for making a decision.

Step 2. Select the best (i.e., most important, most desirable) and the worst (i.e., least important, least desirable) criteria.

In this step, DM only identifies two criteria, corresponding to the best and worst criteria in the set of available criteria. No other considerations or assessments are made between them and the other criteria.

Step 3. Determine the preference of the best criterion over all the other criteria.

DM assigns his/her preference for the best criterion over all the other criteria through a numerical value between 1 and 9 (like the pairwise comparison scale of Saaty (1990) in AHP). The Best-to-Others vector is equal to equation 3.7:

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}) \qquad (3.7)$$

Where a_{Bj} represents the preference of the best criterion *B* over criterion *j*. When the best criterion *B* is compared with itself, the result of the comparison is equal to 1 ($a_{BB} = 1$).

Step 4. Determine the preference of all the criteria over the worst criterion.

DM assigns his/her preference for all the criteria over the worst criterion through a numerical value between 1 and 9 (like the pairwise comparison scale of Saaty (1990) in AHP). The Others-to-Worst vector is equal to equation 3.8:

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW})^T \qquad (3.8)$$

Where a_{jW} represents the preference of the criterion *j* over the worst criterion *W*. When the worst criterion *W* is compared with itself, the result of the comparison is equal to 1 ($a_{WW} = 1$).

Step 5. Find the optimal weights.

This step is slightly different if non-linear (Rezaei, 2015) or linear BWM

(Rezaei, 2016) is adopted. This section describes in-depth the linear BWM (Rezaei, 2016), which gives as a result a unique solution. For more details about non-linear BWM, see Rezaei (2015).

In linear BWM, the optimal weights of criteria $(W^* = (w_1^*, w_2^*, \dots, w_n^*))$ is calculated minimizing the maximum among the set of $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$, as follow (eq. 3.9):

$$\begin{gathered} min\ max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\} \\ \text{s.t.} \\ \sum_j w_j = 1 \\ w_j \geq 0, \text{for all } j \end{gathered} \tag{3.9}$$

Converted into a linear programming problem, it can be written as follows to obtain a unique solution (eq. 3.10):

$$\begin{gathered} \min \xi^L \\ \text{s.t.} \\ |w_B - a_{Bj}w_j| \leq \xi^L, \text{for all } j \\ |w_j - a_{jW}w_W| \leq \xi^L, \text{for all } j \\ \sum_j w_j = 1 \\ w_j \geq 0, \text{for all } j \end{gathered} \tag{3.10}$$

Where ξ^L is the consistency index.

The results of solving the above problem are the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ and ξ^{L*}. In linear BWM, ξ^{L*} directly respects the consistency indicator of the comparisons. The value of ξ^{L*} ranges between 0 and 1: values of ξ^{L*} close to zero show a high level of consistency.

3.5 Individual decisions for estimating the Total Economic Value (TEV) of environmental goods

Most of the studies on the economic valuation of landscapes, environmental amenities, and green areas have used the approach of Total Economic Value (TEV). The TEV approach is based on the assumption that any good or service is composed of various attributes, some of which are concrete and easily measured, while others may be more difficult to quantify.

Different evaluation techniques are available for estimating the TEV.

According to Pearce and Turner (1990), these techniques can be divided into two main families: i) Revealed preference methods and ii) Stated preference methods. The first group of methods estimates the value of an environmental and landscape resource from the observation of individuals' decisions in real markets. Travel Cost Method (TCM) (Voke et al., 2013) and the Hedonic Pricing method (HPM) (Freeman III et al., 2003) are included in this first group. The second group of methods is based on the creation of a simulated market where the data is collected by asking individuals their Willingness To Pay (WTP) for using a good or service, or Willingness To Accept (WTA) losing that good or service. The Contingent Valuation Method (Carson, 2000) and Conjoint Analysis/Choice Experiments method belong to this family.

In the following sections, some Revealed and Stated preference methods are discussed in-depth since they are directly applied to the case study applications presented in Chapters 7 and 8.

3.5.1 Hedonic pricing method (HPM) and its spatial extension

The Hedonic Pricing Method (HPM) is based on the idea that real estate properties are not homogeneous goods (Rosen, 1974). Their market value is influenced by the presence of a bundle of attributes: locational, structural, temporal, geographical, and environmental. Each characteristic has an implicit price embodied in the selling price. A special attention has been devoted in the literature to the analysis of natural capital in exploring the relationship between urban green spaces and property valuation (Ekins, 2003; Jones et al., 2019; Valente et al., 2020). In particular, HPM has been widely applied to estimate the contribution to property values delivered by environmental amenities (Crompton, 2001). The implicit price is revealed only from observed values (i.e., revealed preferences) of differentiated products with a specific quantity of each attribute. The theory is based on the concept that housing prices are divided between housing characteristics (intrinsic) and location characteristics (extrinsic).

More formally, the basic model can be described by equation 3.11:

$$p = \beta_0 + \sum \beta_k s_k + \sum \beta_j L_j + u \qquad (3.11)$$

Where p is the vector of housing prices, s_k is a matrix of intrinsic structural characteristics, L_j is a matrix of extrinsic location characteristics, β_0, β_k, β_j are the corresponding parameters, and u is a vector of random errors.

For empirical estimates, HPM relies on a regression technique, which has been criticised for causing a series of problems that can lead to biased estimates, such as functional form specification, spatial heterogeneity, spatial autocorrelation, housing quality change, multicollinearity, and heteroscedasticity (Elhorst, 2014). In response to these critiques, HPM has been continuously evolving with the help of more powerful computation methods and improved systems. GIS is one of these,

which allows for more precise identification and valuation from a spatial perspective (Anselin, 1988). Recent research has paid particular attention to the issue of spatial autocorrelation, which takes into account how the price of each observation is influenced by the price of the nearby observations (Dubin, 1992; Tsai et al., 2015). Specific models have thus been developed to deal with spatial autocorrelation and overcome possible biases in the regression estimates.

Spatial lag models, in particular, are routinely used in real estate evaluations where house prices are at least partly determined by the prices of the neighbourhood properties (or Spatial Autoregressive model – SAR). The spatial log model addresses the potential spatial interaction between the dependent variable (house price) and its neighbours by introducing the hedonic function through a specific price weight matrix as follows (eq. 3.12 and eq. 3.13):

$$p = \beta_0 + \rho W p + \sum \beta_k s_k + \sum \beta_j L_j + \varepsilon \quad (3.12)$$

$$\varepsilon = \rho W \varepsilon + u \quad (3.13)$$

Where the term $\rho W p$ corresponds to the weighted average price of the neighbouring observations, the parameter is known as the autocorrelation coefficient, and the term *u* is the uncorrelated error term. It is important to note that *W* represents the spatial matrix of the weights. This NxN matrix, being *N* the size of the dataset, is composed of the elements w_{ij} that are the spatial weights, with w_{ij} non-zero when *i* and *j* are hypothesized to be neighbours and 0 otherwise.

Another model used in spatial regression is the Spatial Error Model (SEM), which takes into account the fact that errors are spatially correlated due to unobserved variables or measurement errors. The SEM model can be represented by equations 3.14 and 3.15:

$$p = \beta_0 + \rho W p + \sum \beta_k s_k + \sum \beta_j L_j + \varepsilon \quad (3.14)$$

$$\varepsilon = \lambda W \varepsilon + u \quad (3.15)$$

Where W is the matrix of the spatial weights, λ is the spatial error coefficient, and u is the uncorrelated error term.

3.5.2 Willingness to Pay (WTP)

Willingness to Pay (WTP) is a widely adopted method in the field of environmental economics (Carson, 2000). It allows the analyst to evaluate non-market goods by directly asking stated preferences (SP) of respondents. In particular, SP refers to the WTP of the individual for using a specific good or service under investigation. Among the most used techniques to state WTP, Contingent Valuation Method (CVM) estimates directly the total economic value of a good or service through the elicitation of the maximum monetary value assigned by respondents based on real or hypothetical changes in quality and

quantity of the good or service examined. The elicitation of preferences can be collected from a random sample of respondents using open-ended questions (i), closed-ended interrogations (ii), an iterative bidding game (iii) or through payment cards (iv) (Bateman et al., 2002). (i) In an open-ended question, respondents are free to assign the maximum WTP without any constraints or suggestions from the analyst. (ii) Conversely, in closed-ended questions, the respondent dichotomously chooses if he/she is willing to pay the amount of money defined by the analyst. (iii) The iterative bidding game, as the name suggests, is based on iterative questions, where the respondent accepts or declines to pay the amount of money proposed by the analyst. Specifically, the game starts with a random initial monetary value defined by the analyst, and then the experiment continues, proposing a higher or lower value. The last accepted amount of money is considered the WTP of the respondent. (iv) In payment cards, a set of WTP is presented to the respondent, who chooses the one that best represent his/her WTP. For the estimation of the WTP, the respondent also answers other questions, useful to frame his/her socio-economic profile, such as age, income, education, and professional activity.

Despite a large number of CVM applications, many scholars have expressed their scepticism about this method (Buso et al., 2017). The main weakness is associated with the intrinsic hypothetical value assigned by the respondent to a non-market good (Pearce & Özedemiroglu, 2002; Whitehead et al., 2012). Unlike real goods that can be traded on the market, non-market objects are more difficult to imagine as something that directly influences the choices of a respondent.

Due to the difficulties of deriving individual WTP of environmental goods, the estimation of their value is sometimes derived from Travel Cost Method (TCM) assumptions. Within this context, WTP is considered a trade-off between travel time and travel cost. TCM, in fact, is based on the demand theory and takes the monetary estimation of a good from the frequency of visits, the travel expenses to reach the good and other variables, such as the time spent there, and the activities performed (Iamtrakul et al., 2005). TCM derives the value of a good from the observation of the behaviours of individuals in a real market (RP), and particularly from the gravitational effects related to environmental goods. The estimation of the value of the good through TCM can be performed with three different approaches: the individual travel-cost method (ITCM), the zonal travel cost method (ZTCM) and the random utility model (RUM) (Torres-Ortega et al., 2018).

3.5.3 Choice experiment (CE)

The Choice Experiment (CE) grounds on purchasing behaviour theory, stating that consumers base their utilities on the features that characterize the asset under investigation (Louviere, 2006). In practical terms, the experiment consists of the presentation of different choice sets, also called scenarios or alternatives, to respondents. Among them, respondents select the preferred one. Alternatives present the good through their characteristics, also called attributes, which are expressed at different levels or degrees. This means that respondents do not

evaluate the asset, but the features that characterize it. CE works with contingency tables that give the proportion of choice for each attribute and an index that establishes the influence degree of the single attributes compared to the others (Lancaster, 1966; McFadden, 1973; Thurstone, 1927).

Assuming to ask to generic individual *i*, with some characteristics *s* and driven by rationality, to select the alternative that maximizes his/her utility among two alternatives. These two alternatives belong to a specific choice set A. $P(x|s,A)$ is the probability of alternative *x*, defined as a vector of attributes and belonging to set *A*, being chosen by an individual with *s* as his/her characteristics. Therefore, the maximization of the respondent utility function represents an individual behaviour rule (IBR) belonging to a set of functions (SIBR) that maximize the utility. Based on these assumptions and the random utility model (RUM), it is possible to state that the higher the utility produced by a given alternative, the greater the probability that this alternative will be preferred over the others (Hensher & Johnson, 2018). This statement is expressed by the following equation (3.16):

$$P(x|s,A) = P(IBR \in SIBR|IBR(s,A) = x) \quad (3.16)$$

Where P is the probability that the individual chooses an IBR that corresponds to the choice of the alternative *x*. And, the utility of the respondent is based on the RUM, as shown in equation (3.17):

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (3.17)$$

Where U_{ij} is the utility of the individual i, choosing the object j among the available alternatives A. V_{ij} is the observed utility and ε_{ij} is the error. Therefore, if $U_{ij} > U_{iy}$, i.e., individual i chooses the alternative j rather than y, the probability can be written as follows (eq. 3.18):

$$P(x_{ij}|s_i,A) = P[\varepsilon(s,x_y) < V(s,x_j) - V(s,x_y) + \varepsilon(s,x_j)] \quad (3.18)$$

This means that the probability of selecting the alternative x_j is equal to the probability that the stochastic part of the y-th alternative is less than the utility of the j-th alternative minus the observable part of the y-th alternative.

RUM can be solved with different models, such as the Multinomial Logit Model (MNL) or Random Parameters Logit (RPL), also called Mixed Logit Model (Greene, 2002).

In the standard logit model, the probability (eq. 3.19) of individual *i* of choosing alternative *j* is:

$$P_{il} = \frac{e^{\beta' x_{il}}}{\sum_j e^{\beta' x_{ij}}} \quad (3.19)$$

Then, assuming that the coefficients are individual specific, the probabilities are calculated as follows (eq. 3.20):

$$P_{il} = \frac{e^{\beta_i{}' x_{il}}}{\sum_j e^{\beta_i{}' x_{ij}}} \quad (3.20)$$

Where the parameters are estimated for every individual. This implies that the number of choice situations available to an individual is large. Since this case is rare, a more flexible approach consists of considering β_i's as random draws from a distribution whose parameters are estimated. This model is called RPL or Mixed Logit Model.

RPL evaluates the impact of non-choice features in repeated observations (Bartczak et al., 2017), allowing the parameters to vary between individuals, unlike being fixed (Train, 1998). RPL relaxes the assumption of independence of irrelevant alternatives (IIA) (Train, 2003) and leads to two levels of heterogeneity: (i) the variability of the parameters and (ii) the differences among respondents. The randomness in parameters (Hensher & Greene, 2003) is introduced in the standard indirect utility function accordingly to the following equation 3.21:

$$U_{nj} = V_{nj} + \varepsilon_{nj} = \beta_n' x_{nj} + \varepsilon_{nj} \quad (3.21)$$

Where x_{nj} are observed variables concerning the alternative *j* and the person *n*; β_n is a vector of coefficients of these variables for the person *n,* based on his/her taste; ε_{nj} is the random term that captures the unobserved influences from the choice of the individual with an iid extreme value distribution (Brouwer et al., 2010). The coefficients vary among individuals in the population with density $f(\beta)$. For standard logit, this density is a function of any set of parameters, usually the mean and covariance of β in the population, and ε_{ij} the iid extreme value (Train, 2003). In mixed logit probability, the analyst observes the X_{ij} but not β_i or the ε_{ij}. Therefore, the probability (eq. 3.23) is an unconditional choice, calculated as the integral of $L_i(\beta)$ (eq. 3.22) over all possible variables of β, as follows:

$$L_i(\beta) = \frac{e^{\beta' x_i}}{\sum_j e^{\beta' x_j}} \quad (3.22)$$

$$P_i = \int \left(\frac{e^{\beta' x_i}}{\sum_j e^{\beta' x_j}} \right) f(\beta) d\beta \quad (3.23)$$

The analyst specifies a distribution of the coefficients and estimates the parameters that follow that distribution (Train, 2003). In most cases, the distributions are normal or lognormal (see Revelt and Train, 1998).

3.6 A special mixed method approach

Urban transformation and planning under the triple-bottom-line approach are complex processes, where physical transformations are strongly linked to social, economic, environmental, and institutional elements. Similarly, the definition of policies for the achievement of a sustainable transition requires the consideration of not only infrastructural, financial, and management barriers, but also the role played by individuals and stakeholders in their relation and interrelations among each other and with the surrounding environment. In that context, it is essential the use of appropriate decision support tools able to take into account the full variety of dimensions of the problem and to include the needs, expectations, and values of all parties involved.

The present chapter has underlined the huge number of methods and tools that can help in conducting more structured, complete, and transparent decision-making processes for these complex problems. Each of them has its own specific pros, that can be exploited each time depending on the object under investigation and the aim of the assessment. At the same time, none of these techniques can solve every problem by contemporarily considering the multiple dimensions of a problem, the stakeholders and individual preferences and behaviours, and the spatial and temporal dimensions of policies and strategies.

A promising field of operational research regards the adoption of a mixed-methods approach, offering a powerful choice to integrate systematically quantitative and qualitative data, as well as the different abilities of various techniques. The mixed method approach is, in fact, considered a third paradigm that exceeds traditional qualitative and quantitative research methods. Within this context, the research thesis aims to test some special kinds of mixed method approaches, that step-by-step include more and different techniques. This exploration has a twofold objective. Firstly, proposing a new and innovative integration of methods that starts from a bottom-up approach through the adoption of ABM/MAS for supporting the definition of sustainable policies and urban transformation scenarios. The supporting methods will provide a resolute solution to an ABM/MAS limit every time, spanning the spatial relevance of relationships and interrelationships between people and their surroundings, the massive amount of data required by this bottom-up approach, or the need for more structured decision problems. Secondly, and connected to the previous one, examining the ability and flexibility of ABM/MAS to solve different real-world problems.

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Chapter 4

Agent-based model/Multi-agent system: the state of the art[13]

4.1 Cities and Complexity: why choose ABM/MAS?

The development of ABM/MAS goes in parallel, or better, comes from the studies on complexity. One of the main ideas connected with complexity is that of emergent. The "emergent" concept underlines how a small number of rules and laws at the micro-level and among many entities produce surprising complexity and often ordered patterns in aggregate form (Torrens, 2001). However, these complex patterns do not simply represent the sum of the actions of the single parts (Torrens, 2001), but come from the interaction among their elements and these elements with the decision-making environment (Bennet & Bennet, 2008). Thus, the dynamics of the system are more than aggregating little pieces into larger units (Torrens, 2001). A complex system is therefore characterized by many elements in a non-linear interaction among them, whose individual behaviour can be explained by simple laws, but whose overall behaviour cannot be understood from the laws of the single elements (Nicrosini, 2004). Another aspect connected with complexity and the study of complex systems is that of dynamicity. Complex systems are dynamic and change over time without a linear direction.

The notion of complex systems is part of many research fields, spanning from

[13] Part of this chapter has been developed in the following papers:

- Caprioli, C., Bottero, M., & Pellegrini, M. (2019). An Agent-Based Model (ABM) for the Evaluation of Energy Redevelopment Interventions at District Scale: An Application for the San Salvario Neighborhood in Turin (Italy). In M. S. et Al. (Ed.), *Computational Science and Its Applications – ICCSA 2019. ICCSA 2019. Lecture Notes in Computer Science, vol 11621* (pp. 388–403). Springer, Cham. https://doi.org/10.1007/978-3-030-24302-9_28

physical-mathematical science, in which the term originated, to natural and social-anthropological ones. Cities and their phenomena are no exception. Indeed, the notion of complexity is becoming a crucial issue in urban research. As Batty (2005) writes, "*systems of cities are no longer thought as being "complicated" but rather "complex", in that there is always uncertainty about the outcomes of the process of change that originate from the bottom up. This is what we mean by "complexity"".*

The increasing awareness that the collective behaviour of a system cannot be simply explained through the analysis of the behaviour of its single components has led to the formation of new concepts, sophisticated systems, and mathematical models (Meyers, 2009). In that context, ABM/MAS represents one of the main approaches, able to consider dynamicity and to study emergence in the phenomena under analysis, mainly because they rely on the idea of effects and synergetic characteristics emerging from the analysis of subcomponent relationships (Parker et al., 2003).

Although the methodological potential of ABM/MAS is great, they are rarely adopted to support real-world decision-making processes and policy-making in urban contexts (Lempert, 2002). However, the challenge of using ABM/MAS to support real-world decisions is recently increased, in particular, as a sort of competitor to more traditional mathematical representations, including differential equations of engineering and economic models, statistical forecasters, or system dynamics models. ABM/MAS represents an alternative and "right" way (Borrill & Tesfatsion, 2010; Nigel Gilbert & Terna, 2000) to approach socio-related studies, especially in urban studies (Chen, 2012). In contrast to traditional aggregated models, they are able to capture emergent phenomena by analysing the system from a bottom-up approach and, in particular, from the behaviours of their constituent units, the agents (Chen, 2012). Moreover, they make possible the connection of real-world actors with an environment from which and to which they can exchange resources and information and create relationships and interconnections (Blecic et al., 2009).

The complexity in the social world is that individuals have to recognise, reason about, and react to the institutions that their actions have created. This feature of human society is an area where computational modelling shows promise (Wilson, 2000). Different potential strengths of ABM/MAS show the relevance of applying and investigating more in this field of research that is only partially developed at present.

4.2 Cities and Complexity: ABM/MAS and GIS

In a world characterized by interdependence and uncertainty, models like ABM/MAS represent sophisticated and reliable tools to predict the future evolution of our world (Crooks et al., 2019). Nevertheless, the strong capabilities of

ABM/MAS to predict future changes have to be founded on real-world data, and, particularly, on spatially explicit and geographically distributed data. In that context, GIS represents the foundation of consistent models under complexity problems. As rightly pointed out by Heppenstal et al. (2012) (p. 63), the integration of GIS with ABM/MAS allows the analyst to incorporate into models different elements, such as infrastructure, human objects, and environmental components. They provide an explicit consideration of spatial dimensions in a bottom-up approach. In the same way, Murphy (1995) expresses the necessity to increase awareness "*in the cooperation between the disciplines will be particularly beneficial in areas such as data quality, uncertainty representation and issues related to the management and sharing of large time-reliant and source-dependent data*". This exchange of information from GIS to decision-support systems, like ABM/MAS, is fundamental to studying urban systems in which the management, representation, and interpretation of complex multi-dimensional knowledge are strongly relevant.

Moreover, when approaching urban studies and, in particular, the definition and effectiveness of policies and strategies at the urban scale, we cannot ignore the fundamental role of geographic space and its dynamics. A wide literature has been wondering and has defined the "special" of the spatial dimension, i.e., *"what is special about spatial"* (Anselin, 1988). One of the primary reasons is the extreme heterogeneity of physical space compared to the mathematically defined abstract one. This aspect is particularly relevant in the analysis and resolution of decision-making processes in urban contexts, where the features of the elements involved, the relations among human and non-human objects, and the heterogeneity of the space have consequences that need to be taken into account (Andrienko et al., 2007). Furthermore, geographic space is characterized by multiple objects, phenomena, and events that occur at different times and must be considered simultaneously (Andrienko et al., 2007).

These observations join those, mentioned many before, related to the role of situational factors. Since ABM/MAS works on identifying micro-founded generative mechanisms which might account for macro patterns (Squazzoni, 2012), these situational factors are surely relevant. With the aim of developing empirical research in real-world urban contexts, these factors cannot be considered without the integration of geographical data, such as income levels of individuals, the quality of buildings, and the distribution of infrastructure and services. GIS makes possible the understanding of spatial phenomena, linking behaviours, activities, and events with discrete or set of locations (Crooks et al., 2019). Modelling all these aspects allows the analyst to incorporate into the social system the real local contexts and interactions among individuals/stakeholders and the objects/elements of the surrounding environment.

All these considerations support the view of using integrated approaches, where the combination of GIS and ABM/MAS provides models that enable scalable and granular analysis and modelling of geographical systems (Crooks et al., 2019). In particular, their complementary capabilities contribute to the predictive capacity of

ABM/MAS at an individual level, expressing the heterogeneity, environmental influence, and interactions between behavioural entities and real-world space objects (Crooks et al., 2019; Goncalves et al., 2004).

4.3 ABM/MAS: origin and "competitors"

Despite the advantage of ABM/MAS as a tool for simulation, this model did not begin to feature prominently in the geographical literature until the mid-1990s, when Epstein and Axtell (1996) extended the notion of modelling people to growing entire artificial societies (Crooks, 2012). Planners, geographers, and economists have always been interested, albeit in different ways and with various purposes, in the role and influence of people and individuals within geographical systems (Crooks, 2015). However, answering this question has only recently become feasible due to the amount of data and tools available to achieve this goal. Consequently, this has led to new ways of thinking and approaching urban phenomena and real-world problems, also by using simulation models.

In particular, the evolution that led to the development of ABM/MAS was a long journey, surely influenced by its other "competitors", as synthesized in Figure 4.1. All of them have informed the debate with the aim to integrate dynamicity, even if in different ways (Heppenstall et al., 2012).

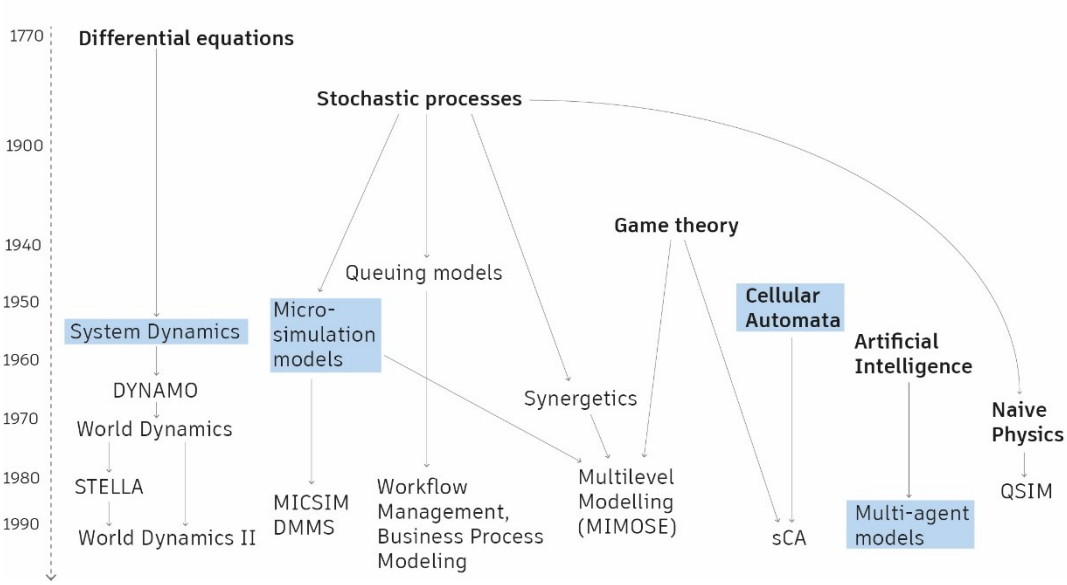


Figure 4.1. Evolution of simulation approaches (elaborated from Gilbert and Troitzsch (2005))

In the early 1960s, the first use of computers in university research coincided with the first development of simulation models, specifically based on differential equations. From these models, the **System Dynamics Model (SDM)** represents their powerful evolution (Forrester, 1980) capable of plotting the trajectories of variables over time (Nigel Gilbert & Troitzsch, 2005) using stocks, flows, internal feedback loops, table functions, and time delays (Guan et al., 2011). Another

model, that emerged in the same years is represented by the **Microsimulation Model (MSM)**. Until the last 20-30 years, MSM was considered the only form of simulation model widely recognized within the social sciences. MSM is based on stochastic processes applied to individual cases and to each simulation step. The procedure generates a predicted hypothetical sample, finally giving an estimation of the structure of the target population after some time steps (Gilbert & Troitzsch, 2005). Nevertheless, some limits can be underlined for these two approaches (SDM and MSM). SDM works at the macro level, without the possibility to break down the whole. This is problematic when the focus is on individuals, groups, or stakeholders and their behaviours and actions. Conversely, MSM is able to overpass this limit since it analyses the individuals or groups, taking into account their individual attributes (such as sex, age, marital status, education, employment) and considering transition probabilities (Gilbert & Troitzsch, 2005). In MSM, however, each individual acts based on a random number generator rather than their attitudes or motivations. Moreover, MSM aims simply to predict future effects, without any intention of being an explanatory model or considering the reactions of individuals based on their interaction with others (Gilbert & Troitzsch, 2005).

Before SDM and MSM, the discrete model of **Cellular Automata (CA)** was developed in the 1940s by Stanislaw Ulam and John von Neumann. The space of the CA model is a grid or a lattice with cells of the same size and shape, usually square, with a finite number of states. Cells can have values of either 0 or 1, or on a scale from 0 to 1. Each cell modifies its previous states based on the interaction with other cells nearby, called neighbourhood (Benenson & Torrens, 2004; Margolus & Toffoli, 1987; Torrens, 2003; Wolfram, 2002). Cells are fixed entities, i.e., they do not move, and their neighbourhoods remain the same all the time, but they change their states and rules. Like ABM, CA is also able to study the complexity of social systems, but from a different and easier perspective. CA considers the emergence of properties from local interactions, whereas ABM/MAS models more complex actions and reactions of agents. These actions and reactions are not only based on proximity (as in CA), but also on the own decisions and behaviours of agents and their individual knowledge of the environment (Birkin & Wu, 2012). CA is frequently used in combination with ABM, in particular to provide ABM with the environmental representation of geographical phenomena. Similar to a raster map, CA represents the space as a grid with the ability to simulate the variation of states of the environment over the time. For example, CA is often used in ABM for analysing land-use changes in landscape and urban modelling. In this latter and other cases, the boundary between the two models is blurred (Heppenstall et al., 2012).

The 1980s were characterized by little experimentation in the social sciences, and MSM represented essentially the only approach adopted for simulation analysis. This contrasts with what happens in the natural sciences, where simulation is a widely used methodology. A change occurred in the 1990s as a result of ABM and MAS implementation and the increasing interest of researchers in them. The

consciousness of the ability of these models to simulate autonomous entities and their interactions has become increasingly promising for studying social dynamics. However, the first attempt of what 20 years later was called ABM or MAS are the 'Simulmatics' project (Ithiel de, 2017), developed in 1962, approximately the same years when SDM and MSM started to be applied. Simulmatics simulates the reactions of voters during the John F. Kennedy's presidential campaign, analysing the individual exposition to change their opinions and attitudes based on information about the referendum and the topic coming from various channels, as well as from the interactions among themselves (Gilbert & Troitzsch, 2005). However, the model developed by Craig Reynolds in 1987 (Reynolds, 1987) is considered the first ABM (and the first time when the name ABM is used) adopted for simulating the movement of a population of artificial birds based on three simple rules (separation, alignment, and cohesion) (Macy & Willer, 2002). ABM is strongly influenced by a specific subfield of artificial intelligence (AI) called distributed artificial intelligence (DAI) (Morse, 1991).

Table 4.1 briefly summarizes the main characteristics of the most used simulation models presented before, with particular reference to the differences in their scale of use, in the construction of population and environment, and in their execution and definition of time.

Table 4.1. Comparison between dynamic models in spatial contexts (Caprioli et al., 2019)

Model	Scale	Environment	Population	Time
Agent-Based Models (ABM) (Multi Agent Systems (MAS))	Small scale (but large scale for land cover)	Environment contains agents (often more passive than population)	Hundreds of autonomous agents (detailed)	Flexible (both short and long intervals)
Cellular Automata (CA)	Quite flexible (often small)	Simplistic and unrealistic	(environment replaces population)	Flexible
Microsimulation Models (MSM)	Any scale (composed by individuals)	Large scale population	Population as distribution of characteristics (of a sample)	Flexible (both short and long intervals)
Systems Dynamic Models (SDM)	Quite flexible	(population replaces environment)	Discrete population (coupled different equations)	Flexible (both short and long intervals)

4.4 Literature review: ABM and MAS in urban studies

ABM/MAS has become a widely used approach in many disciplines in the last 15 years (Heppenstall et al., 2012), spanning physics, biology, ecology, social

sciences, economics, and geography (Grimm et al., 2006; Macal & North, 2010). Macal and North (2010) give a detailed overview of the main applications of this model in the different sciences. However, it is not in our interest to give a comprehensive review of the full range of ABM applications, also because it is quite impractical. On the contrary, it is quite interesting and useful to develop an examination of a representative sample in the context of urban studies.

4.4.1 ABM in urban studies

In order to give a comprehensive view of the main applications of ABM in urban studies, the main references consulted are: the extensive review developed by Huang et al. (2014), the ones developed by Crooks (2012) and by Heppenstall et al. (2012), and the brief ones by Chen (2012) and Parker (2003). Through the analysis of the first two, three research domains emerge, spanning from purely theoretical to intensively empirical models.

The first group includes a series of stylized ABMs developed to investigate questions central to the development of urban form. Most of these ABMs were built on two paradigmatic theoretical antecedents by eventually making some variations on them: (i) the Schelling-style residential segregation and (ii) the monocentric bid-rent model.

(i) Starting from the two parallel models of Schelling and Sakoda (1970), a wide number of variations and extensions have been developed in order to explain residential segregation. In fact, the two antecedents are intentionally primitive, with the representation of space by a grid and people migration based on dissonance measured by the number of other-type (black or white) households within a neighbourhood. However, the models show how segregation patterns can emerge from individual decisions. Due to the increase in computing capacity, many extensions of these studies have been developed, varying both space (and neighbourhood) and conflicting groups. In addition, other effects are considered as driving forces for segregation, such as income and house quality, the attractiveness of public goods, cultural differences, property type, and agent inertia. There are also fine-scale residential segregation examples that use individual census and GIS data to simulate the dynamics of a specific place and for a specific time frame (e.g., Benenson et al. 2002).

(ii) In parallel to the studies on segregation phenomena, ABM has been widely used to explain the location of households and firms and their urban spatial structure (Huang et al., 2014). The decision of "where to locate?" results from complex interrelationships between individual actions constrained by many social, political, and economic factors (Crooks, 2012). The various models developed over the years take their origin from the bid-rent theory of Von Thunen (1966), and in its

extension to urban contexts, the monocentric city model of Alonso (1964), Muth (1969) and Mills (1972). Their extensions and variations have focused both on the development of a polycentric city model and on the interaction among heterogeneous agents and market disequilibrium. These models allow the analyst to determine the price-formation function emerging from interactions between buyers and sellers and depending on different factors (e.g., residents' income, heterogeneity preferences, travel cost, house quality). This implies that these models are able to simulate the formation of expectations of future prices and other complex processes of the market (different market conditions, heterogeneous risks, and the effects of economic incentives) (Huang et al., 2014).

The second group studies different stages of the urbanization process, partially based on theoretical findings and partially on empirical data. The types of urbanization under analysis can vary substantially between developing and developed countries. With respect to the first group, the growth of informal settlements, peripheralization, and rapid urbanization are all simulated. Instead, for developed countries, the analysis goes deeper into the study of gentrification, urban sprawl, and urban shrinkage. In both cases, the majority of the models built are policy-oriented. Through "what if" scenarios, the aim is to understand the influence of policy and planning strategies on urban physical morphology, socioeconomic outcomes, and environmental consequences. Examples are the hypothetical planning scenarios in the Netherlands developed by Ligtenberg et al. (2004), sustainable development strategies in a rapidly expanding city in China by Li and Liu (2008) and urban regeneration policies to encourage social mixing in the UK developed by Jordan et al. (2012). This research is part of a larger body of work in which ABMs (often called MAS in this field) are used to investigate various aspects of land-use and land-cover change (LUCC), ranging from natural-resource management to agricultural economics, archaeology, and urban simulations (Parker et al., 2003).

The third group includes various models largely driven by empirical data to replicate details of a specific case study. In this case, we are talking about incorporating microsimulation modelling with ABM. This integration allows to accommodate a broad dimension of agent heterogeneity (e.g., demographic attributes) within the model and enhance the predictive power of ABM (Huang et al., 2014). Starting from the simulation of the moving and residential choices of households, the location and real-estate-type choices of a developer and of firms and businesses, this model is highly related to policy and planning analysis, integrating the life-cycle events, daily activities, and social behaviour of individuals that play an important role in influencing residential choice.

Then, in the work of Crooks (2012) and Heppenstall et al. (2012), a review of "real" world applications of ABM linked with GIS is given. With the development of GIS, ABM has been increasingly recognized as a powerful tool for spatial

modelling (Chen, 2012), giving rise to strong fields of research, such as the studies of Batty (2005) about the understanding of cities and those of urban geosimulation provided by Torrens and Benenson (Benenson & Torrens, 2004). However, also for these spatially explicit ABMs, the research domains are the same and the difference lies only in the geographical locations of entities and/or environments. Examples in this context are urban housing dynamics (e.g., Benenson et al. 2002), urban growth (e.g., Batty and Xie, 2005), segregation (e.g., Crooks et al., 2008), residential and business location (e.g., Torrens, 2006; Barros, 2004), and gentrification (e.g., Torrens and Nara, 2007). Moreover, the integration of GIS has led to the development of the study of micro-scale phenomena, such as pedestrian models (in urban centres, in-crowd congestion, in an emergency evacuation of buildings, or in terrorist attacks), traffic models, and crime models.

For the aim of this research, more interesting examples are those able to formulate and test alternative policies and guide decision-makers. Brown et al. (2005) focus on individual decision-making with respect to land-use change at the urban-rural fringe to formulate and test alternative policies in the view of environmental cost reduction and environmental benefit enhancement. Yin and Muller (2007) study land-use and land-cover change at the urban-rural fringe, and Bossomaier et al. (2007) analyse house price evolution, considering agent perceptions and desires combined with spatial factors (distance from amenities, environmental aspects) to guide urban planning and predict changes in the real estate market.

4.4.2 ABM in innovation diffusion

A research line, in parallel with the one previously described, is that of ABM as an approach to studying innovation diffusion. In the first instance, this field of research seems of little importance in the context of urban studies. However, due to the increasing awareness of the necessity to adopt energy efficiency in society and the constant pressures of EU and national governments to achieve target sets (Hesselink & Chappin, 2019), the analysis is particularly useful about the effective ways and how policymakers should stimulate the adoption of efficient technologies and sustainable practice. Achieving those issues requires the implementation of policies able to overcome the different barriers (structural, economic, social, or behavioural) that stop households from adopting such technologies and implementing sustainable actions. In that context, modelling and simulation support policymakers in their evaluation of policies and help them decide on possible interventions (Hesselink & Chappin, 2019).

For that reason, a specific literature review was developed with respect to the use of ABM for analysing the diffusion and adoption of sustainable policies in urban contexts. In particular, the literature review starts with the research developed by Kiesling et al. (2012) and Zhang and Vorobeychik (2017). Then, more insights on the adoption of energy-efficient technologies come from Hesselink and Chappin

(2019). Moreover, other references, more related to the empirical research application developed in this thesis and described in Chapter 6, were included and investigated.

Starting from the review of Kiesling et al. (2012), it is quite clear how, in this case also, the majority of the papers reviewed aim at general insights about diffusion processes at a highly abstract level. In this sense, they are much more concerned with theoretical development and explanation than with prediction (Gilbert, 1997).

The same reasoning emerges also from the paper by Zhang and Vorobeychik (2017): the authors underline the necessity to shift from "toy models" that do not reflect reality to empirically grounded ABMs. The role of ABM as an ideal learning tool in innovation diffusion was explored by different authors: Garcia (2005) in innovation/new product development, Dawid (2006) in computational economic models, Peres et al. (2010) in diffusion modelling efforts, and Hauser et al. (2006) in marketing (Kiesling et al., 2012).

However, more interesting, for the purpose of this thesis, is the review in terms of applications to real-world problems. Kiesling et al. (2012) classify the applications and policy analysis essentially into three major domains: agriculture (a), energy, transportation, and environmental innovations (b) and miscellaneous (c). The second group is of particular interest to the objective of the PhD research. The analysis of alternative transportation modes and of innovations for the reduction of domestic water and energy consumption is strongly relevant for the development of sustainable policies at urban-district scales. The major examples to take in mind from Kiesling et al. (2012) paper are: Zhang et al. (2011) that investigate factors that can speed the diffusion of hybrid and electric vehicles in the US market; Schwarz and Ernst (2009) that analyse the diffusion of water-saving innovations in Southern Germany; Faber et al. (2010) that study the adoption of domestic micro co-heating and power (micro-CHP) in the Netherlands; and Zhang and Nuttall (2011) that simulate the diffusion of smart electricity meters in Great Britain.

In a more recent and systematic review, Zhang and Vorobeychik (2017) provide additional references for empirical ABM applications of innovation diffusion. Compared to the three domains defined by Kiesling et al. (2012), Zhang and Vorobeychik (2017) define five research clusters: agricultural innovations and farming (a), sustainable energy and conservation technologies (b), consumer technologies and innovations (c), information technologies (d) and social goods (e). Table 4.2 reports only the references that are strongly relevant to the field of this research and, therefore, those related to sustainable energy and conservation technologies.

Last but not least, additional references and more insights were given by Hesselink and Chappin (2019) in their review of the literature related to the ABM studies on the adoption of energy efficiency by households conducted in 2017 through the Scopus scientific library. In particular, the purpose of this work is to

identify the policy recommendations produced by ABM applications and to learn what properties of ABMs contribute to the formulation of concrete policies, in particular taking into account adoption barriers. Starting from the discussion of energy efficiency adoption barriers and policies, and modelling methods, the paper explores the role and contribution of existing ABMs in the analysis of different technologies, policies, theories, and data. In particular, Table 4.3 reports the additional references provided by this work, in particular with respect to the different technologies and/or behaviours modelled in the paper reviewed.

Table 4.2. References of empirical ABMs that study sustainable energy and conservation technologies (adapted from Zhang and Vorobeychik (2017))

Application	Method	GIS	References*
Water-Saving Technology	Cognitive Model (TPB)	N	Schwarz and Ernst (2009) Agent-based modeling of the diffusion of environmental innovations an empirical approach.
	Discrete Choice Model	Y	Galan et al (2009) An agent-based model for domestic water management in Valladolid metropolitan area.
Heating System	Cognitive Model (TPB)	N	Sopha et al (2013) Adoption and diffusion of heating systems in Norway: coupling agent-based modeling with empirical research.
	Conjoint Analysis	N	Lee et al (2014) An analysis of UK policies for domestic energy reduction using an agent based tool.
	Economic (Cost)	N	Faber et al (2010) Exploring domestic micro-cogeneration in the Netherlands: an agent-based demand model for technology diffusion.
Solar Photovoltaic	Heuristic	N	Zhao et al (2011) Hybrid agent-based simulation for policy evaluation of solar power generation systems
	Economic (Utility)	N	Palmer et al (2015) Modeling the diffusion of residential photovoltaic systems in Italy: An agent-based simulation.
	Cognitive Model (TPB, Deffuant)	Y	Rai and Robinson (2015) Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors.
	Machine Learning	Y	Zhang et al (2016) A study of the diffusion of alternative fuel vehicles: An agent-based modeling approach.
Fuel Cell Vehicles	Cognitive Model (Consumat)	N	Schwoon (2006) Simulating the adoption of fuel cell vehicles.
Energy Innovation	Discrete Choice Model	N	Tran (2012) Agent-behaviour and network influence on energy innovation diffusion.
Electric Vehicles	Cognitive Model (TEC)	N	Wolf et al (2012) The adoption of electric vehicles: An empirical agent-based model of attitude formation and change.
	Economic (Utility)	N	Plotz et al (2014) Modelling market diffusion of electric vehicles with real world driving datapart i: Model structure and validation.
		N	McCoy and Lyons (2014) Consumer preferences and the influence of networks in electric vehicle diffusion: An agent-based microsimulation in Ireland.
Alternative Fuel Vehicles	Conjoint Analysis	N	Zhang et al (2011) A study of the diffusion of alternative fuel vehicles: An agent-based modeling approach.

Alternative Fuels	Heuristic	N	Van Vliet et al (2010) Multi-agent simulation of adoption of alternative fuels.
	Economic (Utility)	N	Gunther et al (2011) An agent-based simulation approach for the new product diffusion of a novel biomass fuel.
	Conjoint Analysis	N	Stummer et al (2015) Innovation diffusion of repeat purchase products in a competitive market: an agent-based simulation approach.
Green Electricity	Cognitive Model (LARA)	N (spatial patterns)	Krebs and Ernst (2015) A spatially explicit agent-based model of the diffusion of green electricity: Model setup and retrodictive validation.
		N	Ernst and Briegel (2016) A dynamic and spatially explicit psychological model of the diffusion of green electricity across Germany.
Air-Quality Feedback Device	Cognitive Model (TPB)	N	Jensen et al (2016) Energy-efficiency impacts of an air-quality feedback device in residential buildings: an agent-based modeling assessment.

*no cited in final references

Table 4.3. References of ABMs that study energy efficiency adoption technologies, barriers, and policies (adapted from Hesselink and Chappin (2019))

Technologies	References*[1,2]	Empirical data	GIS	Initiatives	Policies included	Barriers	Policy conclusion
Lighting technologies: Incandescent, light emitting diode (LED), compact fluorescent lamp (CFL), Halogen	Cao et al (2017) Agent-based modeling of the adoption of high-efficiency lighting in the residential sector	Y: Data from US institutions (no theory to structure decision-making)	N	RA, IVS	a) Lamp ban	a) Other priorities, Ignorance	Banning incandescent light bulbs is most effective policy to increase energy efficiency from lighting.
					b) Information campaigns	b) Lack of information, Inertia	An information campaign can be effective, but the effect is small compared to banning incandescent light bulbs
	Chappin and Afman (2013) An agent-based model of transitions in consumer lighting: policy impacts from the E.U. phase-out of incandescents	Y: Survey data and internet sources	N	EFM, RA	a) Subsidy b) Tax c) Lamp ban	a) High upfront cost b,c) Lack of information, Other priorities, Ignorance, Inertia	Subsidies not as effective as other policy types Banning incandescent light bulbs is most effective policy to increase energy efficiency from lighting.
	Hicks and Theis (2014) An agent based approach to the potential for rebound resulting from evolution of residential lighting technologies	Y: Survey data	N	-	No policies (light consumption scenarios)		
	Hicks et al (2015) Emergent effects of residential lighting choices: prospects for energy savings	Y: Survey data	N	EFM, RA	a) Subsidy b) Tax	a) High upfront cost, Social comparisons b) Ignorance, Other priorities	Subsidy in combination with other policies can be beneficial but rebound effect diminishes savings Banning incandescent light
Residential heating systems: Direct electric heating, Wood pellet heating stoves, Heat pump	Sopha et al (2011) Exploring policy options for a transition to sustainable heating system diffusion using an agent-based simulation **Sopha et al (2013)* Adoption and diffusion of heating systems in Norway: coupling agent-based modeling with empirical research**	Y: Survey data Y: Survey data, National statistics data	N N	EFM, RA, IVS	a) Subsidy b) Regulation (price) c) Technical development stimulation d) Promotion and Education	a,c) High upfront cost a) Lack of Capital b) Uncertainty of fuel prices a,c) High upfront cost d) Lack of information, Inertia	Technical development and financial support in combination with other policies are required A stable price for fuel for wood pellet stoves is one of the conditions needed to stimulate adoption The effect of an information campaign is not significant, only in combination with other policies
Heat pump	Snape et al. (2015) Will domestic consumers take up the renewable heat incentive? An analysis of the barriers to heat pump adoption using agent-	N: predictions from other studies (no theory to structure decision-making)	N	EFM	a) Subsidy for high energy standard (UK Renewable Heat incentive)	a) Lack of capital, High upfront cost	Incentives and standards program has already pushed heat pump diffusion beyond a certain point and more policy stimulation is needed

	based modelling						
Heating, Ventilation and Airco (HVAC) heating, HVAC cooling, Area lighting, Task lighting, Equipment (computers), Hot water supply	Azar and Menassa (2011) Agent-based modeling of occupants and their impact on energy use in commercial buildings	N: (no theory to structure decision-making)	N	-	No policies studied		
Micro-CHP	**Faber et al (2010) Exploring domestic micro-cogeneration in the Netherlands: an agent-based demand model for technology diffusion**	N: publicly available data (no theory to structure decision-making)	N	EFM	a) Subsidy	a) Lack of capital, High upfront cost, Uncertainty of fuel prices	Subsidy is only effective in certain price range and subsidies based on decreasing price difference between competing technologies are much more cost effective than fixed purchase subsidies
Wall insulation	Friege (2016) Increasing homeowners' insulation activity in Germany: an empirically grounded agent-based model analysis	Y: Survey data and publicly available data	Y	RA, IVS	a) Homeowner adoption obligation b) Information campaign	a) Other priorities, Ignorance, Inertia b) Lack of information	Obligating new homeowners to adopt improved wall insulation is the most effective policy Information instruments have relatively small impact on adoption
Solar PV systems	**Palmer et al. (2015) Modeling the diffusion of residential photovoltaic systems in Italy: an agent-based simulation**	Y: statistical data	N	EFM	a) Subsidy (Italian solar PV support scheme)	a) Lack of capital, High upfront cost	Current support scheme is already effective, and diffusion will slow down in the future
	Rai and Robinson (2015) Agent-based modeling of energy technology adoption: empirical integration of social, behavioral, economic, and environmental factors	Y: survey data	Y	-	No policies studied		
	Zhang et al. (2014) Predicting rooftop solar adoption using agent-based modeling	Y: dataset from California Solar Initiative	N	EFM	a) Subsidy b) Seeding (providing for free)	a,b) Lack of capital, High upfront cost	Subsidies have a very poor effect on increasing adoption
	Alyousef et al (2017) Analysis and model-based predictions of solar PV and battery adoption in Germany: an agent-based approach	Y: survey data and official reports	N	EFM	a) Subsidy Price effect scenario	a) Lack of capital, High upfront cost, Uncertainty of fuel prices	Price increase in electricity (subsidy for production and storing) is more effective than subsidizing purchase
Electric Vehicles	**McCoy and Lyons (2014) Consumer preferences and the influence of networks in electric**	Y: survey data	N	-	No policies studied		

	vehicle diffusion: an agent-based microsimulation in Ireland						
	Noori and Tatari (2016) Development of an agent-based model for regional market penetration projections of electric vehicles in the United States	Y: data from previous studies	N	EFM, IVS	a) Subsidy b) Information campaign	a) Lack of capital, High upfront cost, b) Lack of information, Ignorance, Inertia	Subsidies are vital to boost adoption of electric vehicles Information campaign only effective when combined with a subsidy scheme
	Wolf et al. (2015) Changing minds about electric cars: an empirically grounded agent-based modeling approach	Y: survey data	N	EFM	a) Subsidy b) Tax exemption c) Exclusive EV zone	a, b) Lack of capital, High upfront cost, Codes and standards, Inertia	Exclusive electric vehicle zone is more effective than subsidizing
	Silvia and Krause (2016) Assessing the impact of policy interventions on the adoption of plug-in electric vehicles: an agent-based model	Y: with also probabilities	N	EFM, IVS	a) Subsidy b) Awareness campaign	a) Lack of capital, High upfront cost b) Lack of information, Ignorance, Inertia	Subsidies in combination with information campaigns are most effective at stimulating adoption Information campaign only effective when combined with a subsidy scheme
CO2 meter	**Jensen et al (2016) Energy-efficiency impacts of an air-quality feedback device in residential buildings: an agent-based modeling assessment**	Y	N	-	No policies studied		
Behaviour changing feedback device	Jensen et al (2015) Agent-based assessment framework for behavior-changing feedback devices: spreading of devices and heating behavior	Y: Commercial data	N	-	No policies studied		
No specific appliances or technologies modelled	Chen et al (2012) Modeling building occupant network energy consumption decision-making: the interplay between network structure and conservation	Y: Data from empirical experiment	N	-	No policies studied		
	Kowalska-Pyzalska et al (2014) Turning green: agent-based modeling of the adoption of dynamic electricity tariffs	N	N	-	No policies studied		

(Green) eco-innovations	Byrka et al (2016) Difficulty is critical: the importance of social factors in modeling diffusion of green products and practices	N	N	-	No policies studied

EFM: Economic, financial, and market-based instruments; RA: Regulatory approaches; IVS: Informative and voluntary schemes
*[1] In bold the papers that have been already reported in Table 4.2
*[2] no cited in final references

4.4.3 Key applications of ABM/MAS integrated with GIS at urban and district scales

Previously, the dissertation went deep into the examination of the research domains with respect to the role of ABM in urban studies, and in the diffusion and adoption of innovative technologies, particularly energy-efficient technologies. These two insights represent the baseline for structuring the applications developed in this PhD thesis[14].

However, an additional literature review was conducted to outline the most current trends in scientific research. This third literature review is focused on ABM/MAS applications integrated with GIS for supporting urban planning and urban regeneration[15]. The analysis was conducted using Scopus as the bibliographic database. The analysis was finally refined in January 2022.

The analysis of the literature was developed in three different stages. It made possible the identification of different trends with respect to the theme of ABM/MAS in urban planning contexts.

Firstly, it was briefly examined the evolution of ABM contributions, considering all articles related to ABM. The following query was used: TITLE-ABS-KEY ("agent based model" OR "agent based modeling" OR "agent based modelling" OR "ABM"). The number of sources is more than twenty thousand. Some contributions date back to the seventies, but the significant increase (more than 300 results per year) occurred after 2005 (Figure 4.2).

Secondly, it was analysed the publications that uses ABM for supporting urban regeneration and planning processes. In this case, the query is TITLE-ABS-KEY ("agent based model" OR "agent based modeling" OR "agent based modelling" OR "ABM" AND ("urban regeneration" OR "urban planning" OR "urban transformation")). The result of this analysis shows 223 documents. All the manuscripts were written after 2000, and a considerable growth occurred after 2005. Then, considering only the documents that use integration between ABM and GIS in this field, the relevant articles passed from 223 to 32.

[14] In particular, the first investigation has suggested the second case study of this thesis (Chapter 7) about the examination of gentrification effects in urban contexts. Then, the analysis of technological diffusion with ABM has been useful to frame the first case study (Chapter 6) about the investigation of sustainable policies to increase PVs at the district scale.

[15] This analysis supports the identification of the third case study (Chapter 8), focused on the construction of balanced and sustainable regeneration scenarios.

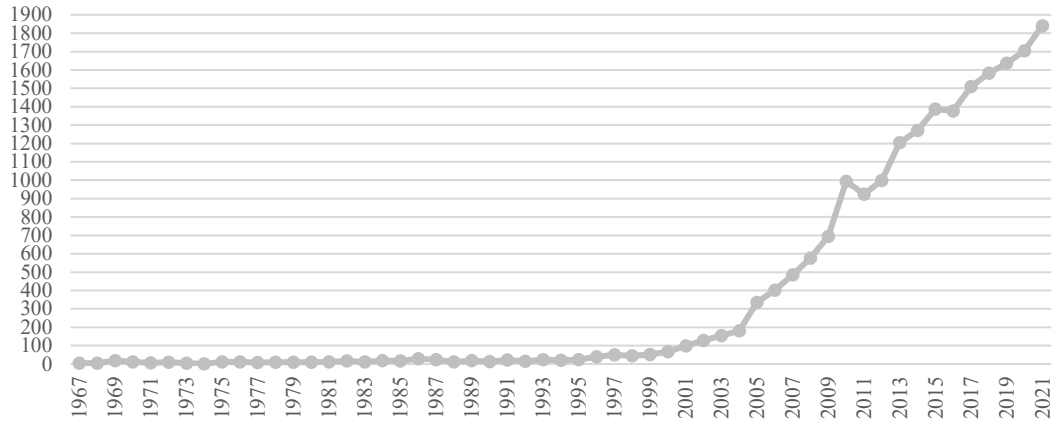


Figure 4.2. Number of publications related to ABM, written over the years

Thirdly, a literature review was performed on MAS in urban transformation and planning research, using the following query TITLE-ABS-KEY (("multi agent system" OR "MAS") AND ("urban regeneration" OR "urban planning" OR "urban transformation")). The result is a number of publications equal to 274, with a decrease to 17 when adding to the query the word GIS.

More insights are given in Table 4.4 (for ABM) and Table 4.5 (for MAS) on empirical applications in urban planning and urban regeneration through the integration of GIS. Only a few of them can be useful for our research topic (those in bold), such as the paper by Motieyan and Mesgari (2018). However, some other examples were collected from the previous research without GIS. In particular, Table 4.6 shows the most relevant ones, which are integrated with additional literature from other database tools (such as Google Scholar).

Table 4.4. References of empirical ABMs that study urban regeneration, transformation, and planning through an integration of GIS

Authors*[1,2]	Title	Scale	Scope	Year
Rosés, R., Kadar, C., Malleson, N.	A data-driven agent-based simulation to predict crime patterns in an urban environment	New York City (USA)	mechanisms that drive crime and can support decision-makers in developing effective crime reduction strategies	2021
Anderson, T., Leung, A., Dragicevic, S., Perez, L.	Modeling the geospatial dynamics of residential segregation in three Canadian cities: An agent-based approach	Three cities: the City of Toronto, the City of Calgary, and Metro Vancouver	drivers of segregation and possible segregation effects in response to incoming immigrant populations	2021
Wozniak, M.	Conceptual Framework for Modeling Complex Urban Systems—From Theoretical Assumptions to Empirical Basis	Artificial city	inhabitants of the artificial city try to achieve the highest possible level of satisfaction maximizing individual utility function (focusing on focus on the labour market and real estate market)	2021
Xu, T., Gao, J., Coco, G., Wang, S.	Urban expansion in Auckland, New Zealand: a GIS simulation via an intelligent self-adapting multiscale agent-based model	City of Auckland, New Zealand	urban expansion of Auckland, New Zealand, a total of 15 urban expansion drivers/constraints were considered over two periods (2000–2005, 2005–2010)	2020
Abel, K.C., Faust, K.M.	Modeling complex human systems: An adaptable framework of urban food deserts	Region in Austin, Texas	simulate food deserts and which policy and built environment disruptors	2020
Caprioli, C., Bottero, M., Pellegrini, M.	An Agent-Based Model (ABM) for the Evaluation of Energy Redevelopment Interventions at District Scale: An Application for the San Salvario Neighborhood in Turin (Italy)	San Salvario neighbourhood in Turin (Italy)	Simulation of policies effects on PV adoption	**2019**
Motieyan, H., Mesgari, M.S.	**An Agent-Based Modeling approach for sustainable urban planning from land use and public transit perspectives**	**7th region and its neighbourhoods in Tehran**	**Sustainable urban planning from land use and public transit perspectives**	**2018**
Alghais, N., Pullar, D.	Modelling future impacts of urban development in Kuwait with the use of ABM and GIS	Kuwait country	Urban growth by rules for different citizen groups, historical growth patterns and the influence of decision-makers	2018
Poplin, A., Shenk, L., Passe, U.	Transforming pervasive into collaborative: Engaging youth as leaders with gis through a framework that integrates technologies, storytelling, and action	Neighbourhood in Des Moines, the capital of Iowa	Engagement framework	2017
Poplin, A., Shenk, L., Krejci, C., Passe, U.	**Engaging youth through spatial socio-technical storytelling, participatory gis, agent-based modeling, online geogames and action projects**	**Neighbourhood in Des Moines, the capital of Iowa**	**Engagement framework**	**2017**
León, J., March, A.	An urban form response to disaster vulnerability: Improving tsunami evacuation in Iquique, Chile	Chilean city of Iquique	Near-field tsunami, and the role of urban form in supporting the populations' core response activities of evacuation and sheltering	2016
Liu, H., Silva, E.A., Wang, Q.	**Incorporating GIS data into an agent-based model to support planning policy making for the development of creative industries**	**Jiading district, Shanghai**	**Optimise the land use assignment in order to support the development of creative industries**	**2016**
Koziatek, O., Dragićevic, S., Li, S.	Geospatial modelling approach for 3D urban densification developments	Part of the City of Surrey, within the Metro Vancouver Region, Canada	Densifying developments in the vertical built dimension with mid- and high-rise buildings	2016
Barau, A.S., Qureshi, S.	Using agent-based modelling and landscape metrics to assess landscape fragmentation in Iskandar Malaysia	Iskandar Development Region	Current and future fragmentation dynamics in Iskandar Malaysia	2015
Yu, J., Wen, J., Jiang, Y.	Agent-based evacuation simulation for spatial allocation assessment of urban shelters	Jing'an District, Shanghai, China	Implementing evacuation simulation so as to conduct dynamic spatial allocation assessment of urban shelters	2015

Hartmann, T., Zerjav, V.	**Optimizing the location of out-care centers in urban space using agent-based modeling**	**Region**	**Supporting localization decision making of such out-care centres within a specific urban setting**	**2014**
Badland, H., White, M., MacAulay, G., (...), Pettit, C., Giles-Corti, B.	Using simple agent-based modeling to inform and enhance neighborhood walkability	Northwest Metropolitan region of Melbourne	Assessing and optimizing the walkability of neighbourhood catchments around actual or potential nodes of interest (e.g., schools, public transport stops)	2013
Long, Y., Shen, Z.	Disaggregating heterogeneous agent attributes and location	Beijing Metropolitan Area	Disaggregating heterogeneous agent attributes and location	2013
Kocabas, V., Dragicevic, S.	Bayesian networks and agent-based modeling approach for urban land-use and population density change: A BNAS model	City of Surrey, British Columbia, Canada	A spatial model that simulates land-use change under the influence of human land-use choice behaviour with the “what-if" scenario capabilities	2013
Yin, L.	Assessing walkability in the city of Buffalo: Application of agent-based simulation	City of Buffalo	Framework for assessing macro-level patterns of walkability across a city using micro-level data	2013
Krämer, M., Kehlenbach, A.	Interactive, GPU-based urban growth simulation for agile urban policy modelling	-	Urban growth simulation for agile urban policy modelling	2013
Jokar Arsanjani, J., Helbich, M., de Noronha Vaz, E.	Spatiotemporal simulation of urban growth patterns using agent-based modeling: The case of Tehran	City of Tehran	A propensity surface of growth that is able to identify the most probable sites for urban development	2013
Chen, L., Ng, E.	Computer simulation of pedestrian's transient thermal comfort in a complex urban context: A bottom-up modeling approach	-	Simulating pedestrian's transient and dynamic thermoregulatory condition while walking in the complex outdoor urban environment	2012
Jjumba, A., Dragićević, S.	**High Resolution Urban Land-use Change Modeling: Agent iCity Approach**	**Part of the City of Chilliwack, Canada**	**Analysing and forecasting possible future urban land use patterns**	**2012**
Li, X., Zhang, Y., Liu, X., Chen, Y.	Assimilating process context information of cellular automata into change detection for monitoring land use changes	District of Panyu in the Pearl River Delta	Monitoring land use changes	2012
Wang, J., Xiong, J., Yang, K., Peng, S., Xu, Q.	Use of GIS and agent-based modeling to simulate the spread of influenza	Kunming, Yunnan province, southwest of China	Simulating the spread of influenza in an urban environment, as a result of individuals' interactions in a geospatial context.	2010
Zhang, L., Murray-Rust, D., Li, W., (...), Rounsevell, M., Chen, G	**Integrating VR, GIS and agent based model to simulate regional residential demand changes**	**Regional scale**	**Framework for understanding urban dynamics and complexities**	**2009**
Kocabas, V., Dragicevic, S.	Agent-based model validation using Bayesian networks and vector spatial data	-	Validation of agent-based models (ABMs) of land-use change	2009
Voigt, B., Troy, A.	**Land-Use Modeling (Book Chapter)**	**-**	**Diverse drivers of urbanization, evolving from aspatial mathematical specifications of linear relationships to spatially explicit dynamic simulations**	**2008**
Li, X., Liu, X.	**Embedding sustainable development strategies in agent-based models for use as a planning tool**	**City in the Pearl River Delta**	**Spatial exploratory tool for generating alternative development patterns, examining the effects of different stakeholders in influencing the process of land development**	**2008**
Li, X., Li, D.	Agent-based modeling of urban land-use change	-	Modelling the urban land-use changes	2005
Haklay, M., O'Sullivan, D., Thurstain-Goodwin, M., Schelhorn, T.	"So go downtown": simulating pedestrian movement in town centres	-	simulating pedestrian movement behaviour	2001

*[1] In bold the papers that have been already reported in previous tables
*[2] no cited in final references

Table 4.5. References of empirical MASs in urban planning, transformation, and regeneration through an integration of GIS

Authors[*1,2]	Title	Scale	Scope	Year
Wang, S., Zhao, L.	Establishment and Application of Mountain City OSCA Model	Jinan city center	rules of the evolution of architectures constructed based on the controlling zones and develops a spatial evolution model of mountain city	2021
Jlassi, S., Tamayo, S., Gaudron, A., Fortelle, A.D.L.	Simulating impacts of regulatory policies on urban freight: Application to the catering setting	Paris, France	scenarios of regulation are evaluated for restaurants delivery services	2018
Li, X., Liu, X.	Spatial information technology for facilitating "three-plan integration" using geographical simulation and optimization	-	simulation and optimization of the "three-plan integration" program in China	2016
Karashima, K., Ohgai, A., Mukudai, T.	A tool to explore community-based activities considering mutual assistance for earthquake disaster mitigation using a Multi-agent System and GIS	-	reproduce various disaster situations and simulate evacuation behaviours with consideration towards mutual assistance	2016
Song, Y., Gong, J., Niu, L., (...), Zhang, W., Cui, T.	A grid-based spatial data model for the simulation and analysis of individual behaviours in micro-spatial environments	-	model for crowd simulations in indoor and outdoor spatial environments (individual behaviours)	2013
Zhang, J., Wang, K., Song, G., (...), Chen, X., Yu, Z.	**Application of multi-agent models to urban expansion in medium and small cities: A case study in Fuyang City, Zhejiang Province, China**	**Fuyang City, China**	**rules for the allocation of time and space in construction land resources**	**2013**
Makarenko, A., Musienko, A., Popova, A., (...), Samorodov, E., Trofimenko, A.	Cellular automata, agents with mobility and gis for practical problems	Kyev, Ukrainian	Migration processes and voting processes	2012
Shen, Z., Yao, X.A., Kawakami, M., Chen, P., Koujin, M.	Integration of MAS and GIS using Netlogo	-	dynamic interactions in an urban system for modeling urban sprawl systems from spatial and temporal perspectives via simulation	2012
Maillé, E., Espinasse, B.	A modeling tool integrated Dynamic risk of wildfire for assistance in territorial planning	peri-urban territory of a French Mediterranean area	simulation of different land cover dynamics for environmental risk management in territorial planning	2011
Wang, J., Xiong, J., Yang, K., Peng, S., Xu, Q.	Use of GIS and agent-based modeling to simulate the spread of influenza	Kunming, Yunnan province, China	spatial explicit epidemiologic model of flu is proposed for a greater understanding of the disease's spatial diffusion through a network of human contacts	2010
Zhang, K., Bian, F.	**A design and application of a multi-agent system and GIS for simulation of expansion in urban planning**	**Beijing, China**	**rule of allocation for urban land resource by the interaction of agents which impact on urban land outspreading**	**2010**
Peng, C., Cheng, J.	**Using multi-agent system for residential expansion models - A case study of Hongshan District, Wuhan City**	**Hongshan District of Wuhan City, Hubei Province, China**	**behavioral effects of stakeholders on the processes of land use/cover change**	**2007**
Peng, C., Du, N., Liu, Y.	Understanding residential expansion in big cities using MAS/RE	[same as before]	[same as before]	2007
Schuett, R.	**GIS planning support system in glasgow case study: The glasgow canals regeneration**	**Glasgow, UK**	**"hot spots" and "cool spots" for investment in different types of infrastructure, based on stakeholders' differing interests of investment**	**2007**
Liu, X., Li, X., Ai, B., (...), Wu, S., Liu, T.	**Multi-agent systems for simulating and planning land use development**	**Haizhu district of Guangzhou, China**	**spatial and temporal efficiency in using land resources is implemented according to the theories of environmental economics and sustainable development for simulating various planning scenarios and providing a**	**2006**

			spatial exploratory tool for planning purposes	
Benenson, I., Aronovich, S., Noam, S.	Let's talk objects: Generic methodology for urban high-resolution simulation	-	generic methodology for urban high-resolution simulation	2005
Wang, T., Tang, S., Pan, P.	3D urban traffic system simulation based on geo-data	-	traffic model	2004
Palmer, J.F.	**Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts**	**Cape Cod community of Dennis, Massachusetts**	**residents' perceptions of scenic quality during a period of significant landscape change for guiding landscape planners and designers about the preferred composition and configuration of human landscapes**	**2004**

*[1] In bold the papers that have been already reported in previous tables

*[2] no cited in final references no cited in final references

Table 4.6. The main articles from the literature review in the context of urban regeneration, transformation, and planning

Authors	Title	Description	Year
Babakan, A.S., Alimohammadi, A.	An Agent-Based Simulation of Residential Location Choice of Tenants in Tehran, Iran	ABM + GIS; urban level	2016
Bush, J., Roelich, K., Bale, C.S.E. & Knoeri, C.	Scaling up local energy infrastructure; An agent-based model of the emergence of district heating networks	ABM; scenarios at district level	2017
Filatova, T.	Empirical agent-based land market: Integrating adaptive economic behaviour in urban land-use models	ABM + GIS; town level	2015
Friege, J.	Increasing homeowners' insulation activity in Germany: An empirically grounded agent-based model analysis	ABM + GIS; urban level	2016
Galán, J.M., López-Paredes, A., del Olmo, R.	An agent-based model for domestic water management in Valladolid metropolitan area	ABM + GIS; metropolitan area	2009
Gaube, V. & Remesch, A.	Impact of urban planning on household's residential decisions: an agent-based simulation model for Vienna	ABM; urban level	2013
Heppenstall, A.J., Crooks, A.T., See, L.M. & Batty, M.	Agent-Based Models of Geographical Systems	ABM + GIS	2012
Hinker, J., Hemkendreis, C., Drewing, E., Marz, S., Hidalgo Rodriguez, D.I. & Myrzik, J.M.A.	A novel conceptual model facilitating the derivation of agent-based models for analysing socio-technical optimality gaps in the energy domain.	ABM/MAS; district level	2017
Hosseinali, F., Alesheikh, A.A. & Nourian, F.	Agent-based modelling of urban land-use development, case study: Simulating future scenarios of Qazvin city.	ABM; scenarios at urban level	2013
Jordan, R., Birkin, M., Evans, A.	An agent-based model of residential mobility: Assessing the impacts of urban regeneration policy in the EASEL district	ABM; district level	2014
Khansari, N., Silverman, B.G., Du, Q. & Waldt, J.B.	An Agent-Based Decision Tool to Explore Urban Climate & Smart City Possibilities.	ABM + GIS; urban level	2017
Le, Q.B., Park, S.J. & Vlek, P.l.g.	Land Use Dynamic Simulator (LUDAS): A multi-agent system model for simulating spatiotemporal dynamics of coupled human-landscape system 2. Scenario-based application for impact assessment of land-use policies.	MAS; scenarios at region level	2010
Liang, X., Yu, T., Hong, J., Shen, G. Q.	Making incentive policies more effective: An agent-based model for energy efficiency retrofit in China	ABM; urban level	2019
Ligtenberg, A., Beulens, A., Kettenis, D., Bregt, A.K. & Wachowicz, M.	Simulating knowledge sharing in spatial planning: an agent-based approach.	MAS; scenarios at region level	2009
Liu, H., Silva, E.A. & Wang, Q.	Incorporating GIS data into an agent-based model to support planning. Policy-making for the development of creative industries	ABM + GIS; district level	2016
Martinez, L.M., Viegas, J.M.	Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal	ABM + GIS; urban level	2017
Picascia, S.	A theory driven, spatialy explicit agent-based simulation to model the economic and social implications of urban regeneration	ABM + GIS; district/urban level	2014
Tian, G., Ouyang, Y., Quan, Q. & Wu, J.	Simulating spatiotemporal dynamics of urbanization with multi-agent systems – A case study of Phoenix metropolitan region, USA.	MAS; scenarios at urban level	2011
Tong, X. et al.	Behaviour change in post-consumer recycling: Applying agent-based modelling in social experiment	ABM; different communities	2018
Torrens, P.	Can Geocomputation Save Urban Simulation? Throw some agents into the mixture, simmer and wait	CA+MAS; urban level	2001
Wang, A., Wang, H., & Chan, E.	The incompatibility in urban green space provision: An agent-based comparative study	ABM + GIS; urban level	2020

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Chapter 5

Agent-based model/Multi-agent system methodology[16]

5.1 Main characteristics of ABM/MAS

Until now, we have spoken quite generally about the characteristics of ABM/MAS and their potential ability to support the evaluation of sustainable strategies and policies. However, to better underline the methodological implications of developing this model in its integration with GIS for supporting these analyses, it is necessary to deepen its characteristics. This enables to highlight the elements that must be considered for the model development (agents, environment, and interactions) and the rules governing the model itself (attributes and methods).

As mentioned many times, ABM/MAS is a powerful model able to build complex systems starting from individual actors (called agents) whose coincident acting leads to emergent effects or outcomes (Hinker et al., 2017). The results do not come from the actions of a single agent, but the final effects of the interactions of all actors (Grimm et al., 2006). Simulating individual actions of many diverse agents and measuring the resulting system makes to realize a decision-making process really based on a bottom-up approach, in which the stakeholders act to achieve their own objectives and interests (Caprioli & Bottero, 2018). Another element that characterizes this approach is the presence of a shared environment in

[16] Part of this chapter has been developed in the following paper:

- Caprioli, C., & Bottero, M. C. (2018). Agent-based modelling and Geographic Information System for the evaluation of eco-district's scenarios. In A. Leone & C. Gargiulo (Eds.), *Environmental and territorial modelling for planning and design* (pp. 35–45). FedOAPress. https://doi.org/10.6093/978-88-6887-048-5

which the agents interact. Connecting the environment with the multidimensional aspects of the decision-making process can be useful for studying the effects of processes that operate at multiple scales and organizational levels (Brown, 2006).

More precisely, it is possible to define three components as the key elements that characterize all ABM/MAS, i.e., the **agents**, the **interactions,** and the **environment**. These three components of ABM/MAS are described in-depth in the following lines.

AGENT

The literature does not provide a univocal definition of agents and their characteristics. However, Macal and North (2010) underline certain essential characteristics that the agents need to have:

- *Autonomy* in their environment and in their interactions. The agents are self-directed. This implies that an agent has behaviours that guide them in making decisions and taking actions. These behaviours can be specified in different ways (see behavioural models in Section 5.4) from simple rules to abstract models. Moreover, decisions and actions are affected by information that comes through interactions with other agents and with the surrounding environment.
- *Self-sufficiency*, uniqueness, individual identifiability, and modularity. Agents have boundaries that determine what is or is not part of an agent and what is a shared attribute. Moreover, they have specific and unique characteristics (attributes) that distinguish the agent from others and make them able to recognize themselves.
- A *state* that varies over time. The agent state consists of the collection of their state variables and, also, those variables associated with their current situation. In ABM/MAS, the state at any time consists of all the information that makes the system move forward from the current point.
- A *social dynamic* that influences agent behaviours through interactions with other agents. Agents have some rules for their interactions (such as communication, movement and comprehension of space, and the capability to respond to the environment).

Then, agents may also have other useful characteristics:

- *Adaptivity* allows the agent to modify their behaviours through rules and mechanisms. Changes in behaviours can take place through learning and adaptability based on the accumulated experiences of the agent.
- *Goal-directed behaviour* is what drives the agent to achieve their goals and objectives. These objectives may or may not be oriented toward maximization, but they do allow the agent to compare outcomes and change their responses in the future.
- *Heterogeneity* is defined by the full range of agent diversity across a

population. The number of variables considered, the interactions of agents with others and with the environment, the behavioural rules, and the methods of action and learning, all had an impact on the simulation model results.

This classification of agent properties provided by Macal and North (2010) defines a practical modelling standpoint on how ABM/MAS is built in the wide spectrum of applications, as well as on how it can be implemented. Another good description of agents, more related to the social sciences, is the one reported by Gilbert and Terna (2000) and Wooldridge and Jennings (1995), in which agents were considered as *"processes implemented on a computer that have autonomy (they control their own actions); social ability (they interact with other agents through some kind of "language"); reactivity (they can perceive their environment and respond to it); and pro-activity (they are able to undertake goal-directed actions)"*.

All the characteristics previously described are determined by two components that each agent has: their *attributes* and/or the *methods* that operate on the agent. The sum of those elements allows the agents to interact with others and with the environment, and to act on it.

The *attributes* of an agent can be static and/or dynamic. In the first case, those attributes are not changeable during the simulation, and they are simply descriptive, such as the name. In the second case, the attributes vary over time. These attributes are calculated endogenously by the model and updated for the agents, such as the agent's memory of past interactions (Macal & North, 2010; Macal & North, 2014).

The *methods* are the ways the agent acts, i.e., their behaviours and rules. A variety of models for developing those behaviours exists. They can be supported by theoretical and empirical evidence, and, in that case, the simulation model could be developed based on that; otherwise, it is possible to define a normative model, in which agents attempt to optimize profits, utility, etc, as a starting point for a more realistic descriptive model of behaviour (Macal & North, 2010). A detailed overview of the types of decision models found in ABM/MAS is given in Section 5.4.

INTERACTION

An intrinsic aspect of ABM/MAS concerns the relationships and interactions modelled between the agent-agent and agent-environment. Modelling these interactions requires figuring out with whom agents are connected and the mechanisms of dynamic interactions. As in real-world systems, agents interact with a subset of a population of agents, called *neighbours* (Macal & North, 2010). In fact, the rationale behind ABM/MAS is that only *local information* is available to an agent (Macal & North, 2010). This local information comes mainly from the interactions of an agent with their neighbours. The connections among agents are generally termed as model *topology*, which could be a spatial grid or a network of

nodes (agents) and links (relationships) (Macal & North, 2010). For that reason, with the term neighbourhood, we refer both to neighbours located closely in a physical (or geographical) matter, as well as those located close-by in a social manner, i.e., the agent social network. This social network could not be affected by proximity, but similarities, connections made along life's journey, among others. In some applications, agents interact according to multiple topologies.

The main interaction topologies used for modelling agent interactions are (Macal & North, 2010):

- Those related to Cellular Automata (CA), such as von Neumann "5-neighbour" or Moore "9-neighbour". Agents move on a grid or lattice environment and interact with a fixed set of neighbouring cells that surround them.
- In 2D or 3D Euclidean Space, agents can move around in two, three, or higher-dimensional spaces.
- The Network topology, compared to previous topologies, allows an agent neighbourhood to be defined more generally. In particular, it is possible to define a static or dynamic network topology. The first one provides that links are pre-specified and do not change. In the second one, however, links and nodes are determined endogenously according to mechanisms programmed in the model.
- GIS topology is characterized by cells, called patches, in which the agents move in a realistic geospatial landscape.
- The "Soup" model is an aspatial model in which agents have no location and their interactions are randomly selected.

ENVIRONMENT

The environment represents the place in which agents interact and, at the same time, an element that agents interact with (Caprioli & Bottero, 2018). It could provide different information and detail levels: it may give only information about the agent spatial locations or a rich set of data, like a GIS (Macal & North, 2010). It allows an agent both to acquire resources and information from the different data contained in the environment and to modify it as a result of these actions.

Figure 5.1 schematically shows the three main elements of ABM/MAS previously described (agents, environment, and interactions) and how they are generally considered in the three case studies developed in this thesis (Chapters 6, 7, and 8). Then, the same graphical representation will be presented at the beginning of each case study to illustrate similarities and differences among them, starting from the same initial and common structure.

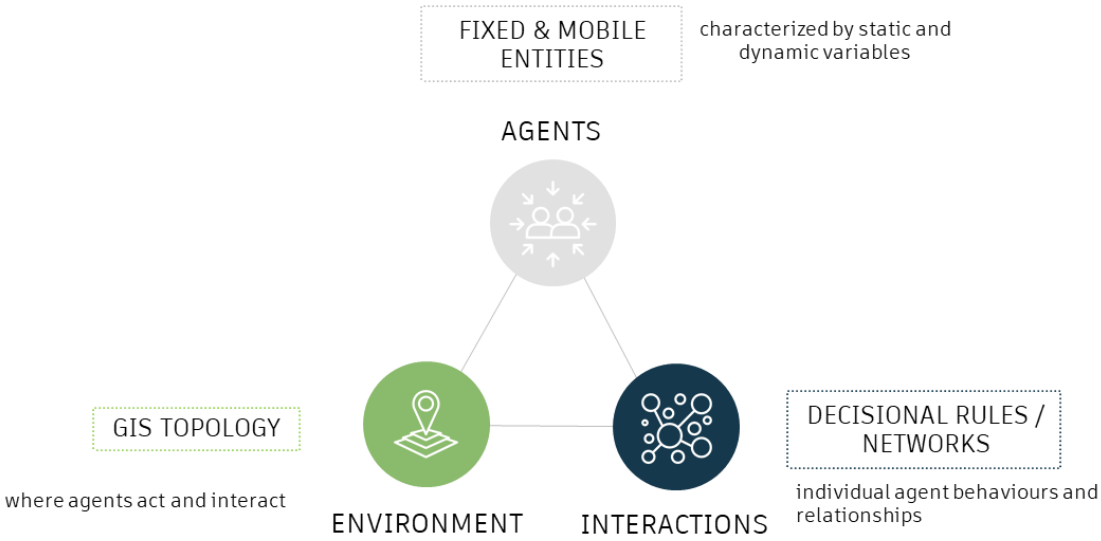


Figure 5.1. ABM/MAS main pillars as developed in this PhD research thesis

5.2 The ODD protocol and the ABM/MAS methodological steps

In order to define the stages for building the simulation models in the thesis applications, the analysis started with the research of a common structure to develop ABM/MAS. Generally, publications do not explicitly show the adoption of a consolidated and common methodological structure for developing ABM/MAS. This is probably due to the variety of disciplines using this kind of approach. More common, instead, is the use of the ODD protocol for communicating the structure of ABM/MAS. Developed by Grimm and Railsback in 2004, revised in 2010 and updated in 2020, this protocol consists of three blocks (Overview, Design concepts, and Details), which are subdivided into seven elements: Purpose, State variables and scales, Process overview and scheduling, Design concepts, Initialization, Input, and Submodels (see Table 5.1) (Grimm et al., 2006, 2010, 2020). However, its aim is mainly focused on the communication and description of the simulation model rather than its construction. It consists of a general structure for describing ABM/MAS, that makes the description of the model independent of its specific structure, purpose, and form of implementation (Grimm et al., 2006).

Table 5.1. The seven elements of the ODD protocol (Grimm et al., 2020)

	ODD elements	Questions to be answered
Overview	1. Purpose and patterns	What is the purpose of the model?
	2. Entities, state variables and scales	What kinds of entities are in the model? By what state variables, or attributes, are these entities characterised? What are the temporal and spatial resolutions and extents of the model?
	3. Process overview and scheduling	Which entities do what, in what order? When are state variables updated? How is time modelled — as discrete steps or as a continuum over which both continuous

		processes and discrete events can occur?
Design concept	4. Design concept: - Basic principle - Emergence - Adaptation - Objectives - Learning - Prediction - Sensing - Interaction - Stochasticity - Collectives - Observation	There are ten design concepts. How have these concepts been taken into account in the model's design?
Details	5. Initialization	What is the initial state of the model, i.e. at the time t = 0?
	6. Input data	What input does the model use from external sources, such as data files or other models to represent processes that change over time?
	7. Submodels	What, in detail, are the submodels that represent the processes listed in "Process overview and scheduling"? What are the model parameters, their dimensions, and reference values? How were submodels designed or chosen, tested, and parameterised?

When this protocol was performed, Grimm et al. (2006) also underlined the need for a specific structure in parallel to the ODD to clearly define how the model is implemented. For that reason, a general structure for developing ABM/MAS, the modelling cycle (Figure 5.2), was first proposed by the same authors, Grimm and Railsback, in their book entitled "Individual-based Modeling and Ecology" (2005). Then, they re-elaborated this model in the book "Agent-Based and Individual-Based Modeling – A practical Introduction" in (2011). The following part presents the main stages of the modelling cycle of Grimm and Railsback, with some insights on its operativity for developing the empirical models of this research.

The modelling cycle shows two fundamental characteristics of model construction: systematicity and interactivity. A model is systemic in the sense that the assumptions made, the tasks identified, and the variables selected produce certain consequences. At the same time, the model is interactive, since it can always be improved many times during the process: it could be too simple or too complex in the first approximation, so, some phases must be reformulated through smaller or bigger loops.

Taking these considerations into account, the following stages were considered in the modelling cycle: (1) Formulate the question; (2) Assemble hypotheses for key processes and structures; (3) Select scales, entities, state variables, processes, and parameters; (4) Implement the model; (5) Analyse, test, and revise the model (Grimm & Railsback, 2011).

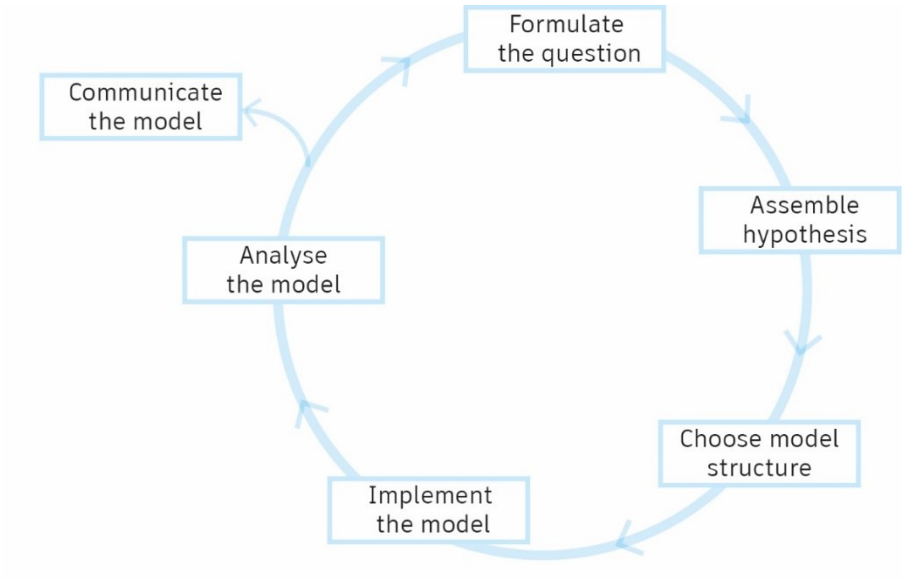


Figure 5.2. The modelling cycle (elaborated from Grimm and Railsback 2004)

1. Formulate the question

Formulating a clear research question represents the primary compass and filter for designing a model. Even if it seems like an easy task, in complex systems, it is particularly important to get focused on the important issues. In many cases, the question seems obvious, since it represents exactly the reason why the evaluation is carried out. However, making adequate decisions requires having very clear objectives. In some cases, when questions are experimental, they can be reformulated during the process, because they can be either not clear enough or too complex (as well as too simple). Examples of questions related to the case studies of this thesis could be: *what policies need to be undertaken to increase the adoption of sustainable technologies in urban contexts? What actions can generate social inequalities? What scenarios are most appropriate to achieve a sustainable transformation, considering the various stakeholder preferences?*

Starting from these questions, it is possible to structure the following stages.

2. Assemble hypotheses for essential processes and structures

In this phase, hypotheses and assumptions of the model are defined. However, many of them could be made about the processes and structures. In particular, in the context of urban transformation and planning aiming to a transition to sustainable development, it is fundamental to pass from the theory to the validation into real-world perspectives and actions. For that reason, the analysis needs to go through a multi-level perspective, from more general and theoretical considerations to more detailed and specific data and characteristics of the case study. In particular, the theory allows to define the background and the field of exploration of policies and practices. Then, this knowledge is useful to structure the model and experiment with the effects of these policies and practices in a real-world

simulation.

For example, existing knowledge coming from the literature and current legislation should be combined with understanding and reasoning in a "brainstorming" phase (Grimm & Railsback, 2011). From that, a wide number of variables and parameters will come, but it is necessary to simplify as much as we can, or even more. Understanding all components will be gradual and a step-by-step process. One of the purposes of the model can be also to teach us what is important and what is not.

3. Choose scales, entities, state variables, processes, and parameters

This stage represents the most intensive one, and it is essential for the entire modelling process. After the definition of simple assumptions and hypotheses to represent the system under analysis, it is necessary to think about the model in detail (Grimm & Railsback, 2011). This phase requires the clarification of various aspects of the model. For that reason, this stage should be divided into a set of steps[17]:

i. Identifying the agents (if one, e.g., the inhabitants, or multiple, e.g., inhabitants, municipality, providers, associations) and their characteristics (both static and dynamic, e.g., number of inhabitants, age, income level, family unit).
ii. Identifying the objects in the model (e.g., buildings, streets, services), their characteristics (e.g., year of construction, maintenance condition, surface), and defining the environment representation (e.g., a square grid, raster maps, or vector maps).
iii. Defining the decision-making rules of the agent (e.g., utility and optimization functions, statistical models, heuristic models, evolved models, or behavioural models). In this sub-phase, the analysis of previous ABM/MAS applications can be useful to identifying all the relevant variables.
iv. Defining the network structure of agents and the environment. This could be only related to the spatial distribution of the objects or a more complex and multi-level interaction among these components. For example, the network could be based on proximity among agents, similarity or diversity in characteristics and behaviour of the agents (e.g., social and cultural stratification of the population) or among agents and the objects inside the environment (e.g., services, buildings, cars). Network analysis is particularly important, because it not only determines the way in which agents interact, but also who interacts with whom. To limit the number of independent variables and make the model as realistic as possible, geospatial information system data on the location of buildings, households, and stakeholders can be used to set up the spatial structure.

[17] In order to better clarify the different steps, some examples are given, considering the case studies applied in the present research

v. Defining the time of observation (e.g., 1, 10, or 50 years) and the time step of the model (how often the agents take an action and, so, the context changes).

vi. Exploring new policy options deduced from literature and empirical findings. In this case, a reference scenario (P_0), i.e., the current policy/scenario situation, can be compared with other policy/scenario solutions (P_1, P_2, …).

Figure 5.3 shows, in an abstract way, the basic elements proposed as a common framework for the development of the models presented in this thesis.

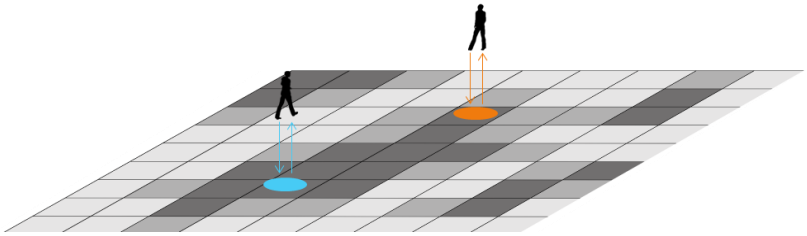


Figure 5.3.a. Cell-grid environment

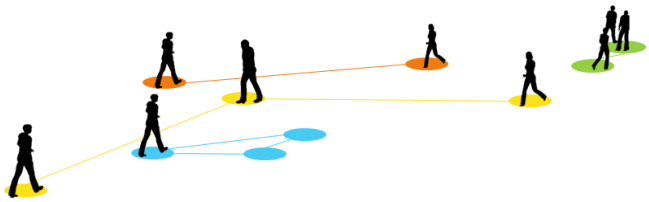


Figure 5.3.b. Interaction network of agents

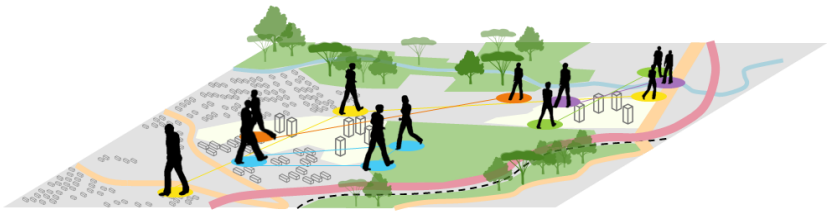


Figure 5.3.c. Interaction network among agents-agents and agents-objects

Figure 5.3. Complex multi-layer environment (elaborated from Hinker 2017)

Generally, agents act and interact in a grid-based environment (Figure 5.3.a) due to the strong correlation with cellular automata theory[18] from which ABM also derives. The interactions among agents can be related to their proximity (as it happens for green ones) or to their similarity (e.g., for yellow ones) (Figure 5.3.b), creating the network-based model. Agents can interact not only with other agents but also with the environment around them, and the objects contained in this environment. A complex multi-layer environment could be implemented in order

[18] A cellular automaton is a discrete model studied in automata theory and consists of a regular grid of cells with a finite number of states. For each cell, a set of cells called its *neighbourhood* is defined relative to the specified cell. The neighbourhood is where the modification of the initial step occurs. For more details, see Chapter 4, Section 4.3.

to connect the different interactions among objects-agents and agents-agents (Figure 5.3.c).

In this phase, it is clear how all the data should be collected to calibrate the simulation model in the next stage. When the model combines GIS data and maps (as is the case of the empirical simulations developed in this research), it is necessary to include different sources and layers to represent the spatial dimension and the objects relevant for the model (such as building conditions, service distribution, environmental conditions, and so on). Since the social component plays a key role in ABM/MAS, the socio-demographic, socio-economic, and psychological/behavioural characteristics of the population needed to be investigated and modelled in detail, as well as the past and present habits and attitudes, such as the route to work, renovation activities, innovation level, or environmental awareness. As it is easy to guess, a wide number of sources should be consulted in order to collect all the data mentioned before: institutional databases (e.g., ISTAT, Geoportale della città di Torino, and so on), but also open data platforms (e.g., openstreetmap). Moreover, specific surveys can be implemented to collect the more intangible variables, in particular those related to the social attitudes and preferences of the population. For this purpose, other methods can also be integrated into ABM/MAS+GIS approach, to investigate, more in detail, the agent preferences, the decision rules, and the level of importance of each relevant criterion. Examples of methods applied in this thesis are the Hedonic Price Model (HPM), Choice Experiment (CE), and Multicriteria Analysis (MCDA). For more details about these methods, see Chapter 3.

The result of the entire process and all the data collected is illustrated schematically in Figure 5.4. A combination of different layers (spatial data, suitability maps, human behaviours, and networks) produces a combined level, that represents the starting point for the simulation and for testing alternative policies and scenarios for achieving sustainable development in urban contexts.

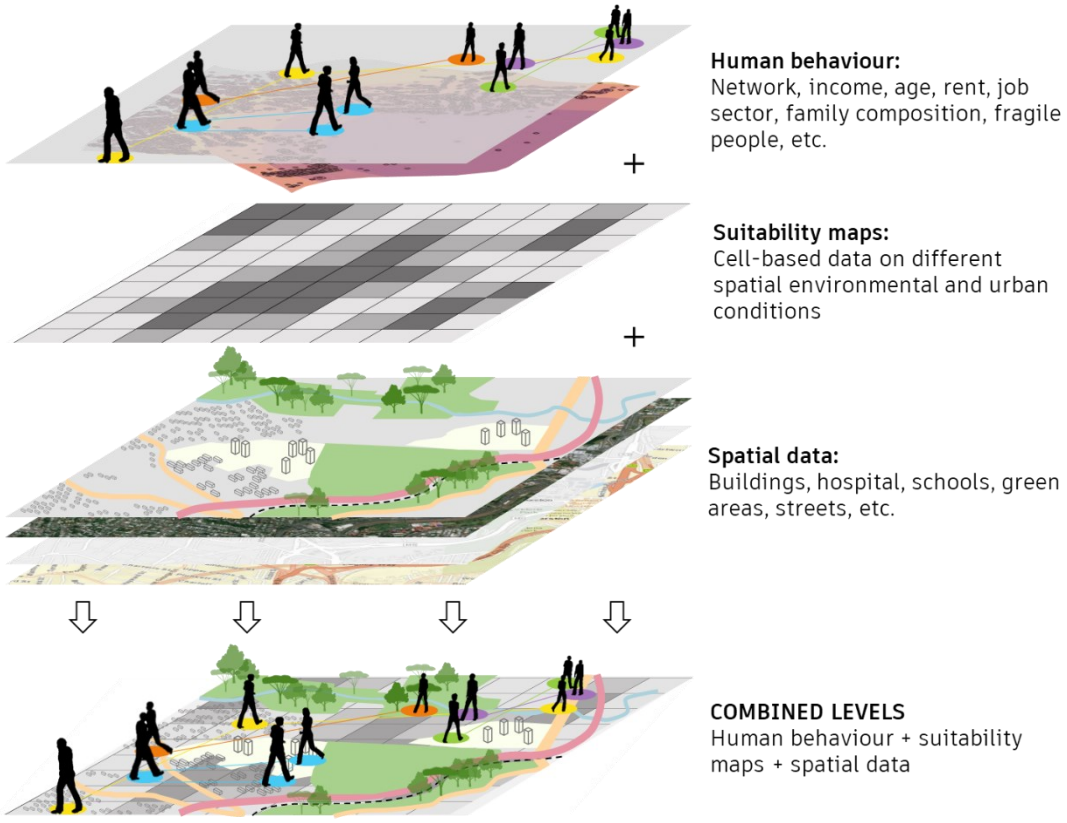


Figure 5.4. Multi-layers and multi-data scheme for the simulation model

4. Implement the model

When the model is completely defined (i.e., all the data is collected in a GIS environment, the decision rules and variables are defined, and the interaction network is fixed), it is possible to build the simulation model. This stage represents the hardest part in terms of execution. In fact, the verbal description previously defined must be converted, as Lotka (1926) said, into "animated" objects through mathematics and computer programs. The implemented model, through its internal dynamics and logic, allows the analyst to explore the consequences of the assumptions defined and see whether the initial model looks useful (Grimm & Railsback, 2011). A variety of software exists to support the implementation of the model (more details are given in Section 5.3).

5. Analyse, test, and revise the model

More than the other stages, the analysis of the results, their verification, and validation represent the most critical phase. The difficulty is not in terms of time-consuming or programming language, but it is related to learning (and learning in the right way) about the real world. This phase permits to understand what agent behaviours can explain the problem investigated and predict important characteristics of the real system being investigated. This stage highlights if the model requires changes in its execution or, on the contrary, if it fits well with the real-world condition, through, for example, the comparison with historical data.

Due to the approximations and assumptions defined along the process, it is strongly necessary to understand the validity of the model. In that context, it can be useful to develop Robustness Analysis for validating patterns, test the sensitivity of the results under changes in model parameters and structures through Sensitivity Analysis, and evaluate the reliability of the results through an Uncertainty Analysis are fundamental (Railsback & Grimm, 2011).

5.3 Software

A relevant consideration regards the choice of the software for developing ABM/MAS for the case study applications of this thesis. There are several tools available to develop ABM/MAS. In the papers of Gilbert and Terna (2006) and Macal and North (2010), a comprehensive review of ABM/MAS tools is given, such as Swarm[19], Repast[20], Mason[21], StarLogo[22] or Netlogo[23], to name a few of them. Of this set of software, probably the most well-known and diffused software for building ABM/MAS is Netlogo, a free software based on an evolution of the programming language Logo. It is a powerful data processing system with an intuitive interface, effective graphic support, and ease of use, also in code writing (Tisue & Wilensky, 2004). In addition, it is able to load vector GIS data (points, lines, and polygons) and raster GIS data (grids) into the model. The extension supports vector data in the form of ESRI shapefiles (.shp), i.e., the most common format for storing and exchanging vector GIS data, and raster data in the form of ESRI ASCII Grid files.

5.4 Behavioural models

In the context of ABM/MAS research, numerous and different behavioural models are used and adopted to simulate the actions and re-actions of agents in a given system. This great number of behavioural models can be explained by the different fields of application of ABM/MAS (e.g., from physics to social sciences) and the various types of agents to be modelled (e.g., humans, societies, animals, and territories). Moreover, in ABM/MAS, these behavioural models often include the procedures and rules governing the network, that agents use for creating their relationships among each other and with the surrounding environment[24]. All these

[19] https://www.santafe.edu/research/results/working-papers/the-swarm-simulation-system-a-toolkit-for-building

[20] http://repast.sourceforge.net

[21] https://cs.gmu.edu/~eclab/projects/mason/

[22] https://education.mit.edu/project/starlogo-tng/

[23] https://ccl.northwestern.edu/netlogo/

[24] In some books and manuscripts, networks are considered separate from behavioural models. However, they simply represent the connections and relationships between humans and objects, or objects among each other. Particularly in the social sciences, networks make it possible to explore

aspects explain why it does not exist in current literature, and probably, why it is not possible to have, an exhaustive classification of the whole spectrum of approaches to simulate the behaviours of humans and non-humans.

The present section tries to collect the most common behavioural models, integrating them with the previous work developed by An (2012) (based on a review of articles related to modelling human decisions in coupled human and natural systems), and an in-depth investigation of these models in the context of socio-technical systems in urban contexts. It is possible to classify nine types of decision models: (1) microeconomic models, (2) space theory-based models, (3) psychosocial and cognitive models, (4) institution-based models, (5) experience-based or preference-based decision models (rules of thumb), (6) participatory models, (7) empirical-or-heuristic rules, (8) evolutionary programming, and (9) assumption and/or calibration-based rules. In the following lines, each of the nine decision models to simulate real-world behaviours is presented and detailed.

1. Microeconomic models

These models are based on the concept of utility maximization by individuals, who make their decisions to maximize certain profit, revenue, or rate of profit associated with various options. This maximization can also be guided by other reasons than monetary ones, sometimes taking the additive or exponential form of a weighted linear combination of many criteria under consideration. Then, this maximization can be used to consider the probability of the agent making a choice based on McFadden's theorem.

A problem concerning the use of this model is that the agents are often assumed to make rational choices. This is rarely true in real-world contexts, where choices and decisions are usually affected by imperfect resources, such as knowledge and information, or limited ability to use them (An, 2012). In fact, people are more likely to make decisions based on satisfactory utility rather than optimal utility.

2. Space theory-based model

At the basis of a space theory-based model, there is a direct relationship between agents and space. In a space theory-based model, two different ways of treating distance are defined: the absolute and the relative space approach. In the first approach, the physical proximity to social features (e.g., public services, city centre, road network, train stations) determines the potential attractiveness of a site. On the contrary, in the relative space approach, not only the characteristics of a

similarities, social relations, interactions, and flows (Crooks et al., 2019). In the following parts of this section, you will see how these components are included in the behavioural models, yet. Nevertheless, it is possible to re-call three models widely used to represent stylised social network structures, which, in some way, are separated from behavioural models: the random network, the small-world network, and the scale-free network (Watts & Strogatz, 1998). They are described in-depth in the first application (Chapter 6), where these networks are used to generate relations among the households.

certain location in space affect its attractiveness, but also its relative location to other locations contributes to defining this attractiveness.

From the combination of the two approaches, individuals can assess the suitability of a given location for a certain purpose through a function of variables that represent both absolute and relative locations. Coherently, interaction among agents can affect final decisions.

This behavioural model is characterized by a certain degree of arbitrariness in the choice of the attractive spatial components and relations between agents' decisions and the chosen element. Consequently, more insights and justifications are necessary for the specification of the weights related to the different distances or variables.

3. Psychosocial and cognitive models

In psychosocial and cognitive models, agents act and take decisions based on different abilities (e.g., memory, learning, innovation) and cognitive characteristics, beliefs and intentions, aspirations, reputation, and social norms.

Within this context, different frameworks were developed in order to model agents and their social behaviours. An (2012) reports three families of these models, but, some additional models have to be reported and underlined as strongly connected with the purpose of this work and socio-technical systems. Generally, these models can be clustered into three different groups, as follows.

- In the first group, the Giddens (1984) actor-centred structuration theory (ST) and the theory of interpersonal behavior (TIB) proposed by Triandis (1980) are included. The first theory assumes that social systems and practices are at the inseparable intersection of structures and agents. Giddens proposes the so-called concept of duality of structure, according to which *"[...] the essential recursiveness of social life, as constituted in social practices: structure is both medium and outcome of reproduction of practices. Structure enters simultaneously into the constitution of the agent and social practices, and 'exists' in the generating moments of this constitution."* (Giddens, 1984). The second theory states that agent decisions are affected by a combination of intentions, habits, psychological arousal, and conceptual factors (Triandis, 1980). This theory is complementary to two other theories, highly used in ABM/MAS, the theory of reasoned action (TRA) (Fishbein & Ajzen, 1975) and the theory of planned behavior (TPB) (Ajzen, 1985). The Belief-Desire-Intention (BDI) could also be included in this group of models. This theory assumes that agents act based on a certain mental attitude consisting of a combination of beliefs, desires, and intentions (Parikh et al., 2017). Different architectures of BDI were implemented (Haddadi & Sundermeyer, 1996), such as IRMA (Bratman et al., 1988), PRS (Georgeff & Lansky, 1987), COSY (Burmeister & Sundermeyer, 1992) and GRATE

(Jennings, 1993).

- The second group of models is represented by Fuzzy Cognitive Maps (FCM). Although they are not extensively adopted in the simulation of human-environment and human-systems compared to biological or ecological studies, they make possible a representation of influences, through a set of directional edges that connect the nodes (i.e., the concepts).
- The third group is based on the idea that individual agents learn about their environment along with pre-conceived biases and influence other peer agents to adopt the same biases (An, 2012). At the basis of this view, there is the work of Weick (1979) and his Organizational Information Theory (OIT).

The great interest in these psychosocial and cognitive models underlines the necessity to investigate more social networks in affecting human decisions, in particular in the context of empirical models. The good representation of social networks, which have high influence, helps in determining how actions may arise from their interactions.

4. Institution-based models

Institution-based models can be considered, to a large extent, a specific type of cognitive models (described before), as institutions determine a special type of social norm. In fact, this theory is based on the assumption that agents in the same environment copy each other either because they are forced to or because they gain legitimacy from copying what other members in the same environment do (DiMaggio & Powell, 2000)

5. Experience-based or preference-based decision models (rules of thumb)

Experience-based or preference-based decision models use procedures or standards found in practical experience. These models are not intended to be strictly accurate or reliable in various situations, but they are often explanatory and effective in the description of real-world events through the use of (big) data (both quantitative and qualitative), direct observations, ethnographic histories, or stylized facts abstracted from real-world studies. These models are also known as "rules of thumb" since they often represent a common guideline or practice that is generally followed (sometimes without knowing why).

6. Participatory model

The participatory model is an extension of the experience-based or preference-based decision models explained before. They are characterized, as the name suggests, by the direct elicitation of desires and expectations of real people involved, for example, during focus groups or surveys.

7. Empirical or heuristic rules

As well as for experience-based or preference-based decision models, also in empirical or heuristic models, the rules derive from empirical data or observations, without a strong theoretical basis or other guidelines. In this case, however, models are based on rules obtained by relatively complex data compilation, computation, and/or statistical analysis, also in a stochastic manner. Other examples are those developed through neural networks or decision tree methods to derive and learn rules from empirical data (An, 2012).

Sometimes agents are grouped, forming clusters of agents characterized by a certain typology that determines how they make decisions or perform some behaviours. These groups are often derived from survey data.

8. Evolutionary programming

Evolutionary programming is a subclass of empirical or heuristic decision models in that a set of numbers, characters, or strategies characterize the agents and allow them to make different decisions and behave in a specific way. This model is separated from empirical or heuristic models because its computational processes are similar to those in natural selection theory. In fact, the most widely used models in evolutionary programming are genetic algorithms (Holland, 1975), which are widely used in ecological and biological studies, but also in the study of emerging social organizations.

9. Assumption-based and/or calibration-based rules

Assumption-based and calibration-based models are used when inadequate data or theories exist for explaining or studying a particular phenomenon. These models assume that an event or an action occurs with the same probability when certain conditions (activities, location, or time) are associated with agents.

In other cases, calibration-based rules are applied to verify the fitness of different decision models. By comparing the outcomes of the simulation model with observed data, it is possible to find which decision model is most likely to be used. As a sort of sensitivity analysis, the variation of values of a set of selected parameters helps in the identification of patterns most similar to the real-case study under analysis.

The ABM/MAS applications, presented in Chapters 6, 7 and 8 of this thesis, test and adopt some of these behavioural models. The first case study integrates a predefined network structure, i.e., the Small-World-Network with a space theory-based model (2), and a psychosocial model (3), i.e., TPB. The second case study adopts a simplified version of the microeconomic model (1), combined with a rule of thumb (3), the potential of a participatory model (6), and a space theory-based model (2). Then, the third case study again uses a simplified version of the

microeconomic model (1) combined with a participatory model (6), empirical rules (7), and a space theory-based model (2).

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CASE STUDIES

Chapter 6

I CASE STUDY – The San Salvario district, Turin (ITA)[25]

The first case study aims to investigate the individual choices of agents in the adoption of a sustainable energy product, i.e., the photovoltaic system (PV) at a district scale. The model will reflect on the rules and opinions of family households over time using a psychological model (i.e., the Theory of Planned Behavior by Ajzen (1991)), considering their individual characteristics and spatial location (based on statistical spatial data and a building-scale GIS environment). The model tries to observe the behaviours of the agents (the inhabitants of San Salvario) and the dynamic trends of PV adoption according to different policies. This is simulated in an environment in which choices and actions of the agents influence the decisions of others after communication and interaction among them. These interactions and exchange of information is based on existing network structure and a GIS space theory-based model, combining a Small-World-Network (Watts & Strogatz, 1998) and the Relative agreement algorithm (Deffuant et al. 2002). According to the general scheme contained in Chapter 5 (Figure 5.1) about the three main elements of ABM/MAS, Figure 6.1 details how these

[25] This chapter is mostly based on the contents contained in the following paper:

- Caprioli, C., Bottero, M., & De Angelis, E. (2020). Supporting Policy Design for the Diffusion of Cleaner Technologies: A Spatial Empirical Agent-Based Model. *ISPRS International Journal of Geo-Information*, *9*(10), 581. https://doi.org/10.3390/ijgi9100581

three elements are declined in this first case study.

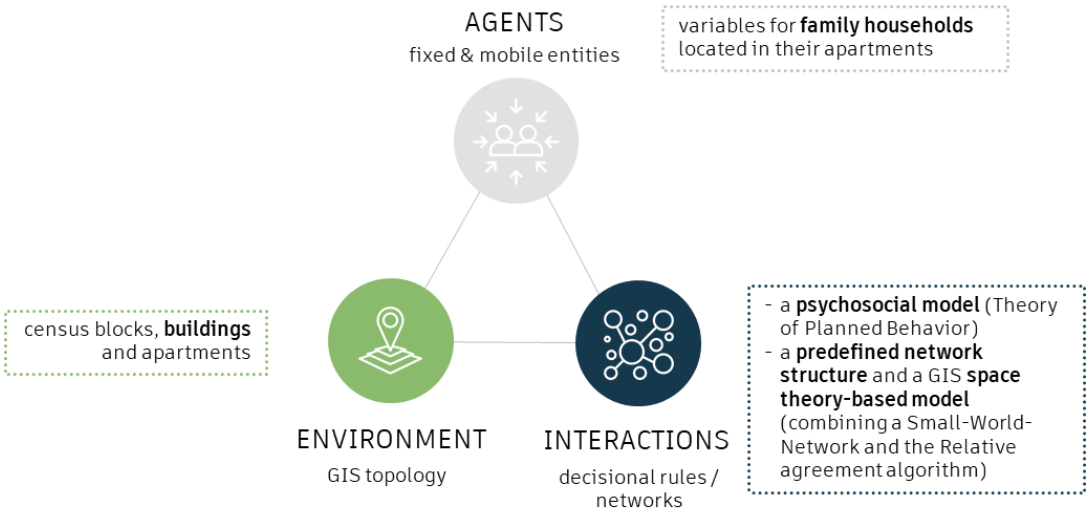


Figure 6.1. ABM/MAS main pillars as developed in this case study application

6.1 An integrated evaluation model for supporting SOCIO-ENERGETIC policies

Renewable energy resources and energy-efficient technologies, as well as building retrofitting, are only some of the possible strategies that can achieve more sustainable cities and reduce greenhouse gas emissions (Bottero et al. 2018). Subsidies and incentives are often provided by governments to increase the number of people adopting these sustainable energy efficiency actions (D'Alpaos & Bragolusi, 2018). Many market surveys have demonstrated a very positive attitude towards eco-innovations and sustainability, but despite this, sales of green products are currently not as high as would be desired (Byrka et al., 2016). Moreover, the increasing pressure of the state about the transition of our cities through the sustainable development model implies an urgent need to identify and evaluate the environmental, economic, and social impacts of alternative policies (Napoli, 2018; Napoli et al., 2020). Policy design can deal with sectoral policies, which are implemented across different territories, or, on the other hand, with area-based policies implemented at a more specific scale (such as the neighbourhood) (Navarro-Yáñez & Rodríguez-García, 2020). As underlined in Chapter 2 (Section 2.2), the scale and characteristics of neighbourhoods vary a lot around the world, and this has consequences for the area-based policies adopted. The internal dynamics within a given neighbourhood, combined with the multi-dimensionality of urban problems, require multiple policy strategies and the engagement of both public and private stakeholders (van Gent et al., 2009). However, as testified by many eco-districts and sustainable neighbourhoods that have been developed all over the world (Bottero et al., 2019), the neighbourhood scale represents a good compromise for testing efficient strategies and policies (Luederitz et al., 2013).

More than other scales, sustainable neighbourhood policies require a spatial approach, with an analysis of detailed information and finer data on buildings and inhabitants.

To do this, the present application investigates the potential of integrating ABM and GIS, in supporting the decision-making process and the definition of strategic policies. The integration of individual behaviour simulations through the adoption of ABM, and the real-world spatial distribution of data and people through GIS is particularly promising, although it is not well codified either in simulation analyses or policy design. In the context of PV adoption, the integration of ABM and GIS is useful for integrating real spatial data of a specific context related both to environmental characteristics (such as building properties, service localization, and pollution distribution) and data on individuals (such as income, attitude, needs, age). The consideration of people as single agents with their own decision rules and personal attributes located in a real-world space is particularly feasible in building policies, rather than looking at them in terms of statistics. Moreover, by taking time into consideration, it is possible to predict the impact of single or multiple features within a given timeframe. Over time, the model simulates consumer behaviour in the adoption of PV systems by integrating real geospatial data with social network theories, opinion dynamics formation, and individual preferences of homeowners. The "exploratory simulation" capability (Parker et al., 2003) of ABM makes them extremely useful in studying complex systems, becoming like a sort of virtual laboratory, where multiple simulation sessions occur, varying inputs and changing attributes (Railsback & Grimm, 2011).

The chapter is structured as follows: after this introduction on the role of the integrated evaluation model proposed for supporting the definition of urban policies, Section 2 describes the main behavioural theories applied in the model, as well as the main references used for defining the variables considered in the simulation. Then, the case study is presented in Section 3. Section 4 focuses on how the model was built, which variables were considered, and how the data was collected. The results section (5) illustrates the outcomes of the research and the role of the policy mix in achieving more successful policies. In particular, the results were validated with historical real-world data and sensitivity analysis/parameters sweeping across the variables selected. Finally, the last section (6) contains the concluding remarks of the analysis, the illustration of the pros and cons of the integrated model, and an in-depth description of the future perspectives of the research.

6.2 A multi-methodology perspective: ABM (adapted TPB + SWN + RA) + GIS

The present application proposes a mixed hybrid ABM, that combines the small

world network (SWN) theory (Watts & Strogatz, 1998) and the relative agreement (RA) opinion formation dynamics (Deffuant et al., 2000, 2002) into an adapted theory of planned behaviour (TPB) (Ajzen, 1991), using a rich set of real-world data and spatial representation through the integration of GIS maps. This multi-methodology perspective makes it possible to simulate the individual single-family household calculations for the adoption of the PV system in the San Salvario neighbourhood.

Section 6.2.1 contains a literature review on the main references used for the definition of the methodological framework of the present case study. Moreover, the other sections methodologically describe the main theories applied to building the individual decision-making process of adoption.

6.2.1 Literature Review

ABM has been extensively used to study the diffusion of innovation, also in the context of innovation technologies at the urban scale (see Chapter 4, Section 4.4.2 for more details). Existing literature reviews on the use of ABM for studying innovation diffusion are performed in the last ten years, such as the first by Kiesling et al. (2012), the one by Zhang and Vorobeychik (2017) and the most recent on energy-efficient technologies by Hesselink and Chappin (2019). About energy and environmental innovations, Zhang and Vorobeychik (2017) and Hesselink and Chappin (2019) collect respectively 17 and 21 contributions. This list makes clear the increasing and strong efforts and interest of research on the topic of innovation diffusion, in this context.

In the specific framework of this research, it is also possible to state that, precisely in the PV system diffusion and the definition of related policies, there is a very recent and increasing interest in ABM adoption. This is testified, for example, by the recent papers by Haelg et al. (2018), Lee and Hong (2019), Schiera et al. (2019), Nuñez-Jimenez et al. (2020). However, other previous examples also show the strong effort of the research in this context (such as Rai & Robinson, 2015; Rai & Sigrin, 2013; Robinson, Stringer, Rai, & Tondon, 2013; Zhao, Mazhari, Celik, & Son, 2011).

Table 6.1 reports the main documents in which ABM is applied for analysing the temporal diffusion of PV technologies. Table 6.1 is precisely focused on the main theoretical models used in those research studies, the time and scale of simulations—in particular, if GIS was applied and in which way—the identification of the analysed policies, as well as the variables considered and the level of detail of people's characteristics. In particular, this information is used for defining the methodological framework of this thesis application. In Table 6.1, the elements used in the thesis simulation model are highlighted in grey. Then, Table 6.2 reports the mixed ABM used in the present research, also showing the innovativeness of the analysis over the others.

Table 6.1. The main references on photovoltaic (PV) diffusion used for defining the methodological framework of the research

Authors	Behavior model [1]	Time [2]– Timeframe	Scale	Model purpose	Policy	Variables	GIS	Agent initialization	Data validation
Bottaccioli et al. (2019) (Schiera et al., 2019)	TPB + RA + SWN	Q – 20 years	District/ household	Policy design	(1to1) actual Italian regulatory framework vs. (1toM) joint self-consumption citizen (Clean Energy package)[26]	• Opinion uncertainty • Innovation • Income • Payback period • Electricity consumption, electricity rates, PV generation • Building type, total rooftop area, gross floor area, and year of approval • Density, average age, and officially assessed land price • Technical performances of the rooftop solar PV system • Economic performance of the rooftop PV • Payback period	Yes, block scale	Italian statistics characteristics	Sensitivity of the attributes
Lee and Hong 2019 (Lee & Hong, 2019)	LR/PL + peer effect	Y – 9 years	District/ household	Diffusion study	-		Yes, block scale	Census block data	Empirical data-driven behavioural rules of rooftop solar PV adoption
Nuñez-Jimenez et al. (2020) (Nuñez-Jimenez et al., 2020)	TF/UF + peer effects	Y – 6 years	State	Policy evaluation	Adjusting incentives: • Deployment (EUR/kWh per MWp) • Policy cost (EUR/kWh per EUR million) • Profitability (EUR/kWh)	• Available information about PV • Environmental awareness • Investing attractiveness	No	Electricity consumers in Germany	Calibration of the attributes (historical cumulative installations between 1992 and 2016)
Rai and Robinson 2015 (Rai & Robinson, 2015)	TPB (partial) + RA	Q – 6 years	State/ household	Policy design	• Rebate/price changes on the level of PV adoption • Low-income solar program	• Agents' attitudes (financial (Fi), environmental (Ei), and social (Si) belief indices) and uncertainty • Individual control beliefs (size of the house (s), tree cover (T), and irradiance received (I)) • Payback period	Yes, distribution with linear regression and results (city-level median)	• System details, location, installation date, etc. • Survey on installation decision • Home value, parcel size, land-use code, etc. • LIDAR images and National Elevation Dataset	Calibration of the attributes (empirical adoption levels between 2008 and 2013)

[26] European Commission. *Clean Energy for all Europeans| Energy Policy Framework*. [Online]. Available: https://ec.europa.eu/energy/en/topics/ energy-strategy-and-energy-union/clean-energy-all-europeans

Rai and Sigrin 2013 (Rai & Sigrin, 2013)	FE	Y – 25 years	State	Financial decision-process of consumers	-	• Income • Electricity consumption, electricity rates, PV generation	No	Homogeneous (income, age, degree)	5 Scenarios on electricity and PV system
Robinson et al. (2013) (Robinson et al., 2013)	TPB + RA + SWN	Q	District/ household	Diffusion study	-	• Opinion on PV • Environmental awareness • Income • Payback period	Yes, block scale	Social, economic, demographic and behavioural attributes of Austin (Texas) population (not more specified)	Calibration of the attributes based on historical data of adoption (2005–2008)
Zhao et al. 2011 (Zhao et al., 2011)	TF	M – 21 years	Region	Policy evaluation	Two incentives (Investment Credit Tax and Feed-in Tariff)	• Payback period • Electricity generation (PV) and consumptions, incentive levels, PV module price, and hourly electricity price (grid) • Income • Word-of-mouth effect • Advertisement effect	No	U.S. Census Bureau	Sensitivity on the attributes and real statistical data

[1] TPB = theory of planned behavior, RA = relative agreement, SWN = small-world network, LR = logistic regression, PL = adoption probability level; UF = utility function, TF = threshold function, FN = financial evaluation;

[2] Y = yearly, Q = quarterly, M = monthly, W = weekly.

Table 6.2. The framework of the model performed in the present research based on the literature review

Authors	Behavior model	Time–Timeframe	Scale	Model purpose	Policy	Variables	GIS	Agent initialization	Data validation
The proposed model	TPB + RA + SWN	Y – 30 years	District	Policy design	• Actual Italian regulatory framework • Vouchers from PV sellers to adopters for sharing with "friends" • Low-income incentives • Information diffusion (both environmental awareness and technology information)	• Opinion uncertainty • Environmental awareness • Information technology • Environmental awareness information • Innovation • Income • Return on investment • Electricity consumption, electricity rates, PV generation, PV rates • Payback period	Yes, block scale	• San Salvario spatialized people characteristics at block scale (degree, number of components, occupation, rent/owner, nationality) • Italian statistics characteristics	Calibration of the attributes based on historical data of adoption (2011–2019) and sensitivity of the attributes

6.2.2 Theory of Planned Behavior

The theory of planned behavior (TPB) was developed by Ajzen in the 1970s and definitively tested in 1991 (Ajzen, 1991). This theory still represents one of the most used approaches in the social sciences to predict people's intentions to perform a behaviour. It is, thus, particularly useful for studying the diffusion of innovations, as testified by several very recent applications, such as (Abreu et al., 2019; Perri et al., 2020; Schiera et al., 2019). According to Ajzen, the *intention* "can be predicted with high accuracy from *attitudes toward the behavior*, *subjective norms*, and *perceived behavioral control*" (Ajzen, 1991), as shown in Figure 6.2.

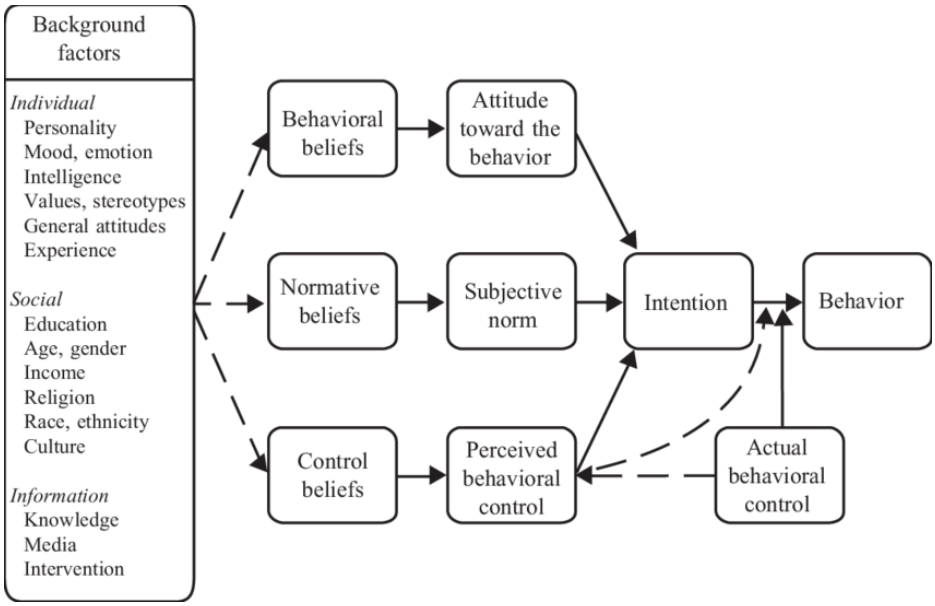


Figure 6.2. The theory of planned behavior framework (Fishbein and Ajzen, 1975)

Individual factors (such as personality, emotions, values, experience, intelligence), social aspects (such as education, age, gender, income, religion, race, ethnicity, and culture), and information (such as knowledge or media) contribute together to the formation of *beliefs*, which are the basis of the *attitude toward behavior, subjective norm,* and *perceived behavioral control* formation.

A favourable or unfavourable *attitude toward the behavior* (*att*) is represented by the *behavioral beliefs*, i.e., *"the likely outcomes of the behavior and the evaluation of these outcomes"* (Ajzen, 2006). Personality, emotion, values, experience, intelligence are some of the factors that influence the formation of the *attitude toward the behavior*.

Subjective norm (also called *perceived social pressure*) (*sn*) is the result of *normative beliefs* which are connected to the *"normative expectations of others and motivation to comply with these expectations"* (Ajzen, 2006). This means that individuals are influenced in different ways by those people who are important to them, such as family and friends, or the community of people around them, as well as by the government and the common sense and feel of their community. The

social and job positions of individuals can also influence their choices: the motivation to comply can be stressed by what people do for the position they have.

Perceived behavioral control (*pbc*) derives from *control beliefs*, i.e., *"factors that may facilitate or impede the performance of the behavior and the perceived power of these factors"* (Ajzen, 2006).

These three components contribute to the formation of the *intention* to the behaviour, as reported in the Equation 6.1:

$$bi = att * W_{att} + sn * W_{sn} + pbc * W_{pbc} \quad (6.1)$$

Where *att*, *sn* and *pbc* are the three components explained before, W_{att}, W_{sn} and W_{pbc} are, respectively, the weights for distinguishing between the level of importance given to *att*, *sn* and *pbc* by each individual.

Finally, the final behavior (*B*) is given by "a sufficient degree of *actual control* (*act*) over the behavior" that people have "to carry out their intentions when the opportunity arises" (Ajzen, 2006) and formulated as follows (eq. 6.2):

$$b = bi * Wbi + act * Wact \quad (6.2)$$

Where *bi* is the intention of the behavior explained in Equation 6.1, *act* is the actual control, whereas *Wbi* and *Wact* are, respectively, the weights assigned by the individual for these two components.

6.2.3 Relative agreement algorithm

As underlined by Deffuant et al. (2000), the opinion dynamics model is mostly based on binary opinions (such as Deffuant et al., 2000; Dittmer, 2001; Galam & Wonczak, 2000; Hegselmann & Krause, 2002; Krause, 2000), which social actors modify according to social influence or their own experience. It is possible to consider opinion as a continuous variable in time, which can also influence the final behaviour of individuals. In the present model, opinion formation dynamics were used to perform the evolution mechanism of the word of mouth, which directly influences the definition of the *attitude toward the behavior* and the *social norm* of TPB. In the present model, opinion formation dynamics follow the relative agreement (RA) algorithm, proposed by Deffuant et al. (2002), which incorporates a degree of uncertainty into the opinion of individuals.

According to this model, each individual (agent *i*) is characterized by two variables: an opinion x_i and an uncertainty u_i. Both opinion and uncertainty are real numbers, but the opinion varies between -1 and 1, and the uncertainty between 0 and 2. Graphically, they are represented by a point on an axis and a segment, respectively, as is possible to see in Figure 6.3. The theory implies that random pair interactions among the agents can influence (and can update) each other's

opinions (and uncertainties). In particular, as can be seen in Figure 6.3, the change in the opinion x_j of agent j is due to the influence of agent i and it is proportional to the overlap (h_{ij}) between both segments (the agreement a_{ij}) divided by the uncertainty of the influencing segment (for that reason, the method is called "relative" agreement ra_{ij}) (Deffuant et al., 2002).

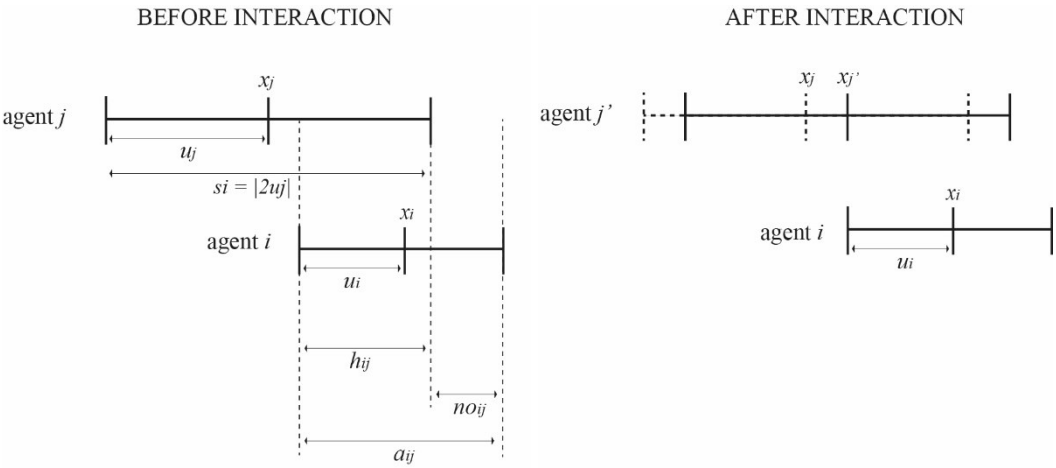


Figure 6.3. The influence of individual *i* on individual *j* based on the "relative agreement rules" (adapted from Deffuant et al., 2002)

The calculation to obtain the updated opinion and uncertainty is reported below.

The overlap h_{ij} is given by Equation 6.3:

$$h_{ij} = \min\,(x_i + u_i, x_j + u_j) - \max\,(x_i - u_i, x_j - u_j) \quad (6.3)$$

The non-overlapping (no_{ij}) (eq. 6.4):

$$no_{ij} = 2u_i - h_{ij} \quad (6.4)$$

The agreement (a_{ij}) is the overlap minus the non-overlap (eq. 6.5):

$$a_{ij} = 2 * (h_{ij} - u_i) \quad (6.5)$$

The relative agreement is the agreement divided by the length of segment *si*, which corresponds to the double of the abs value of the uncertainty of agent *i* (eq. 6.6):

$$ra_{ij} = \frac{2*(h_{ij} - u_i)}{2*u_i} = \frac{h_{ij}}{u_i} - 1 \quad (6.6)$$

If $h_{ij} > u_i$, the variation of agent j's opinion (x'_j) and uncertainty (u'_j) due to the interactions is significant and it is updated as follows (eq. 6.7 and eq. 6.8):

$$x'_j = x_j + \mu * \left(\frac{h_{ij}}{u_i} - 1\right) * (x_i - x_j) \quad (6.7)$$

$$u'_j = u_j + \mu * \left(\frac{h_{ij}}{u_i} - 1\right) * (u_i - u_j) \quad (6.8)$$

The same process and updating occurs per each pair of interactions among agents.

6.2.4 Social Network Theories

The process of pair interactions at the basis of the RA algorithm needs to be more formalized in the context of real-world case studies like as the one in the present research. The way two random agents begin to interact is usually due to similarities in their characteristics and/or their proximity. Many theories on the formation of social networks, also related to ABM development, have been developed over time, ranging from neighbourhood models (von Neumann "5-neighbour" or Moore "9-neighbour" (Goles & Martínez, 1990) to the 2D or 3D Euclidean Space (Macal & North, 2010), Network structure (such as Scale-Free Network and the most recent Preferential Attachment (Barabási & Albert, 1999), or the Small-World (Watts & Strogatz, 1998)) to GIS topology. An in-depth analysis of the model of interaction is, therefore, strongly necessary since interaction represents one of three key elements of ABM (together with the agents themselves and the environment).

The present paper adopted the small-world network (SWN) developed by Watts and Strogatz in 1998 (Figure 6.4) adapted to the real-world environment of agents whose distance is determined by information contained in GIS maps. The name "small-world" is properly an analogy to the small-world phenomenon (Kochen, 1989; Milgram, 1967) known as six degrees of separation (Guare, 1990). SWN represents an intermediate network between a regular network and a completely disordered network, where p is the probability of random interactions among agents. For $p = 0$, each node is connected with other local edges; if p increases, the connections become increasingly disordered; for $p = 1$, we have the maximum randomness and all edges are rewired (Stokstad, 2015). For intermediate values of p, the network generated is properly the SWN, which is generally characterized by local interactions like the regular network, but with some path length, like a random graph (Stokstad, 2015).

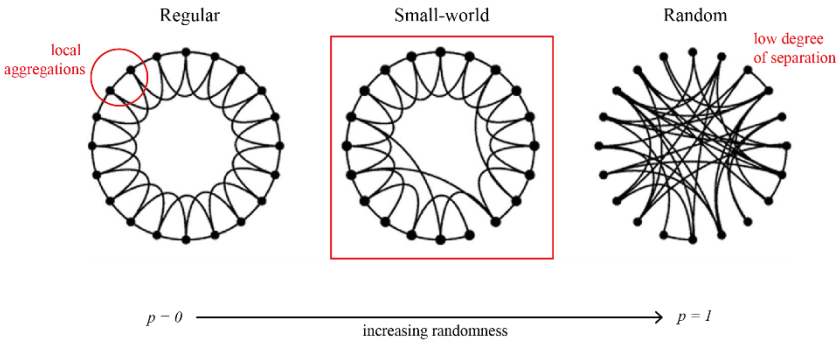


Figure 6.4. Small-world network (SWN)

6.3 Case study description

San Salvario is a neighbourhood of the city of Turin (Italy), officially recognized by the municipality for administrative purposes. Its boundaries clearly separate the district from the other parts of the city: to the west, the Porta Nuova station; to the south, the main hospital of the city; to the east, the Po river; and to the north, the city centre (Figure 6.5) (Caprioli et al., 2020).

San Salvario represents an interesting place for testing ABM for essentially two main reasons: firstly, for its intrinsic characteristics (detailed below) and, secondly, for the interest of the Energy Center Lab (a specific office in charge of the energy policies for the city of Turin)[27]. This office has the aim to transform the San Salvario neighbourhood into an exemplary eco-district for the city of Turin, where to experiment with different policies and actions, that could be spread to the overall city. This interest is set out in the policy orientation for Turin, expressed by the International Energy Agency (IEA) which encourages implementation of building renovation measures and district heat networks to achieve the energy and emission reduction targets (IEA, 2016). Moreover, on a wider scale, the Piedmont Region has taken part in the European Project called Together 2020 with the aim of implementing territorial strategies and plans to support the energy efficiency of public buildings and lighting lines and the production of energy from renewable sources, through alternative financial support strategies based on public-private partnership (3P) for the realization of investments[28].

Not far from the city centre and the Porta Nuova railway station, this neighbourhood (Figure 6.5) is characterized by a multi-ethnic population, many leisure places and some relevant historical buildings, such as the Castello del Valentino. With a surface of about 2.2 km^2, it is characterized by a diverse population of about 35.400 inhabitants (4% of the total population of the city), and a heterogeneous building stock.

[27] http://www.energycenter.polito.it/energy_center_lab [access: 21/09/2019]
[28] http://www.cittametropolitana.torino.it/cms/ambiente/risorse-energetiche/progetti-energia-sostenibile/2020together/



Figure 6.5. San Salvario neighbourdhood (Turin) localization

Since 1995, the local population started to decline, but the number of residents in the neighbourhood remains quite stable, thanks to the increasing number of young people, mainly students, and foreigners. However, as in many parts of the city, the population is mainly old (Figure 6.6) (Caprioli & Bottero, 2018).

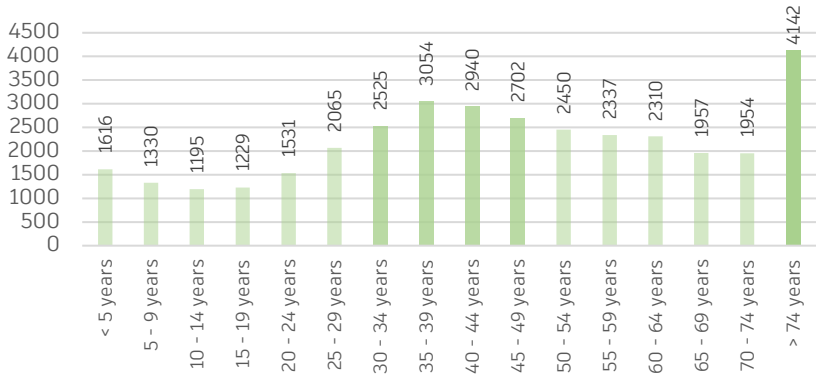


Figure 6.6. Population ages in San Salvario (ISTAT 2011)

Concerning the building stock, the nineteenth-century buildings have a considerable architectural value, but the lack of ordinary maintenance has caused their degradation over the years. In Corso Vittorio Emanuele, many buildings have a consistent architectural value. Public housing, craft activities, shops, and clubs are mainly located in Via Madama Cristina and Via Nizza. Via Nizza is also characterized by buildings with the typical nineteenth century shape, called the C-shape, while Corso Marconi by the architectural typology known as "umbertina", dating back to the eighties of the nineteenth century. The most recent developments are along Valentino Park (Caprioli & Bottero, 2018).

6.4 Application of the multi-methodology approach

6.4.1 Model Implementation and Variables Setting

The model was implemented in Netlogo 6.1.1 (see Appendix A.1).

For the initialization, calibration, and validation of the model developed, empirical data were considered. Table 6.3 shows all entities considered in the model, the static and dynamic variables connected to each entity, and how these variables were set, as well as the references used for identifying and setting those variables. Four types of entities were used in this model:

The **global type** refers to all entities responsible for the system-level implementation, such as electricity and policies. The current Italian regulatory framework was integrated with alternative policies to analyse the effective increase in PV adoptions.

The **technological type** is a type of global entity, specifically related to the characteristics of the technology analysed in the model, i.e., the PV system.

The **environmental type** collects those entities that refer to the spatial characterization of the district. In the present research, it was considered only information about the location of buildings and the census block division, since more details are not necessary for this simulation model (such as building age, rooftop surface), even if available from municipal databases. However, these entities contain real-spatial data related to family characteristics and composition. In Netlogo, the building/census block representation was performed thanks to the GIS extension based on raster data performed in QGIS 3.4.14. Each raster has specific information on the **family composition, level of instruction, job employment, nationality,** and **property status** (owners or tenants). In this way, in Netlogo, the agents with their specific characteristics contained in the raster were "sprouted"[29] from their census blocks.

The **agent type** considers the single-family residential households distributed in the district. As described before, some characteristics of each family arise from the raster and represent the real-spatial distribution of specific families in the different census blocks. In this way, potential adopters are individual, heterogeneous agents representing the population of electricity consumers in the district.

For each agent, a set of variables was identified. The static variables are the fixed once in the entire timeframe of the simulation; the dynamic variables change every time step. For simplicity, the families created at the time 2011 do not change for the entire simulation (2011–2040) and are based on the data from the census block provided by ISTAT for the year 2011. This choice also helps us to understand the real contribution of the policies implemented without

[29] Sprout is a specific command in Netlogo, that mainly refers to the agents sprouting from the related environment (patches).

compromising the results due to the variation of people characteristics.

At the time 0 (the year 2011 in the proposed model), other features were provided to each family:

Energy expenditure and **energy needs** were defined based on the family composition. Data on the average energy expenditure for family composition at a national level was provided by ISTAT (ISTAT, 2019) and these values were simply converted into the energy need of each family as follows: energy need = energy expenditure * 12 months / electricity cost;

Status, innovation level, and **income** are all static variables that are dependent on different combined features, such as education level, job occupation, number of components, and nationality. The **status** classification was based on the social groups provided by ISTAT in its 2017 Annual Report (ISTAT, 2017). The **innovation level** was assigned to the family based on its status class, which was, in turn, related to the diffusion of innovations classification provided by Rogers' adopters categories (Rogers, 2003). Finally, the **income** was assigned as a normal distribution value for each status class. In particular, the ISTAT analysis (ISTAT, 2017) gives information on the equivalent income and the GINI coefficient of each class. The income was, then, obtained by multiplying the latter value by the mean national income (equal to EUR 29,998 in Italy in 2017) and considering, as a standard deviation, the GINI coefficient for the income of the class. The same assumptions for the definition of status, innovation level, and income have been made by Schiera et al. (2019) and are synthetized in Table 6.4;

Environmental awareness is a static variable of the family which refers to the awareness of environmental problems. This variable represents how much a family is conscious and pro-active in adopting sustainable actions for the environment. This variable adds to the innovation and income level an alternative catalyst in the diffusion of eco-products and sustainable energy technologies (studies on this topic are, for example, Mokha, 2018; Paul et al., 2016);

Opinion and **uncertainty** are two static variables defined at time 0 of the model, which represent the individual family household's consideration of the PV technology. These variables, however, can change after interactive communication among the agents during the time flow. Based on the theoretical model of opinion formation and dynamics by Deffuant et al. (2002) and Meadows and Cliff (2012), explained in the Method section, the distribution of opinions and uncertainties follows a random-flow distribution, between -1 and 1 for the opinion and between 0 and 2 for the uncertainty, respectively. In the assignment of uncertainties, the minimum value was set at 0.1, in order to avoid problems with values equal to 0.

In the initialization phase, it was defined as a fixed number of **initial adopters** and **ecologists**. Here, 1.2% of families with a status level equal to 5 in the model—the innovators—were randomly chosen as initial adopters. Once the PV adoption occurred, the family in question changed its opinion and uncertainty (equal to 0.8 for opinion and equal to 0.1 for uncertainty). The initial percentage of adopters was proportionate to the population density of the district under analysis using the

data provided by GSE (Gestore Servizi Energetici, 2018) on the number of residential PV adoptions in the metropolitan city of Turin. The adoption trend provided by GSE (Gestore Servizi Energetici, 2018) for the years between 2011 and 2019 was also used for the calibration and validation of the model (see Section 6.4, Results). At time 0, about 2% of households were set as **ecologists**, i.e., those who have already adopted sustainable actions (such as building retrofitting, replacement windows). For those, the environmental awareness characteristic was set equal to 1. In the same way, for each following step of the simulation, the same percentage of new ecologists was added to the model. The number of ecologists per year was based on the data provided by ISTAT (ISTAT, 2015) on the families who invested in reducing energy consumption expenditure in Piedmont (the region of Turin) between 2009 and 2014.

Table 6.3. Entities, static and dynamic variables in the model

G/E/A/T[1]	Entities	Static variables	Dynamic variables	Setting	Source
G	electricity	electricity cost		median electricity cost in Italy	Eurostat database [83]
G	electricity		electricity increment cost rate	-8% per year	GSE (Gestore Servizi Energetici, 2018)
G	policy	subsidies per kW		0.5% of investment cost per 10 years	2020 Italian Budget Law[30]
E	census block	family distribution		number of families and their characteristics (family composition, level of instruction, job employment, nationality, and owners or tenants)	census block – municipality of Turin database 1:1000 (shp) + ISTAT census variables at census block (ISTAT, 2011)
E	buildings	family distribution		number of families	building – municipality of Turin database 1:1000 (shp)
A	family	number of components		1–6 components	ISTAT census variables at the census block
A	family	energy expenditure		median energy expenditure for n of components	ISTAT energy expenditure based on the number of family components (ISTAT, 2019)
A	family	energy need		energy expenditure * 12 months / electricity cost	
A	family	property status		n of property and rent families	ISTAT census variables at the census block
A	family	employment/ unemployment		n of households employed and unemployed	ISTAT census variables at the census block
A	family	nationality		n of foreign citizens	ISTAT census variables at the census block

[30] lettera h, articolo 16-bis del TUIR http://documenti.camera.it/leg18/dossier/pdf/AP0128.pdf

A	family	education level		illiterate, literate, primary school, secondary school, graduation	ISTAT census variables at the census block
A	family	status		from 1 to 9	(ISTAT, 2017; Schiera et al., 2019)—Family classification for social group
A	family	income		normal distribution based on equivalent income per each class * mean income of household (standard deviation based on the class GINI coefficient)	(ISTAT, 2017; Schiera et al., 2019)—Family classification for social group
A	family		PV adoption	true or false	
A	family	opinion	opinion after interaction	random between -1 and 1	(Deffuant et al., 2002; Meadows & Cliff, 2012)
A	family	uncertainty	uncertainty after interaction	random between 0.1 and 2	(Deffuant et al., 2002; Meadows & Cliff, 2012)
A	family	environmental awareness		random between 0 and 1	
A	family	innovation level		1–5 (based on the status)	(Rogers, 2003; Schiera et al., 2019)
T	PV system	PV power		3 kW	
T		PV cost		EUR 2000 per kW	
T			PV decreased rate cost	-0.08 per year	Italian trend[31]
T			reduction efficiency	0.6 per year	De Paoli et al. (De Paoli & Ricupero, 2006)
T		maintenance and operational cost (O&M cost)		EUR 35 * kWh per year	Italian trend[32]
T			O&M increment cost rate	0.02	Italian trend[6]

[1] G = global entities; E = environmental entities; A = agents; T = technological characteristics (PV)

[31] Data provided by the practical use and tests on materials, for example: https://www.fotovoltaiconorditalia.it/idee/quanto-cala-il-rendimento-di-un-impianto-fotovoltaico-nel-tempo-e-nello-spazio

[32] Data provided by the practical use and tests on materials, for example: http://www.consulente-energia.com/ao-quanto-costa-la-manutenzione-dei-pannelli-fotovoltaici-costo-annuo-manutenzione-ordinaria-di-un-impianto-fotovoltaico-costi-interventi-manutenzione-periodica-fv.html

Table 6.4. Status, level of innovation, and income with related references (adapted from Schiera et al. (2019))

ISTAT social group	Status	Roger's adopters' categories	Innovation level	ISTAT Equivalent income	ISTAT GINI coefficient	Income
Ruling class (RC)	9	Innovators, Early adopters	5	1.694	0.283	Normal distribution: Equivalent income * National median income Standard deviation: GINI coefficient * National median income]
Clerk household (CH)	8	Early adopters	4	1.323	0.257	
Young blue collars (YB)	7	Early adopters, Early majority	4	1.135	0.232	
Silver pensioners (SP)	6	Early majority	3	0.965	0.246	
Low-income Italian households (LI)	5	Early majority, Late majority	3	0.934	0.226	
Lonely old ladies and young unemployed (LY)	4	Late majority	3	0.804	0.324	
Traditional provincial households (TP)	3	Late majority, Laggards	2	0.758	0.282	
Retired blue collars (RB)	2	Laggards	2	0.707	0.290	
Low income with foreigners (LF)	1	Laggards	1	0.606	0.283	

6.4.2 Individual Family Adoption Calculation

As described in Section 6.2, the mixed hybrid agent-based model presented here performs an adapted TPB for developing the individual single-family household calculation for the adoption of PV systems. In particular, TPB combines SWN and RA into a real-world environment where agents are spatialized at a census block scale thanks to the integration into the Netlogo software of some GIS maps, which contain a set of information about families' characteristics.

In this section, a detailed explanation of the different components (*att, sn, pbc*) of TPB is given. Figure 6.7 shows, for illustrative purposes, exemplary questions and reasonings of individuals in the formation of the intention and actual control in the present analysis and according to TPB. Equal weights were assigned to the different TPB components. This choice was made due to the lack of information caused by the inability to conduct a specific questionnaire in the neighbourhood due to the COVID-19 spread in the city of Turin.

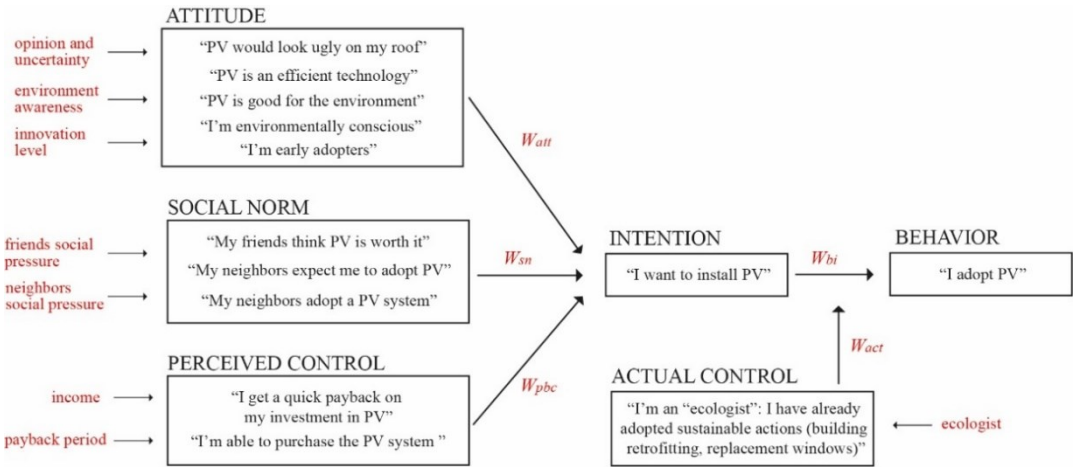


Figure 6.7. Components of the behaviour for PV adoption (adapted from Ajzen (2002) and Robinson et al. (2013))

Concerning the **Attitude Toward the Behavior (*att*)**, three different beliefs were considered, i.e., opinion, environmental awareness, and innovation level. These beliefs are also defined based on the literature review of ABM applications for the adoption of PV (as reported in Figure 6.8).

Opinion (*opi*) is strictly related to the PV technology and, more specifically, to the consideration that each agent has on the technology itself (for example, "Would PV look ugly on my roof?" or "Is PV an efficient technology?") (see for example Robinson et al., 2013; Schiera et al., 2019). The definition of agent opinion, as mentioned in the Methodology (Section 6.2.3), follows the RA theory. Every year, agents create their own networks, following the SWN theory (see Section 6.2.4), as shown in Figure 6.8. These networks, then, change every 5 years, simulating the variation of relations among people during the years. The assignment of the opinion (as for the uncertainty) does not depend on one or more background factors of the agents, but simply is assigned to each agent as a random opinion between -1 and 1 (as for uncertainty between 0.1 and 2, where the minimum uncertainty 0 was excluded to avoid problems in the calculation). As mentioned in the previous section, 1.2% of families at time 0 had already adopted the PV. They represented the innovators (or extremists in the model) and their opinions and uncertainties were set as follows: x >= 0.8 and u = 0.1. The opinion should be standardized for the final formulation of the agent's attitude. In the present analysis, interval standardization was performed: $(x - x_{min})/(x_{max} - x_{min})$.

Environmental awareness (aw_{env}) is a constant awareness between 0 and 1 (see, for example, Nuñez-Jimenez et al., 2020), where 0 represents low awareness of environmental problems, whereas 1 indicates high interest in the environmental issue. Environmental awareness, like opinion and uncertainty, is defined by a random distribution with no dependence on other characteristics of the agent. This variable can change only when an agent is selected as a new ecologist over the lifespan.

Innovation level (*inn*) is the last component of the individual attitude of an agent and represents the propensity toward innovation. This static variable depends on many characteristics, such as lifestyle, habits, and personality, and for that reason, in this model, it was assigned to an agent based on their social role (Schiera et al., 2019), as shown in Table 6.4. The innovation values vary from 1 to 5, where 1 means a low level of innovation, whereas 5 represents the high innovativeness of the agent. An interval standardization of the innovation level is then performed, for the aggregation of all components in the final calculation of the attitude.

Opinion (*opi*) and *environmental awareness* (aw_{env}) are very complex beliefs that are commonly based on a variety of agents' background factors and their interrelations, such as personality, experience, education, knowledge, and/or feelings. The approach adopted in the present research is, thus, certainly simplified. In fact, *opinion* (*opi*) and *environmental awareness* (aw_{env}) are only assigned through a random distribution, and these beliefs can be changed due to interactions with other agents. However, because of the complexity in modelling those beliefs, a simplification of reality is needed, in particular when no data or empirical analyses show how to detail them. For the *innovation level* (*inn*), which is more consolidated in literature, the present research tried to combine the different background factors that influence the formation of the innovation level, such as lifestyle, habits, and personality, following Roger's adopter categories (Rogers, 2003) (see Table 6.4).

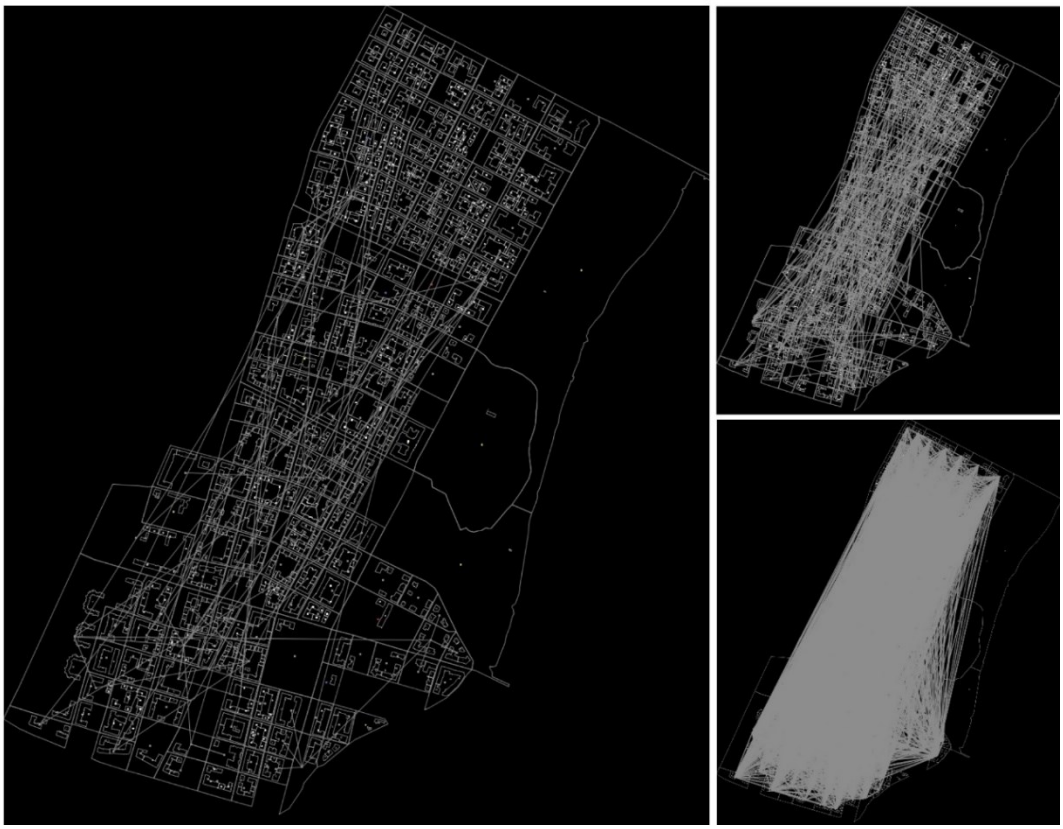


Figure 6.8. Dynamic network formation of the agents in the neighbourhood following SWN

The agent's attitude toward the behavior was performed as follows (eq. 6.9):

$$att = opi_{std} * W_{stz} + aw_{env} * W_{env} + inn_{std} * W_{inn} \quad (6.9)$$

Where W_{stz}, W_{env} and W_{inn} represent the different weights assigned by individuals to each component in the construction of their personal *att*. For lack of specific data and surveys on that topic, the three components all have the same weight, equal to 0.33.

For the calculation of **Subjective Norm (*sn)*** (second element of the TPB theory), two types of pressures on behaviour are considered: the social pressures of those in the same network (considered as «friends») and the pressures generated by common feelings in the entire neighbourhood. The result is a weighted sum of these two pressures as below (eq. 6.10):

$$sn_i = sp_{link} * W_{splink} + sp_{district} * W_{spdistrict} \quad (6.10)$$

Where the weigh W_{splink} is defined in the simulation as stronger than $W_{spdistrict}$, assuming that friends have a predominant role in influencing behaviour (respectively, 0.7 and 0.3) and sp_{link} and $sp_{district}$ are both calculated based on the mean values of attitude in the network and in the neighbourhood, as represented in equation 6.11:

$$sp_{ij} = att_i * \left(1 - w_{ij^*} * \left(att_i - att_{j^*}\right)\right) \quad (6.11)$$

Where sp_{ij} is the social pressure exerted on agent *i* by agent j^*, which is a fictitious agent described by the mean of the attitudes of the agents in the network (for sp_{link}) or in the neighborhood (for $sp_{district}$), and w_{ij^*} is the strength of the influence exerted by agent j^* over agent *i* (eq. 6.12):

$$w_{ij^*} = \frac{\frac{unc_i}{unc_{j^*}} - 0.05}{20 - 0.05} \quad (6.12)$$

Where 20 and 0.05 are, respectively, the maximum and minimum values for establishing the influence rate between 0 and 1.

Perceived behavior control (*pbc*) (the third component of the TPB) was calculated in the present research by combining a rapid payback period quantification and a comparison of the income of the agent with the minimum and maximum income in the neighbourhood, as follows (eq. 6.13):

$$pbc_i = pf_i * W_{pf,\ k^i} + if_i * W_{if,\ k^i} \quad (6.13)$$

Where the weights ($W_{pf,\ k^i}$ and $W_{if,\ k^i}$) are both equal to 0.5, pf_i is the payback of the agent *i* and if_i is the income of agent *i* compared with the mean income of all agents in the model.

The if_i factor represents the capability of the household to purchase the investment, considering his/her income condition compared to the one in the neighborhood. The calculation of this factor is very simplified, considering the most real and easy way of people reasoning, in contrast with the calculation provided by Schiera et al. (2019) and Zhao et al. (2011). These two publications consider the level of income per capita of a household as the average income value of the adopters in the neighbourhood according to an exponential relation. n contrast, this application considers the agent's knowledge of the socioeconomic status of PV adopters to be low; thus, perceived control in this application is simply based on a proportion between the agent's income and the incomes of people in the neighbourhood. Therefore, if_i is calculated as follows (eq. 6.14):

$$if_i = \frac{income_i - \min income_t}{\max income_t - \min income_t} \quad (6.14)$$

The pf_i factor was based on an interval standardization of the payback period (eq. 6.15) calculated by the agent to know the time required to recoup the investment on the PV:

$$pf_i = \frac{pp - 20}{1 - 20} \quad (6.15)$$

Where the minimum value of the standardization is equal to 20, corresponding to the maximum lifetime of the panel.

A dynamic discounted cash flow (DCF) analysis was performed to obtain this payback period. DCF is dynamic because each year of the simulation, some variables change their values. These variations can be related to market conditions, such as the PV variation cost, the incentives on the investment, and the increasing electricity cost over time, or to the reduced efficiency of the panel and its related operational and maintenance costs. These changes during the timeframe had both a positive and a negative effect on the decision to install the PV system. Considering, for example, that the cost of the panel decreased by 15.5% from 2002 to 2016, in this simulation model, it was assumed a constant yearly reduction in the price of 8%, similarly to Schiera et al. (2019). On the contrary, it is assumed that the cost of electricity will increase at a rate of 2% each year, based on the GSE (Gestore Servizi Energetici, 2018) estimation. Details on the variations of the attributes in the model are reported in the column called “Dynamic variables” contained in Table 6.3.

For the payback calculation, each year the agent calculates the net present value (16) in order to report all values to the evaluation time and compare them to the investment cost, as below (eq. 6.16):

$$npv = -I + \sum_{y=0}^{n} \frac{R\,(y)}{(1+r)^y}$$

$$npv \geq 0 \rightarrow y = pp \qquad (6.16)$$

Where r is the discount rate, equal to 0.8%, i.e., the mean discount rate calculated from 2011 to 2019 (for details see the following link: https://www.miolegale.it/utilita/tasso-interesse-legale/); n is the last year of the npv calculation, which corresponds to the maximum PV lifetime (20 years); y corresponds to the time; $R\,(y)$ is the net cash flow (i.e., cash inflow minus cash outflow, at time y). Initially, the net cash flow is equal to the investment I (with a minus sign). The year (y) when the $npv \geq 0$ corresponds to the payback period (pp).

The investment I (eq. 6.17) takes into account when the agent starts to think about the installation and, so, on the variation (t_{PV}) over time of the PV cost in the market:

$$I(y) = C_{PV} * (1 + t_{PV})^y \qquad (6.17)$$

$R\,(y)$ is calculated as the difference between revenues and costs over time (eq. 6.18):

$$R(y) = -O\&M(y) + R_{tax}(y) + R_t\,(y) \qquad (6.18)$$

$O\&M(y)$ corresponds to the yearly maintenance and operational costs. $R_{tax}(y)$ considers all the annual financial reliefs spread over 10 years provided by the Italian government for the purchase of the PV. $R_t\,(y)$ is the sum of the total revenues produced by the PV installation. Their specific calculations are reported in the following equations (6.19 and 6.20):

$$O\&M(y) = C_{O\&M} * (1 + t_{O\&M})^y \qquad (6.19)$$

Where $C_{O\&M}$ is a fixed annual cost (equal to EUR 105/y) per kW installed, whose value increases every year by an incremental quantity equal to 2%.

$$R_{tax}(y) = I(y) / 10$$

$$R_t(y) = R_{PV}(y) - R_{grid}(y) \tag{6.20}$$

$$R_{PV}(y) = \left(En_{comp} - \left(E_{PVoutput}(y) * \left(1 - r_{eff}\right)^y\right)\right) * \left(C_{Egrid} * \left(1 + t_{egrid}\right)^y\right)$$

$$R_{grid}(y) = \left(En_{comp} * \left(C_{Egrid} * \left(1 + t_{egrid}\right)^y\right)\right)$$

Where En_{comp} is the energy need required by each family based on the number of components, and this value is calculated as follows: $En_{comp} = E_{exp} * 12 / C_{Egrid}$. Then, E_{exp} corresponding to the median monthly energy expenditure per the number of components based on ISTAT statistics of 2018 on family expenses (ISTAT, 2019).

$E_{PVoutput}$ is the energy produced by the panel, taking into account the panel efficiency ε (irradiance, exposition, etc.) fixed in the neighbourhood at 0.6. r_{eff} is the reduction coefficient of the panel during its lifespan (0.8% each year[33]).

C_{Egrid} is a constant price for electricity that also includes the service costs; it is fixed at 0.23, while its variation over time is given by t_{egrid} with an increasing rate of 2% each year, according to GSE (Gestore Servizi Energetici, 2018) estimation.

Finally, **Actual control** ($\boldsymbol{act}$) is the last component required for the calculation of the behaviour (see Figures 6.2 and 6.7). In TPB, act is often considered equal to the pbc, when information is limited because pbc is considered veridical (Schiera et al., 2019). However, act is strongly based on past experiences and failures, which could be quite easily measured in the context of green product adoption. For that reason, the present research has considered both the case of act equal to pbc and equal to environmental awareness (aw_{env}). The latter component, as mentioned before, contains information about those who have already adopted sustainable actions (such as building retrofitting or window replacement), thus perfectly representing past behaviour in line with PV adoption. Experiments with these two act calculations show that the second approach accurately represents the actual adoption conditions in the neighbourhood under consideration.

6.4.3 Policy Design

The main objective of this research is to provide a virtual laboratory for testing alternative policy scenarios, thus supporting policymakers in the definition of

[33] https://www.miolegale.it/utilita/tasso-interesse-legale/

effective actions at a local scale. Four different policies are tested in the model:

- Scenario 0 represents the state-of-the-art of the current policy in the Italian context. It consists of a 50% tax relief on the investment cost for the purchase of PV, deferred for ten years;
- Scenario 1 considers different subsidies for low-income and high-income classes. Low-income people receive a subsidy equal to 70% of the investment cost in ten years. For high-income people, two options are tested: the first scenario considers no subsidies, and the second one considers 30%;
- Scenario 2 introduces a discount voucher proposed by PV sellers, to the Italian policy framework. This discount may be obtained by families if in their network there is at least one adopter. The model was tested with different levels of discount (10%, 20%, and 50%);
- Scenario 3 provides for an information campaign on environmental issues in order to increase the awareness of the population about this topic. Two options of information diffusion are tested: in the first option, the level of environmental awareness of the individual increases by 0.5, while, in the second option, by 1.0;
- Scenario 4 considers the development of an information campaign for increasing population awareness over the advantages of adopting the PV system. Additionally, two levels of information diffusion (medium and high) are considered, equal to 0.5 and 1.0, respectively.

6.5 Results

The model was calibrated based on the data of PV diffusion and trends in Italy and the metropolitan city of Turin, contained in the GSE report (Gestore Servizi Energetici, 2018) (Table 6.5). These data are reported for the San Salvario neighbourhood using a simple density proportion (penultimate row of Table 6.5) and a homogeneous distribution of the values in the 8 years considered (last row of Table 6.5).

Table 6.5. PV diffusion in Italy and the metropolitan city of Turin provided by GSE and used to identify the number of adoptions in the San Salvario neighbourhood

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
PV adoption in Italy	160,963	335,358	485,406	596,355	648,196	687,759	732,053	774,014	822,301
PV adoption in the Metropoli	4293	8762	12,529	15,280	16,556	17,526	18,611	19,636	20,813

tan City Turin % residential					81%				
% PV in San Salvario based on the real data	137	280	400	488	528	559	594	627	664
% PV in San Salvario — omogeneous distribution per year	137	203	269	335	401	466	532	598	664

Some parameters sweeping on attributes values were conducted to verify the robustness of the simulation model (such as on the type of interactions, μ, number of turtles in the network, PV installation power, and behaviour threshold), but also on the calculation of the attribute (such as for the income attribute if_i and the actual control act). These analyses were conducted using the BehaviorSpace (for details see the following link: https://ccl.northwestern.edu/netlogo/docs/behaviorspace.html), a tool integrated in NetLogo, which performs parallel experiments on the model.

Figure 6.9 reports the results of the calibration phase, showing the comparison of the real data with a representative set of simulations conducted. As can be seen, only minor differences exist among simulations and real data: the model accurately describes the real condition of diffusion in the neighbourhood.

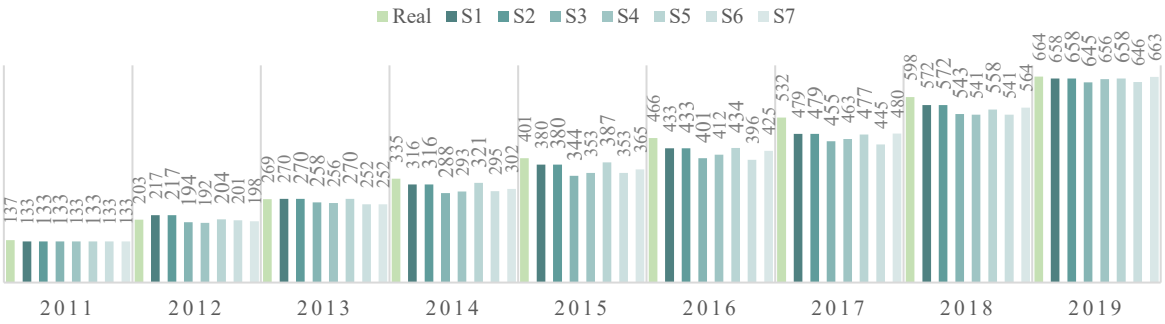


Figure 6.9. Comparison between real-world data of PV adoptions (pink) and seven exemplary simulation results (blue scale)

The differences among the six simulations reported are due to some variations in the family compositions and the random assignment of some values. Table 6.6 shows the aspects that contribute to these variations in the results.

Table 6.6. Variables that can modify the results in each simulation run

Static variables	Dynamic variables	Description
Property status		After the formation of the families with all their characteristics in the neighbourhood, the model excludes all families with a rental contract, because these families cannot decide on adoption. This means that for every simulation run, the families excluded can, to some extent, change the configuration of the possible adopters.
Opinion and uncertainty		These two variables are assigned with a random distribution whenever the model starts to run the simulation.
Environmental awareness		Same as before, the number of ecologists at the beginning of the simulation, and every year, was the same, randomly assigned to different agents
	Attitude toward the behavior	Since this attribute depends on opinion and environmental awareness, the initial configuration of those variables affects the results of the attitude toward the behavior.
	Social norm	Since this attribute depends on opinion, environmental awareness, and attitude toward the behavior, the initial configuration of those variables and attributes affects the results of the social norm.
	Interaction network	Interactions among agents followed SWN, choosing randomly a fixed number of agents (e.g., 6) inside and outside the radius selected (20 m). The model also asked agents to change their network every 5 years. This does not mean that an agent changes his/her opinion, attitude and social norm after five years; in fact, during this timeframe, agents are influenced also by the neighbourhood as a whole, and this influence can also change opinion, attitude and norm in the network.

To analyse the quality of the model implemented, some experiments were also conducted considering extreme conditions of population characteristics (Figure 6.10). In the population with very low income (in Figure 6.10 "lowI") in the entire neighbourhood (and all the other characteristics fixed as in previous simulations), no one decided to adopt the system. In the population with an average income (in Figure 6.10 "averageI"), the number of adoptions was lower than that of the real spatial model implemented (e.g., in 2019 the adopters were less than 400). At the beginning of the simulation runs, for the population with high income (in Figure 6.10 "highI"), the trend of adoptions was similar to the model implemented, but at the end of the simulations, about 900 people adopted PV systems. When extreme values of opinion and uncertainty of the agents were simulated, the results were more similar to those of the model implemented: for high uncertainty and low opinion (in Figure 6.10 "lowO-highU"), it was necessary to wait for a longer timeframe to achieve the same results (e.g., in 2015, only about 180 people had already adopted the technology, but in 2019 about 600 people decided to adopt it). For low uncertainty and high opinion (in Figure 6.10 "highO-lowU"), at the

beginning, the trend was very similar, but at the end, the adoptions started to decrease. This can be explained by the fact that a variety of opinions and uncertainties is more useful in diffusion technology than extreme positions, because, due to the interaction, people can change their positions on a specific topic.

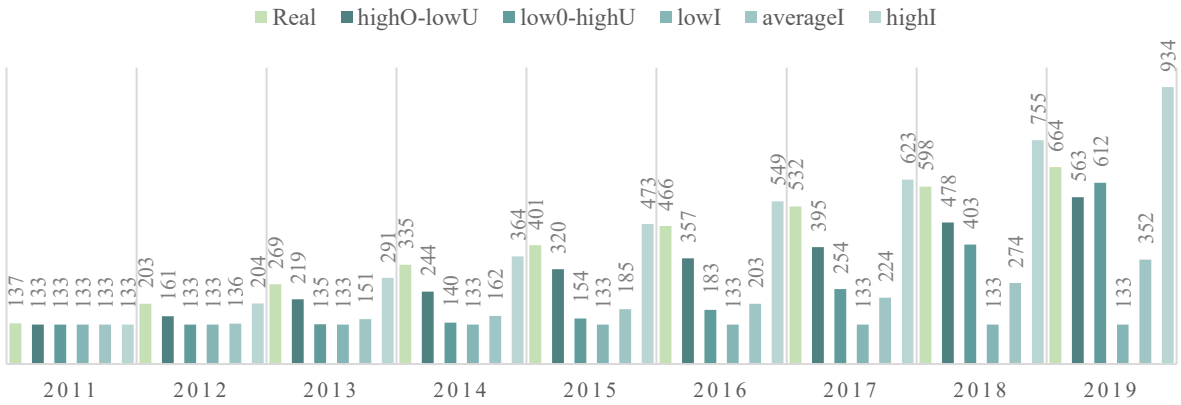


Figure 6.10. Experiments on the quality of the model with extreme population conditions

Next, the alternative policy scenarios were tested to verify their efficiency, see Figures 6.11, 6.12, 6.13, 6.14. All policies were compared to the results of current law simulations (Scenario 0): the x-axis shows the number of people who adopt the PV, and the y-axis shows the years of the performed simulation. In particular, the number of adopters per year was based on the mean value obtained from 20 simulation runs developed for each scenario.

The results of the policy simulations generally show that economic policies did not make a real and effective contribution. Figure 6.11 shows the policies designed for low-income people. Figure 6.12 highlights the contribution of voucher policies with different degrees of discount. None of these policies contributed to an increase in family adoptions. Although these results may seem strange at first, they can be explained for two reasons: firstly, non-economic motivations are fundamental in individuals' decision-making processes (e.g., environmental awareness or innovation level); secondly, economic reasons are often affected by knowledge and information on the technology under analysis. This effect is apparent both in empirical ABM applications in innovation diffusion, such as Weiss et al. (2012), Friege (2016), and Friege & Chappin (2014), and, more generally, in individuals' attitudes and behaviours research, such as Anable et al. (2006) and Müller-Eie & Bjørnø (2017).

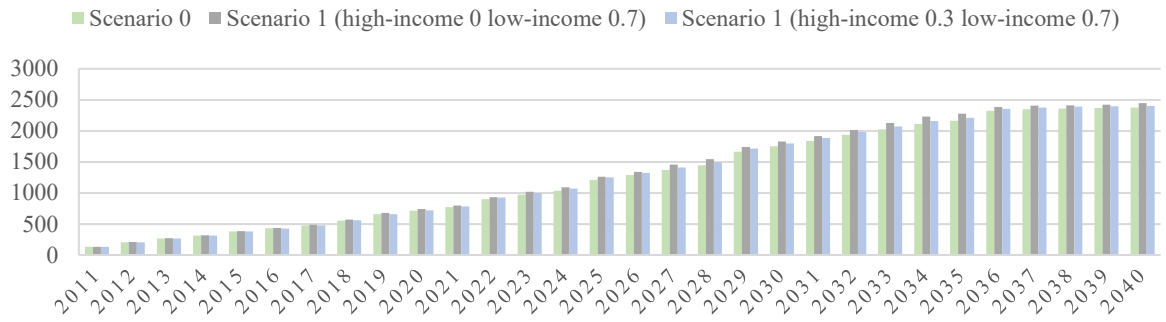


Figure 6.11. Comparison between Scenario 0 and Scenario 1

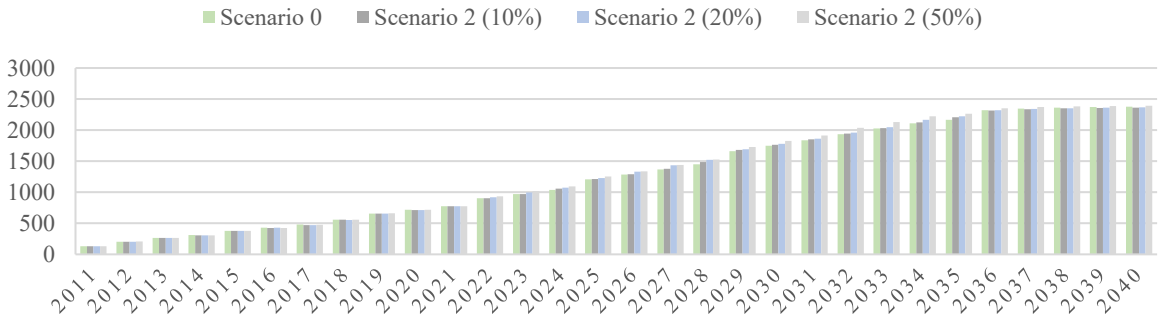


Figure 6.12. Comparison between Scenario 0 and Scenario 2

For these reasons, other policies are tested in the model to consider other motivations for the efficiency of sustainable actions and strategies. Concerning Scenario 3, as shown in Figure 6.13, information campaigns on environmental issues were not efficient in the diffusion of PV systems. However, the increase in technological awareness (Figure 6.14) was more suitable for that purpose, demonstrating the role of communication and information for people about the technological benefits and advantages. In particular, the awareness of the PV advantages was the main catalyst in the adoption of PV in the San Salvario neighbourhood.

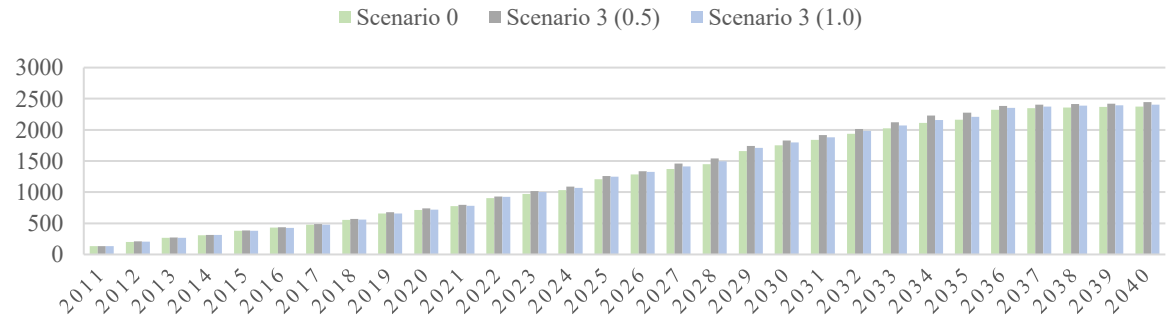


Figure 6.13. Comparison between Scenario 0 and Scenario 3

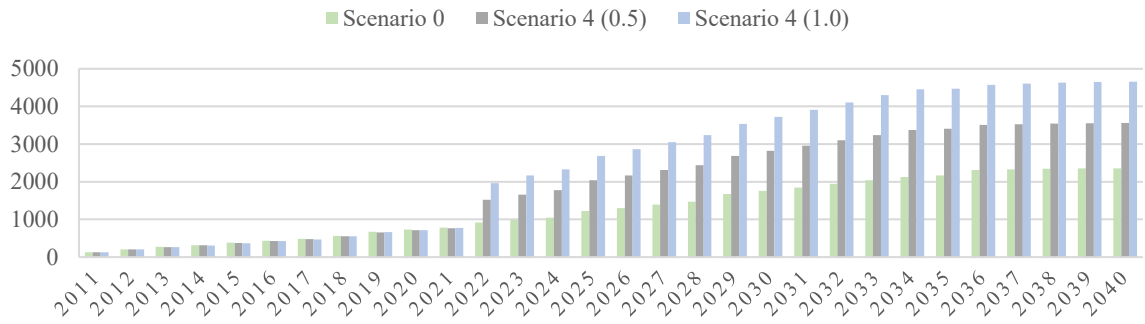
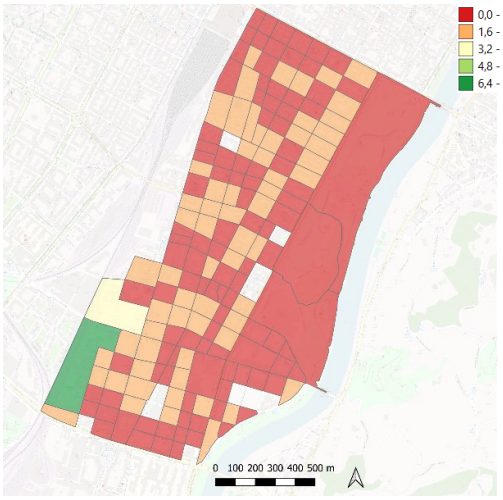
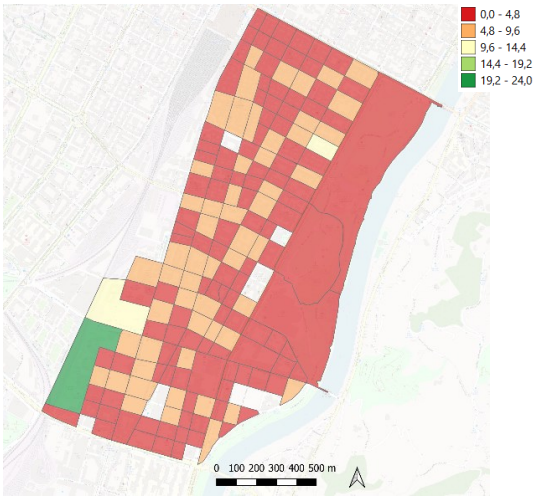


Figure 6.14. Comparison between Scenario 0 and Scenario 4

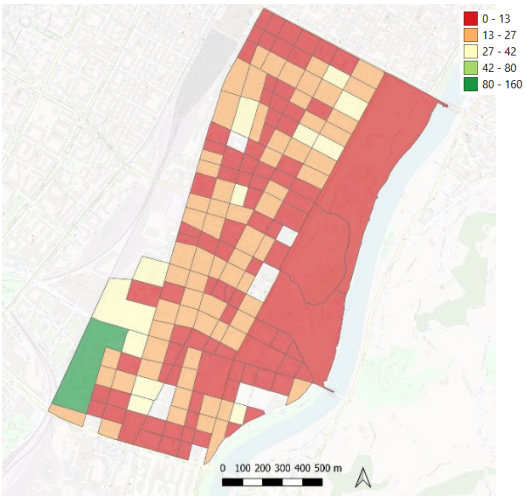
Figure 6.15 shows the variation of quantity in the adoption of PV over time for the different scenarios. These distributions result from the calculation of the mean of adoptions in each single block from ten simulations performed with the same policy scenario at once. The figure exemplifies the combined use of ABM and GIS for a dynamic simulation of the process under investigation. These maps were also useful for visualizing in a clear and easy way the results of the model. From the maps, it is apparent that the difference in the spatial distribution of adopters is very small. The south-west portion remains the area with the greatest adoptions over the years, with an increase of less than 10 adopters in 2011 compared to more than 70 in 2040. The increase in adoptions in the other blocks of the neighbourhood is not concentrated in any particular area, but is rather evenly distributed. However, the north-east portion has maintained a higher number of adopters over the years, unlike the middle area.



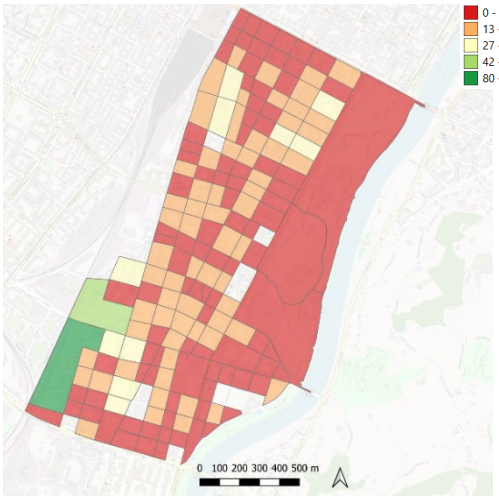
Scenario 0 (2011)



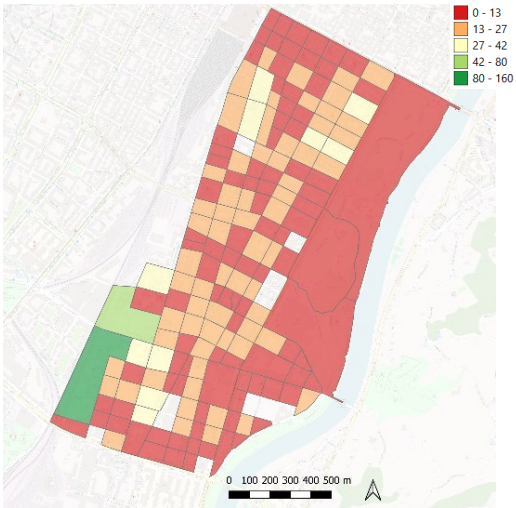
Scenario 0 (2019)



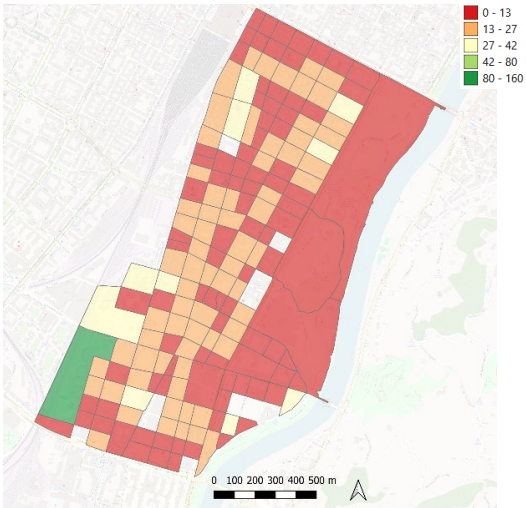
Scenario 0 (2040)



Scenario 1a (2040)



Scenario 1b (2040)



Scenario 2a (2040)



Figure 6.15. Variation of quantity in the adoption of PV over time for the different scenarios

6.6 Conclusions

The present research investigates the potentialities of a mixed-method approach, which combines ABM with GIS in the definition of strategic policies for the diffusion of PV systems in a real-case study of the San Salvario neighbourhood in the city of Turin (Italy). The study demonstrates the "exploratory simulation" capability of ABM (Parker et al., 2003) in studying complex systems and in supporting the decision-making process, thus becoming a sort of virtual laboratory (Railsback & Grimm, 2011) in a vision of sustainable development of our cities.

Some innovations can be detected in the present contribution. Firstly, it represents the first European attempt to simulate PV adoption with a level of detail of individual characteristics at the census block scale. The only examples in the literature are in Austin (Texas) (Rai & Robinson, 2015) and in the Gangnam district of Seoul (South Korea) (Lee & Hong, 2019). This detailed analysis of individual decisions allows DMs to study the effects of policies based on the real conditions of the population and the place under analysis. Secondly, the model tests the efficiency of information programs provided by the municipality on environmental and technological awareness of citizens. The other contributions on PV adoption only explore, in different ways, the role of economic policies in increasing the diffusion of this technology. Findings indicate that information campaigns, in particular those on the advantages of PV adoption, are the main catalysts in the diffusion of the technology—more so than economic or fiscal incentives. Thirdly, the present analysis tests the formation of actual control (*act*) in different ways, showing how past experiences and behaviours describe well the real contribution of this component of the TPB in the context under analysis rather than the repetition of perceived behavior control (*pbc*).

Future research will provide a more in-depth explanation of the results obtained. In this work, it was only presented the final results of policy simulations without considering the characteristics of adopters (e.g., income level, level of education, spatial distribution in the neighbourhood) and the mean level of attitude, social norm, and perceived behavior control. All these insights are highly relevant for the design of effective policies in the real context of San Salvario. Individuals with favourable attitudes are those first convinced to adopt PV. Building on this, it will be possible to test a policy mix based on the case study under analysis, and its specificity and contextual factors.

Another perspective of the research will be the comparison of the results based on proximity random interactions with the ones based on people's characteristics and status. The present model only considers interactions among agents in spatial terms, without connecting them to other aspects, such as similar education level, income, or status.

Furthermore, because of the COVID-19 situation, some data used for model implementation were simply based on statistical data (e.g., the number of

ecologists), which are not site-specific, and refer to the entire Piedmont region or were assigned randomly (e.g., opinion and uncertainty). Consequently, the next steps of the research will consider the construction and conduction of a specific questionnaire in the neighbourhood to collect all these data, thus improving not only the quality of the model performed but also identifying what is relevant and what is not in an individual decision-making process, in particular in the context of San Salvario and for the adoption of new sustainable technology such as PV systems. In this way, it will also be possible to give more reliability to the present simulation, taking into account the attitudes and reactions of citizens where green products and practices are concerned.

Some of the reasoning in TPB can be criticized because it is often difficult for people to understand, for example, the price fluctuation over time or the rational calculation of the payback period. However, other aspects such as social norms, opinions, uncertainties, and environmental awareness are able to capture more intangible and extra-economic reasons in the human decision-making process.

The present application shows the ability of the integrated and adapted TPB to represent the historical trend of PV adoption in the metropolitan city of Turin. This proves that it can be used as a virtual laboratory to test the efficacy of policy mix in a given neighbourhood. However, the main focus of future research development will be the comparison of TPB with other implementation models for the same case study but also for other contexts. This is particularly relevant because TPB is usually considered a good theory to explain past events but is less reliable in predictive terms.

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Chapter 7

II CASE STUDY – Kelvin-Grove & Herston districts, Brisbane (AUS)[34]

The second case study investigates the phenomenon of green gentrification, which results when minority and low-income residents are pushed out of their neighbourhoods when new green spaces are developed. The case study of the future transformation of the Victoria Golf Course into a new urban park in the districts of Kelvin-Grove/Herston (Brisbane, AUS) is used to test the applicability of a proposed mixed-method approach. The mixed-method approach, which combines ABM, GIS, HPM, and MCDA, is proposed with the aim of effectively accounting for gentrification in real-world case studies, considering both the supply-side and demand-side in property market. The spatial HPM is used to verify the impact of recreational parks on property prices in the inner Brisbane. ABM is used to simulate the housing mobility of individuals based on their micro-scale choices in property selection. The decision-making process of individuals about their housing mobility is based on various GIS spatially explicit endogenous (i.e., household socio-economic characteristics) and exogenous (i.e., market variation) factors. Accordingly, MCDA

[34] Part of this chapter has been developed in the following paper:

- Bottero, M., Caprioli, C., Foth, M., Mitchell, P., Rittenbruch, M., Santangelo, M. (2022). Exploring the effects of urban green space on property values: an application of the Spatial Hedonic Model in the city of Brisbane. Urban Forestry and Greening (in press)

(specifically, AHP) is used to determine the degree of importance of the endogenous and exogenous factors in the individual decision-making process. According to the general scheme contained in Chapter 5 (Figure 5.1) about the three main elements of ABM/MAS, Figure 7.1 details how these three elements are declined and how the different methods are used in this second case study to inform and structure them.

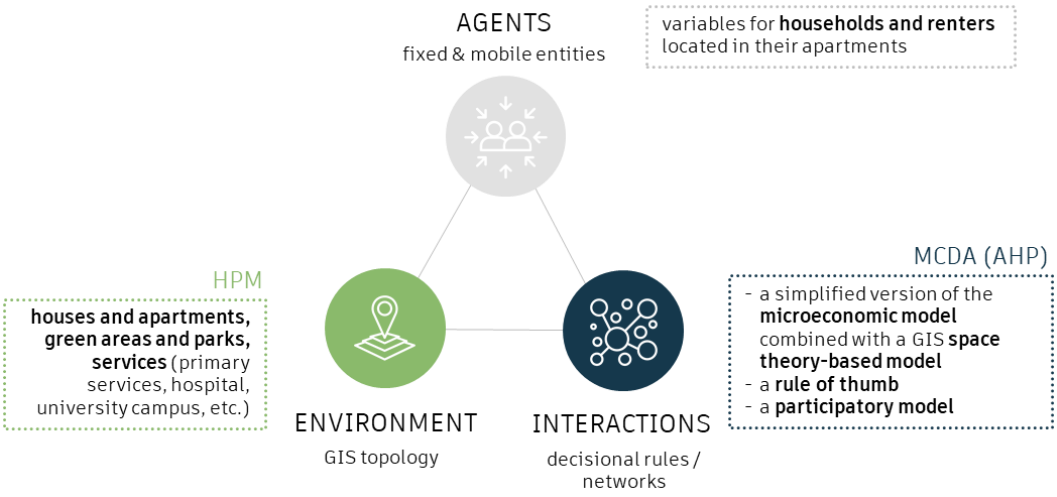


Figure 7.1. ABM/MAS main pillars as developed in this case study application

7.1 An integrated evaluation model for supporting SOCIO-ECONOMIC policies

Housing mobility is a complex phenomenon strongly affecting urban and non-urban shapes and environments. Micro-scale choice of individuals on property selection generates at macro-scale socio-economic and socio-cultural patterns of an area or a territory, which may change over time or take on a stable and clear feature. This is the way, housing and mobility have assumed a central role in urban and housing studies due to the intersection of a variety of aspects, spanning economic, technological, environmental, demographic, and socio-cultural factors (Dufty-Jones, 2012). Within this context, environmental and natural amenities have been considered a crucial element in mobility decisions since people prefer to live close to open public spaces (Clark & Hunter, 1992; Knapp & Gravest, 1989; Mueser & Graves, 1995). At the same time, there is a bunch of literature that evidences by Hedonic Price (HPM) the inverse relationship between housing prices and distance to urban environmental amenities (Benson et al., 1998; Luttik, 2000; Schmidt & Courant, 2006; Wu & Plantinga, 2003). More recently, this correlation has been widely examined by sociologists, planners, and geographers who have examined and demonstrated the injustice of greening initiatives. This phenomenon, called green gentrification, highlights the negative social consequences of green growth

in specific contexts, which are in coalition with the positive environmental effects generated by these areas (Gould & Lewis, 2016). Scholars have proved that such initiatives often create, both intentionally and unintentionally, enclaves of environmental privilege, where minority and low-income residents are pushed out of their neighbourhoods when new green spaces are developed (Anguelovski et al., 2019; Bottero et al., 2019).

However, the current worldwide agenda and the Sustainable Development Goals (SDGs) (General Assembly, 2015) adopted by all United Nations Member States in 2015 have highlighted and promoted the diffusion and development of green urban infrastructures (GUI) since they are able to mitigate the impacts of climate change (Dong et al., 2017) and offer a variety of tangible and intangible benefits, such as CO2 reduction, thermal comfort, health and restorative benefits, social interactions, education, and habitat quality for species (Demuzere et al., 2014). Consequently, this topic is crucial as many cities have made an effort, particularly on environmental policies, to guide their redevelopment and improve their image (Anguelovski et al., 2019; McKendry, 2018), remediating polluted sites, building new parks, and ameliorating bike lanes and corridors. Many of these green initiatives have increased the quality and well-being of an area and its surroundings, generating externalities on properties and the consequent inflow of new residents, but they have also provoked, in some cases, the displacement of long-term residents considered minorities and/or with lower economic possibilities (Rigolon & Németh, 2020).

With the aim of considering urban sustainable development comprehensively, the social components cannot be missed or neglected. Since negative social outcomes can be correlated with environmental initiatives, policymakers and urban planners need to be conscious of the effects that eventually occur after a green transformation. Green initiatives are not all the same: they may not result in green gentrification, or the outcomes can be different based on the location, function, and size of the transformation (Rigolon & Németh, 2020) and the socio-economic and demographic characteristics of residents. Therefore, preliminary analysis of people and the area of transformation, the monitoring and control of ongoing effects, and the definition of public policies can create more sustainable outcomes (Cerreta & Poli, 2020; Gould & Lewis, 2016; Napoli et al., 2016).

Gentrification has been explored in simulation and modelling, essentially in the last decades (such as Diappi and Bolchi (2006), Jackson et al. (2008), O'Sullivan (2002), Torrens and Nara (2007)), but the rapid mutation of the gentrification dynamics and the socio-political contextual variations are probably the reasons why the contributions are limited and more efforts are needed (Sabri et al., 2012). Most modelling and simulation of gentrification refer to three theories, i.e., the filtering theory (Lowry, 1960), Smith's rent gap theory (Smith, 1987) and household life cycles. Filtering theory is a supply-side view, based on "a change in the real value (price in constant dollars) of an existing dwelling unit" (Lowry, 1960). Connected with them, there is the other supply-side theory, Smith's rent gap, which refers to

"the disparity between the potential ground rent level and the actual ground rent capitalized under the present land use" (Smith, 1996). Finally, the household lifecycle is a demand-side theory founded on the effects of population ageing on the housing market (Cheng, 2015). These three theories highlight the first relevant aspect of gentrification simulation, i.e., that both supply-side and demand-side need to be included for an effective accounting of gentrification in real-world case studies. Attempts in this sense are the works of Torrens and Nara (2007) and Jackson et al. (2008), which represent the baseline framework of the present case study. Then, according to Sabri et al. (2012), new-build gentrification is a social, economic, and spatial problem and a multi-actor process where households' status and their desirability and affordability are crucial indicators that can be investigated in neighbourhoods (Lees et al., 2008). Moreover, landscape and aesthetic aspects, redevelopment, and new inflowing residents are facts to be integrated into the gentrification process (Davidson & Lees, 2005).

From these considerations, the present work tries to propose a more accurate real-world modelling that takes into account all the social, economic, spatial, infrastructural, and individual dynamics affecting gentrification. The aim is to support planners and policymakers in the analysis of the impacts generated by green areas. Through the combination of ABM, GIS, and MCDA, the research explores gentrification dynamics from a bottom-up perspective, i.e., the supply and demand sides of residents on property selection and mobility (Hamnett, 1991; Torrens & Nara, 2007). The transformation project of the golf park into a new urban park in the city of Brisbane (Australia) is being investigated to verify the applicability of the integrated approach proposed.

The chapter is structured as follows: after this Introduction, a Methodological Section describes the mixed approach proposed and how it is structured and formulated. Section 7.3 presents the case study. Then, Section 7.4 contains the application of the multi-methodology approach to the real-world scenario of Brisbane. The results and their discussion are presented in Section 7.5. Finally, Section 7.6 contains the main conclusions related both to the methodology and simulation results. Here, future perspectives of the research are also discussed.

7.2 A multi-methodology perspective: HPM + ABM + MCDA + GIS

7.2.1 Conceptual framework

The research introduces a multi-methodology approach for testing and analysing gentrification dynamics in the real-case study of the city of Brisbane. The mixed-method approach is considered the third paradigm for social research as it offers a powerful choice to integrate systematically quantitative and qualitative data (Creswell & Plano Clark, 2013). The complexity of modern problems requires the

consideration of multiple dimensions in play and multiple forms of data (Gunasekare, 2015). Their combination makes it possible to better understand practical problems than using a single method.

There are two hypotheses at the basis of this research. The first one is related to the inverse relationship between housing prices and distance to urban environmental amenities, as consistently evidenced by hedonic analyses of residential housing prices (Wu & Plantinga, 2003). The second one is related to the positive influence of natural amenities on mobility decisions (e.g., Clark & Hunter, 1992a; Knapp & Gravest, 1989; Mueser & Graves, 1995). Since people prefer to live close to public open space, it suggests that these places can influence the features of the urban landscape and the spatial distribution of income groups.

Starting from those assumptions, a multi-stage approach is adopted, integrating HPM with ABM, both which are supported by GIS data analysis, and MCDA.

The first method adopted is that of spatial HPM. Spatial HPM is an advanced version of classic HPM that considers the spatial autocorrelation issue, meaning that each observation price is influenced by the prices of the nearby observations (Dubin, 1992; Tsai et al., 2015). Spatial HPM is used in the present research to verify the effect of recreational parks on property prices by using the Geoda software (Anselin et al., 2006) in the Brisbane inner city area. Methodological details on how the spatial HPM can be found in Chapter 3 (Section 3.5.1).

The spatially explicit ABM is the second method applied. In this case study, ABM simulates the housing mobility of residents over the medium term through an individual decision-making process, where the mobility likelihood of residents is based on various endogenous (i.e., household socio-economic characteristics) and exogenous (i.e., market variation) factors. Both the house and household characteristics derive from GIS empirical data (see Section 7.2.2).

The third method is MCDA. MCDA refers to a group of methods able to consider several criteria, both economic and extra-economic, and assign them a relative importance based on the views and perspectives of the stakeholders involved (Bottero et al., 2021). For methodological details, see Chapter 3 (specifically, Section 3.4.1) In the present work, AHP (Saaty, 1990, 2008a) is integrated into ABM to identify the importance degree of the endogenous and exogenous factors contained in the mobility likelihood function. A panel of local experts was involved to identify the priorities of all the elements in the housing mobility choice.

7.2.2 A flexible gentrification model through ABM

The modelling cycle proposed by Grimm and Railsback (2004) (see Chapter 5, Section 5.2) suggests the analyst clearly define the scales, entities, state variables, processes, and parameters, once the question, the aim, and the hypothesis of the model are framed. In this section, the three first elements (i.e., scales, entities, and state variables) are firstly detailed, then, the information about the processes and

parameters is described, and, finally, it is illustrated how the model was formulated. This latter part of this section is mainly focused on the detailed description of the individual decision-making process of the households in the model, using the support of MCDA.

The gentrification model proposed works mainly at a district scale, which is recognized as the most appropriate level of analysis and action, where various social networks and institutions are directly active, offering greater opportunities for participation in collective decisions (Lützkendorf & Balouktsi, 2017; Paiho et al., 2019). However, this scale is strictly related to phenomena at the city-scale (such as housing price trends and population trends) and at the micro-scale (among others, household characteristics and the distribution of services).

Then, the model considers two categories of entities: fixed and mobile entities. Fixed entities are all the elements that constitute the environment of ABM, which comes from GIS data and spatialization. Fixed entities are the properties, services, infrastructure, and open areas distributed in the area analysed. More specifically, each property contains information about intrinsic characteristics, such as housing typology or the number of bedrooms, but also extrinsic characteristics, such as the distance and density of services, infrastructure, and open areas. Mobile entities, instead, are the residential households that interact with each other and with the environment. Mobile entities are also able to go away from the environment or to go in and are divided into two main groups, i.e., renters and homeowners. Each residential household is endowed with a set of state variables, including income, age, family composition, socio-ethnic status, and the ability to sense their neighbouring environment. All these variables can be used to develop preferences for housing options based on the individual's characteristics, property features, and neighbourhood quality and status. Homeowners and renters differ in the property status, but their decision to stay or leave the neighbourhood depends for both groups on income and endogenous and exogenous factors of the individual and his/her preferences on property and neighbourhood state. The basic rule in the model states that if the income is too low, then the agent is forced to leave the neighbourhood. Conversely, if the income is sufficient to stay, then other factors influence the choice.

To take into account all the useful variables for the implementation of the integrated approach, an in-depth literature review of gentrification models was reviewed. Table 7.1 contains the variables obtained from this literature review, divided into global, environmental, and agent variables.

Table 7.1. List of the variables used in gentrification models

G/E/A	Variables	References
G	Population increasing trend	(Gilbert et al., 2009; Picascia, 2014; Torrens & Nara, 2007)
G	Population class variation trend	(Gilbert et al. 2009; Picascia 2014)
G	Housing price/rent index	(Gilbert et al. 2009)

	trend	
E	Property value	(Caruso et al., 2007; Diappi & Bolchi, 2006; Filatova, 2015; Gilbert et al., 2009; Guo et al., 2019; Jackson et al., 2008; Jordan et al., 2012; Li & Liu, 2008; O'Sullivan, 2002; Picascia, 2014; Shirzadi Babakan & Alimohammadi, 2016; Torrens & Nara, 2007; Wasserman & Yohe, 2001; Wu & Plantinga, 2003; Yin & Muller, 2007)
E	Surface	(Wasserman and Yohe 2001; O'Sullivan 2002; Wu and Plantinga 2003; Torrens and Nara 2007; Filatova 2015; Guo et al. 2019)
E	Housing type (detached, semi-detached, apartment)	(Torrens and Nara 2007; Jordan et al. 2012; Guo et al. 2019)
E	N of occupied/unoccupied property	(O'Sullivan 2002; Torrens and Nara 2007; Gilbert et al. 2009; Jordan et al. 2012)
E	Services mix (or type of services)	(Caruso et al. 2007; Torrens and Nara 2007; Jackson et al. 2008; Li and Liu 2008; Jordan et al. 2012; Shirzadi Babakan and Alimohammadi 2016)
E	Neighbourhood status in a radius (property value, residents' socio-econ status, agent class similarity)	(O'Sullivan 2002; Torrens and Nara 2007; Jordan et al. 2012; Guo et al. 2019)
E	Maintenance status (age)	(O'Sullivan 2002; Diappi and Bolchi 2006; Picascia 2014; Filatova 2015)
A	Property status (tenant/homeowner)	(Torrens and Nara 2007; Jordan et al. 2012; Filatova 2015)
A	Income	(Wasserman and Yohe 2001; O'Sullivan 2002; Wu and Plantinga 2003; Diappi and Bolchi 2006; Caruso et al. 2007; Torrens and Nara 2007; Yin and Muller 2007; Jackson et al. 2008; Li and Liu 2008; Gilbert et al. 2009; Jordan et al. 2012; Picascia 2014; Filatova 2015; Shirzadi Babakan and Alimohammadi 2016; Guo et al. 2019)
A	Rent/mortgage	(Caruso et al. 2007; Guo et al. 2019)
A	Age or Agent class (student, elderly, ..)	(Jackson et al. 2008; Jordan et al. 2012; Shirzadi Babakan and Alimohammadi 2016)
A	Family composition	(Li and Liu 2008; Jordan et al. 2012; Shirzadi Babakan and Alimohammadi 2016)
A	Socio-ethnic status (language, religious, ..)	(Wasserman and Yohe 2001; Torrens and Nara 2007; Jackson et al. 2008; Jordan et al. 2012; Picascia 2014; Guo et al. 2019)
A	Amenity preference	(Wasserman and Yohe 2001; Wu and Plantinga 2003; Caruso et al. 2007; Yin and Muller 2007; Jackson et al. 2008; Filatova 2015)
A	Job distance	(Wasserman and Yohe 2001; Wu and Plantinga 2003; Caruso et al. 2007; Yin and Muller 2007; Jackson et al. 2008; Jordan et al. 2012; Filatova 2015; Shirzadi Babakan and Alimohammadi 2016; Guo et al. 2019)
A	Housing goods preference	(Filatova 2015)
A	Mobility propensity	(Torrens and Nara 2007; Jordan et al. 2012; Picascia 2014)
A	Status (stay/move)	(Torrens and Nara 2007)

Then, several events occur in the gentrification simulation model, as synthetized in Figure 7.2.

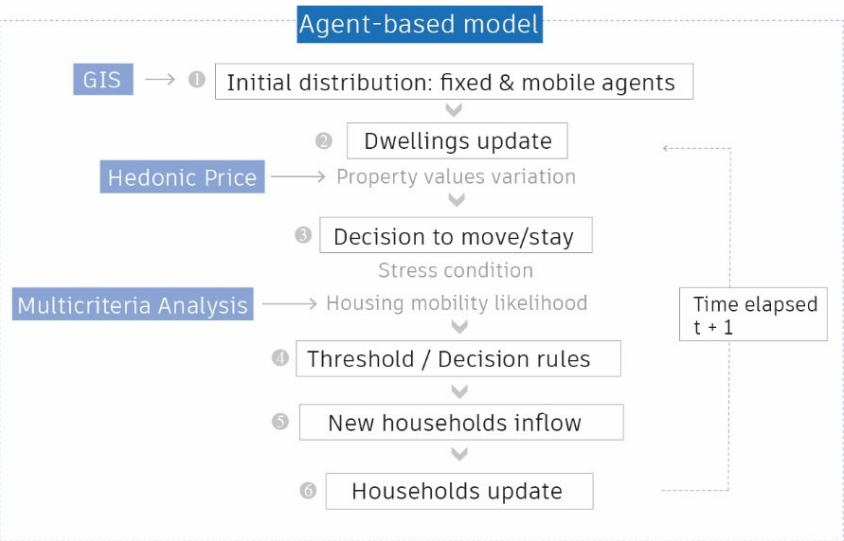


Figure 7.2. Process overview of the general gentrification model proposed

Once fixed and mobile agents are spatially distributed and initialized (1), the model starts to execute these events over time. At this stage, and for all the following years, the model increases the property values (2) based on the city trends both for houses and units. This step can be further implemented by the integration of hedonic analysis, as for this application (see Section 3.5.1).

This increase can affect not only the rental price, but also the decision of homeowners to sell their properties. A relevant aspect in the individual decision-making process is related to the proportion of income spent on renting a house or paying a mortgage. A stress condition that follows a worldwide rule of thumb is included in the model. It refers to negative conditions experienced by the household when he/she spends more than 30% of his/her pre-tax income on the house. Then, households start to examine their property and their surroundings (3), as well as themselves and their specific characteristics and status. Eventually, the value increase of properties can modify the previous reflections of households about staying or leaving. These reflections and actions of individuals affect dynamics at the market scale that have an impact again at the micro-scale. Each household calculates his/her housing mobility likelihood, which refers to the probability that the household will stay or go away. This decision is based on the specific characteristics and preferences of the individual regarding the endogenous and exogenous features of the property where he/she lives. This housing mobility likelihood is compared with a defined threshold and the stress condition to set alternative mobility decision-making rules (4). If the result of the individual decision-making process is to leave (for renters) or sell (for homeowners), new households arrive in the neighbourhood (5). These new households can or cannot be gentrifiers: alternative simulation runs are tested in the model. Finally, households update their age (6). Specifically, households calculate how many years he/she live in his/her house. If the age is lower than 65 years and the year-inhouse is equal to 10, the household passes to the subsequent age range. This update is useful to define age preferences in the likelihood parameters.

Through this simulation process, gentrification happens as a cautious emerging phenomenon of actions and interactions of individuals and their environment across different scales and events (Torrens & Nara, 2007).

Step (3) is further detailed in the following paragraph, whereas steps (4), (5), and (6) are directly explained in the application part. Steps (4), (5), and (6) are constructed based on the specific context of Brisbane, its real-estate market and the number and characteristics of people living in the neighbourhoods considered. However, the logic of these steps can be flexibly used and easily applied with slight modifications in other contexts (such as in the number of rules, the stress level, or gentrification conditions).

In Step (3), the proposed model uses a household mobility choice that is based on an individual decision-making process. This means that not all universal laws are defined across modelled households, but their decisions depend on a personal utility likelihood function. The likelihood function considers the benefits generated by the house or unit of the household and the neighbourhood where he/she lives. Household choices are therefore the combination of benefits at the property scale and the district scale, including housing intrinsic characteristics, the provision of services and infrastructure in the neighbourhood. At the same time, personal constraints and preferences affect the final decision.

To take into account these various aspects in the utility likelihood function, the research makes use of MCDA. More specifically, AHP (Saaty, 1996) is adopted due to its ability to hierarchically decompose the complexity of the decision-making process (principle of decomposition) and to assign priorities to all the elements at each level of the hierarchy (comparative judgments) (Saaty, 2008b). The principle of decomposition breaks up the decision-making problem into criteria and sub-criteria, while the comparative judgements give different importance to all the aspects considered. Examples of ABM and AHP integration are Shaaban et al., (2019), Tian & Qiao (2014), and Yu et al. (2018). For more methodological details, see Chapter 3, Section 3.4.1.

The individual decision-making process was therefore structured as a weighting sum, constituted by eight sub-criteria divided into three criteria, as reported in equation 7.1, detailed in Table 7.2 and represented in Figure 7.3.

$$Pc = c_1 * [\, b_1 * (1 - Ps)\,] + c_2 * [\, b_2 * Tp + b_3 * Sp\,] + c_3 * [\, b_4 * Wp + b_5 * Ap + b_6 * (1 - EcS) + b_7 * (1 - ScS) + b_8 * Accp\,] \quad (7.1)$$

where *Pc* is the individual mobility likelihood calculation; *Ps, Tp, Sp, Wp, Ap, Ecs, Scs, Accp* are the sub-criteria; b_1, b_2, …, b_3 are the weights for the eight subcriteria; c_1, c_2, c_3 are the weights at the criteria level.

Table 7.2. List of criteria and sub-criteria

Level	Criteria	Description	Sub-criteria	Description
Household	Economic aspects (EA)	EA refers to economic constraints that households should consider when they rent / buy an house / unit	Price suitability (Ps)	Ps measures the proportion between mortgage / rent and household income
Property	Intrinsic characteristics (IC)	IC considers the intrinsic features of the house/unit where the household lives	Type preference (Tp)	Tp describes the preference of the household about the typology of the house where he/she lives.
			Size preference (Sp)	Sp describes the preference of the household about the size of the house where he/she lives.
Neighbourhood	Extrinsic quality (EQ)	EQ refers to the mix of services and infrastructure characterizing the neighbourhood, as well as its connection with the other area of the city. Moreover, it takes into account the main characteristics of the people living there.	Work preference (Wp)	Wp describes the preference of the household about the distance of his/her house/unit to his/her work.
			Amenity preference (Ap)	Ap refers to the preference of the household about the proximity of his/her house to amenity spaces.
			Economic status (Ecs)	Ecs is used to measure the possible level of "segregation" of the household and, therefore, the increasing probability of leaving his/her house. Ecs is based on the difference between the household income and the mean income of the households in his/her neighbourhood
			Sociocultural status (Scs)	Scs is used as a sociological combined total measure of households. The combined measure is based on the following own attributes of the households:

		education, religion, parents' origin and language. This variable considers the possible level of "segregation" of the household and, therefore, the increasing probability of leaving his/her house.
	Accessibility preference (Accp)	Accp refers to the proximity and density of various services from the households' house

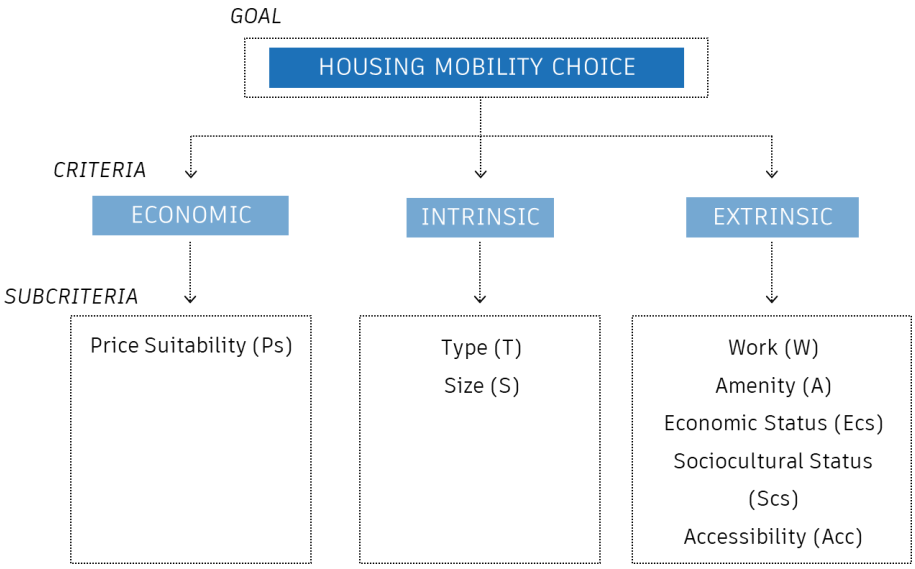


Figure 7.3. The hierarchic structure of criteria and sub-criteria

7.3 Case study description

Brisbane is a subtropical city located in Queensland, Australia (Figure 7.4). It is the third-largest city in Australia, with a population of around 1.2 million in the metropolitan area. Brisbane city comprises over 150 suburbs and localities and covers an area of 1.3 km^2. There is currently significant sprawling development on the outskirts of the city, but the majority of the population is concentrated in a strip through the centre. Brisbane is a city with considerable amounts of green space per capita, and public green spaces and parks are distributed rather evenly across the city. The present study focused on the Inner Brisbane area (Figure 7.5), which is a homogeneous area characterized by a very similar density compared to other external areas. The area covers a surface of around 1,367 km^2 and has an overall population of 250,207 inhabitants (Australian Bureau of Statistics, 2016).

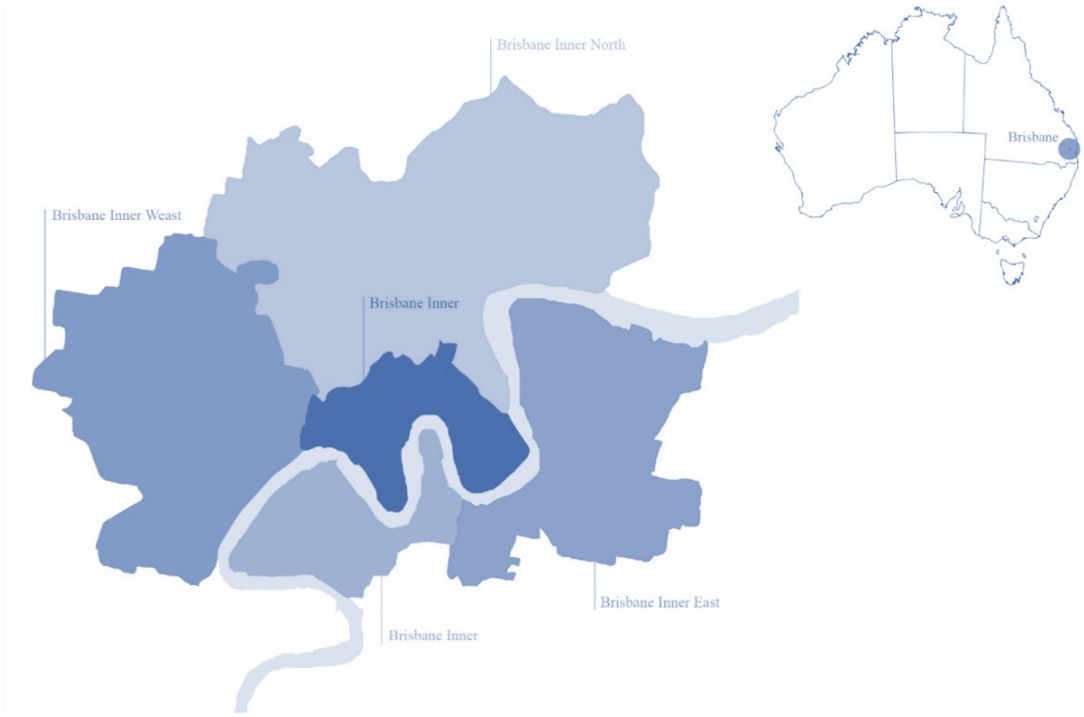


Figure 7.4. On the right, Brisbane location in the Queensland State (Australia) and, on the left, a map of the Brisbane Inner City suburbs

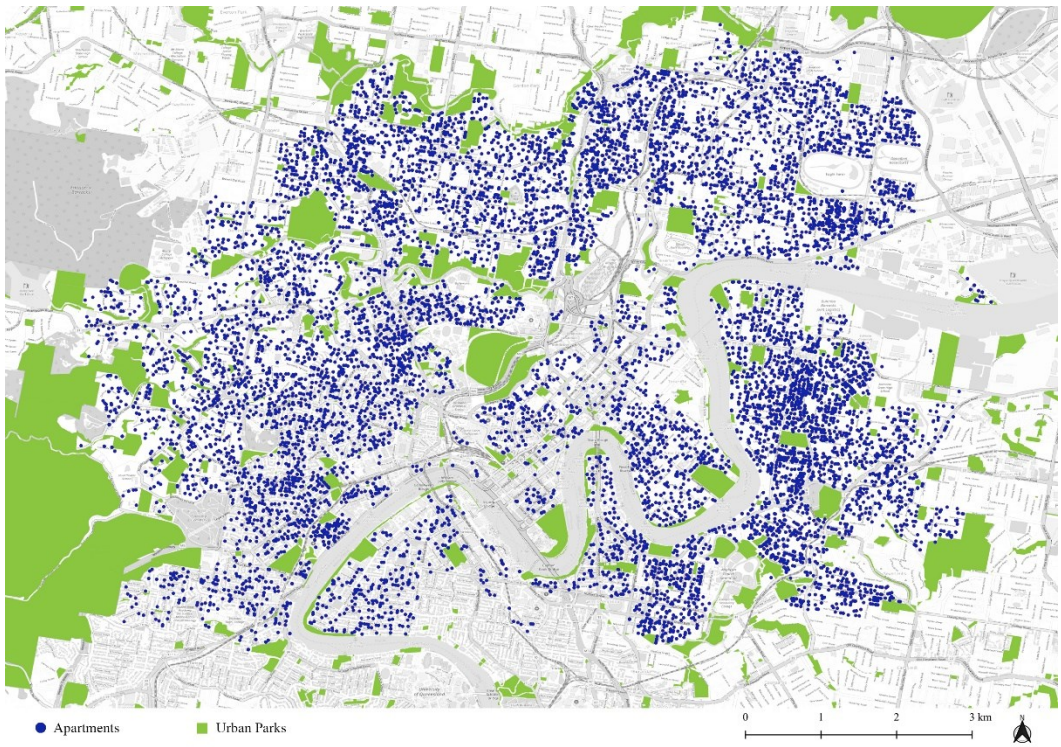


Figure 7.5. Distribution of urban parks and apartments used for the analysis

Brisbane is experiencing considerable spatial renewal, improvement, and shaping of the city. Especially on the river and in the central business district (CBD), in recent years, many projects have been concluded or will start soon, such as the changes in New Farm, what is happening at West End and around the

University of Queensland (QUT), the game-changing Queen's Wharf development, South Bank and the cultural precinct.

With the aim of becoming the Australia's new world city, the Brisbane City Plan 2014 has defined five themes that collectively represent the policy intent for the future: (i) Brisbane's globally competitive economy; (ii) Brisbane's outstanding lifestyle; (iii) Brisbane's clean and green leading environmental performance; (iv) Brisbane's highly effective transport and infrastructure; and (v) Brisbane's CityShape (Brisbane City Plan 2014).

Some of the actions undertaken can be explained as a consequence of establishing the city in a global knowledge economy. As Pancholi et al. (2015) pointed out, after Sydney and Melbourne, "*Brisbane is one of the emerging knowledge cities of Australia".* The objective is *"to attract and retain skilled human capital in the form of knowledge workers by providing them with quality of life in ultimately unique places"* (Yigitcanlar et al., 2007). The Kelvin Grove Urban Village (KGUV) is an example of an urban renewal project in that context, developed as a joint initiative by Queensland University of Technology (QUT) and the Queensland Government Department of Housing (Pancholi et al., 2015). Only 2 kilometres from Brisbane's CBD, KGUV is a sustainable urban community developed as an integrated and master-planned urban village within a mixed-use and highly urban environment in the Kelvin-Grove neighbourhood (Brisbane City Plan 2000;Yigitcanlar et al., 2016). The aim was to create a strong sense of place and community in a safe environment (Pancholi et al., 2015).

In this neighbourhood, it was recently announced that the Victoria Golf Course would be transformed into a new park for the city of Brisbane. During 2019-2020, the community is called to take part in a consultation to create a vision for Victoria Park (Brisbane City Plan 2014). From 2021, the project realization is expected to start to transform the golf course into public parkland (Brisbane City Plan 2014[35]). For the project development, the council asked some of Brisbane's leading design professionals to propose some ideas for Victoria Park in the future. The result (Figure 7.6) is five different projects and some ideas from citizens, as follows:

- Active Forest Visionary Idea by Urbis;
- Barrambin - Reconnection and Restoration Visionary Idea by Lat 27;
- Brisbane Rock Pools Visionary Idea by Place Design Group;
- Connect and Celebrate Visionary Idea by Tract;
- Nature that Nurtures Visionary Idea by Conrad Gargett.

In parallel, 464 ideas have been proposed by citizens (access to the website: https://yoursay.brisbane.qld.gov.au/VP?tool=brainstormer#tool_tab: 22-09-2019).

The positive effect of this transformation on the surrounding areas is quite predictable. On the contrary, the effects on parts of the population in neighbouring communities due to the property uplift are less obvious.

[35] http://eplan.brisbane.qld.gov.au/CP/KelvinGroveUrbanVillageLP

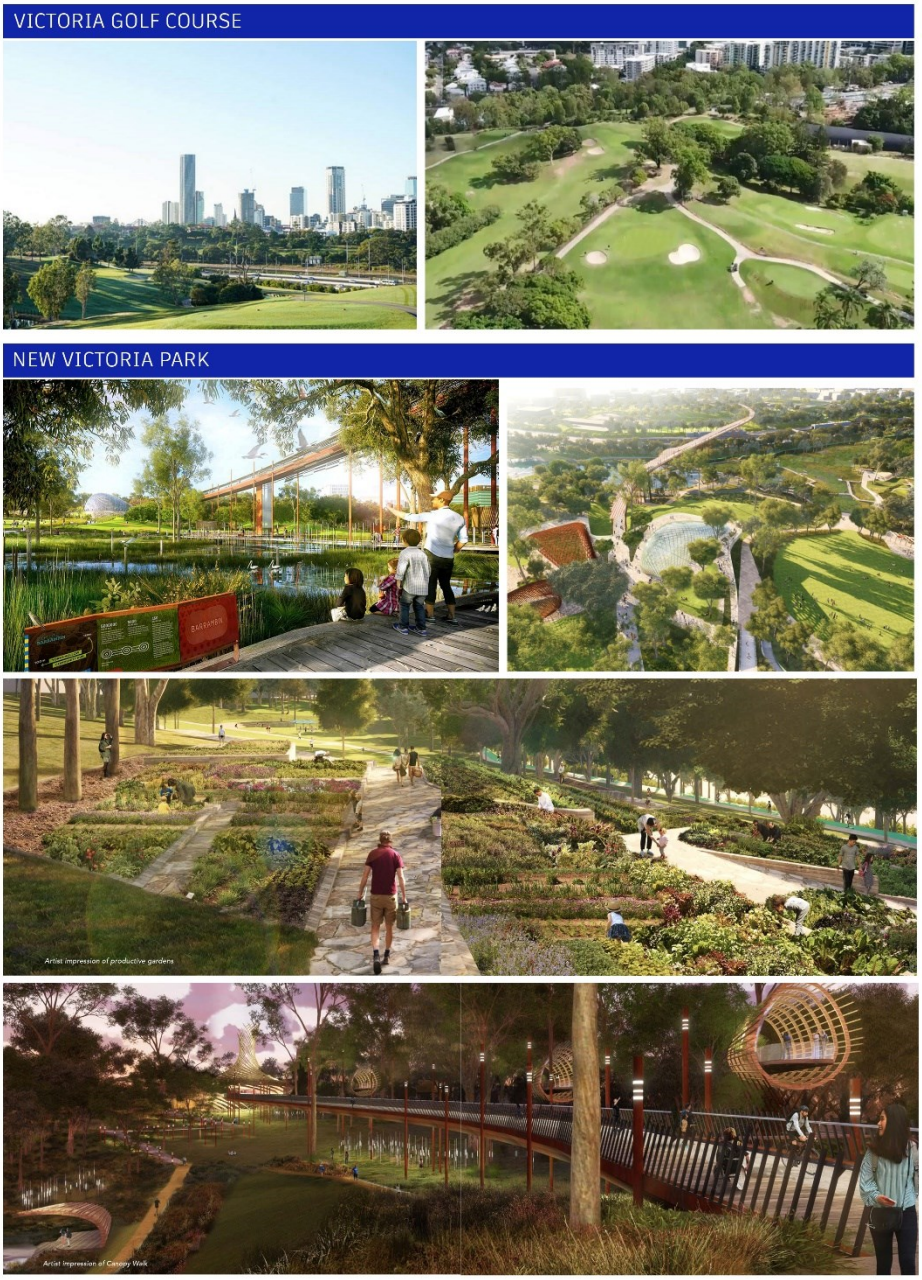


Figure 7.6. Vision for the Victoria Park as emerging from the consultation process (elaborated from Brisbane City Council, 2020)

If this is combined with the aim of the KGUV project to attract skilled human capital (but, probably, also temporary inhabitants such as students due to the proximity of the QUT campus), the impacts of this transformation should be analysed in-depth and considered in advance to avoid the creation of gentrification phenomena with the replacement of inhabitants with higher socioeconomic characteristics or, alternatively, the production of neighbourhoods without a consistent, stable population - as the "gentry" are – but "temporary inhabitants" (Santangelo & Krähmer, 2018).

The area under analysis is, therefore, the two districts surrounding the future Victoria Park, i.e., the Kelvin-Grove and the Herston districts. The other

neighbourhoods are quite separated from the future park, due to the presence of a high traffic road along the east-south.

Victoria Park is one of Brisbane's largest and oldest green spaces. The park is located on the city centre's northern edge, surrounded by residential suburbs, business precincts, and large institutions including universities, hospitals, schools, and churches. The surrounding suburbs are some of the most densely populated and economically diverse areas of Brisbane. The resident population of these localities is projected to increase from approximately 52,500 people in 2019 to 80,500 people by 2041. As part of the Victoria Park Vision, the Council is committed to protecting and enhancing almost 45 hectares of this greenspace for future generations.

7.4 Application of the multi-methodology approach

The model was implemented in Netlogo 6.1.1 (see Appendix A.2), combining the six steps mentioned in the process overview (i.e., initial distribution of fixed and mobile agents, dwelling update, decision to move or stay, threshold/decision rules, new household inflow, and households update). The sections that follow will go over each of these steps, beginning with the initialization stage and ending with the gentrification experiments.

7.4.1 Initialization

The first model codes integrate GIS data into the Netlogo software. Only most important maps - i.e., statistical areas division level 1 (SA1), dwelling location, dwelling typology (single-family house, semi-detached house, apartment), number of units per building – are imported to reduce the computational execution time of the model. The other spatial data are referred to and modelled starting from these four maps (Figure 7.7). Specifically, both house/unit features and household characteristics were constructed mainly based on the 2016 Australian Census Data (ABS, 2016) with a level of detail at SA1. The initialization phase of the model contains 21 SA1 in the Kelvin-Grove and Herston districts (from 1 to 14, from 17 to 19, from 21 to 24). 1981 buildings and 4475 dwellings are spatialized, as well as services and infrastructure in the neighbourhoods. 4063 households are modelled with their specific characteristics. Specifically, Table 7.3 reports the entire lists of variables characterizing dwellings and households in the proposed applied model.



Figure 7.7. Netlogo (white) spatial representation of Kelvin-Grove and Herston districts, their infrastructure, and dwellings

Table 7.3. Detailed description of the variables used for the applied gentrification model

N/D/H*	Variables	Description	u.m.	Data source	Calculation
N	Statistical areas division level 1 (SA1)	Number of SA1 and their spatial location	-	Brisbane City Spatial Plan 2014 (Brisbane City Council, 2014)	-
D	Dwelling location	Number of dwellings and their spatial location	-	Brisbane City Council Datasets (Property address location) (Brisbane City Council, 2016)	-
D	Dwelling typology	Dwellings are classified as single-family houses, semi-detached, apartments	1/2/3	Brisbane City Council Datasets (Property address location, Landuse code) and 2016 Census AUS Bureau of Statistics) (ABS, 2016; Brisbane City Council, 2016, 2019)	-
D	Dwelling unit	Number of units per dwelling	num	Brisbane City Council Datasets (Property address location) (Brisbane City Council, 2016)	-
D	occupation	Occupied or unoccupied dwelling	1/0	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly distributed the occupied and unoccupied dwelling. For example, the 3112601 SA1 has 89% of occupied dwellings and 11% of unoccupied. Each simulation run assigns occupation and inoccupation to different dwellings
D	tenure	Dwelling owned, owned with mortgage, rented	1/2/3	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly distributed the dwelling owned, owned with a mortgage and rented. Example: The 3112601 SA1 has 21% of owned dwellings, 34% owned with a mortgage and 45% rented. Each simulation run assigns tenure type to different dwellings
D	price	Property value	€	CoreLogic database; 2016 Australian Census Data (ABS, 2016)	Property prices were assigned starting from 543 spatialized properties transactions obtained from the Corelogic database. More specifically, the prices are distributed in each SA1 according to a random normal function. Each random normal distribution makes use of the mean, standard deviation, minimum and maximum values obtained from the spatially explicit Corelogic data per each SA1 and it is different for single-family houses, semi-detached houses and apartments. This means that for each SA1, there are 3 different random normal distributions.
D	bedrooms	Number of bedrooms per dwelling (from 1 to 4 or more). Bedroom numbers was	num	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly distributed the number of bedrooms per dwelling. Example: The 3112601 SA1 has

		preferred to sqm, both for data availability reasons and since single-family houses use lot size more than sqm			11% of one-bedroom dwellings, 19% of two-bedrooms, 35% of three-bedrooms and 35% of four or more bedrooms. Each simulation run assigns 1,2,3, 4 or more bedrooms to different dwellings. However, since the number of bedrooms is strongly correlated to the houses' price, the number of bedrooms was associated also considering the price (the lower the price, the lower the number of rooms and vice-versa) based on the specific percentage in each SA1
D	services	The degree of services and connections of the dwelling. This value considers the density of small and big services, number of bus stops, main roads and bike paths.	[0-1]	Brisbane City Spatial Plan 2014 (Brisbane City Council, 2014); OpenStreetMap	Each dwelling was associated with a value ranging from 0 to 1 referring to the concentration of services and infrastructures in its SA1. This value was calculated in GIS and normalized based on the maximum and the minimum number of services revealed in SA1.
D	park proximity	Dwelling inside the 750 meters from the new Victoria Park	1/0	Brisbane City Spatial Plan 2014 (Brisbane City Council, 2014)	Euclidean spatial distances were performed in GIS to identify dwellings inside the 750 m from the new urban park
D	set-mortgage	Weekly mortgage repayment of dwellings	€/week	Home buyers report 2021 (QBE, 2021); Brisbane home loans calculator (https://www.realestate.com.au/home-loans/mortgage-calculator)	From the property prices, it was calculated the mortgage weekly repayment according to a set of AUS specific coefficients, including mortgage deposit percentage over the price (20% from Homebuyers report 2021) and the interest rate (3.42 from Brisbane home loans calculator)
D	set-rent	Weekly rent repayment of dwellings	€/week	realestate.com.au	From the property prices, it was calculated the rent weekly repayment according to a set of AUS specific coefficients, including the proportion of rent over house price and unit price (respectively, 3.48 and 5.22 from realestate.com.au)
H	Household composition	Household composition (family, group or single). If it is a family, it was also considered the type (couple family with or without children, one parent family, other)	1/2/3 and if 1, then 1a/1b/1c/1d	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned the household composition and type of family. For example, the 3112601 SA1 has 65% of families, 18% of single and 17% of group households. Then, it is also know that 43% of households are in a couple without children, 36% in a couple with children, 14% are one-parent family and 7% have another kind of family. Each simulation run assigns composition and type of family in different ways to households.
H	gender	Household gender (female/male)	1/2	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, in each SA1, it was randomly assigned the gender to each household. For example, the 3112601 SA1 has 57% of females, and 43% of males. Each simulation run assigns gender in different ways to households.
H	income	Weekly income	€/week	2016 Australian Census Data (ABS, 2016)	The weekly income of each household was assigned through a random normal distribution: the mean value for the function is contained in the 2016 AUS census data for each SA1. Then, in the same database, there is also the

					percentage of households with a lower income (under 650$) and with a high income (over 3000$) per each SA1. For example, in the 3112601 SA1, the mean household income is equal to 2,392, and there are 14% of people with a low income and 40% with a high income. The distribution of household income must verify these three data. Each simulation run assigns weekly income in different ways to households.
H	aboriginal	Number of aboriginals per each SA1	y/n	2016 Australian Census Data (ABS, 2016)	Based on the data provided by AUS census dataset, per each SA1 it was randomly assigned to a set of households the aboriginal origin. For example, the 3112601 SA1 has 3 aboriginals.
H	age	Range of household age (15-24 years old, 25-34 years old, 35-44 years old, 45-54 years old, 55-64 years old, ≥ 65 years old)	1/2/3/4/5/6	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned the age to each household. Specifically, households are clustered in six different class to identify range of age. For example, the 3112601 SA1 has 23% of people with age between 15-24 years old (class 1), 26% with 25-34 years old (class 2), 18% with 35-44 years old (class 3), 13% with 45-54 years old (class 4), 11% with 55-64 years old (class 5), 9% with ≥ 65 years old (class 6). Each simulation run assigns age in different ways to households.
H	education	Level of education (no education, 12 years, certificate II, certificate IV, diploma, degree)	1/2/3/4/5/6	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned the education level to each household. Specifically, the households are clustered in six different class to identify range of education. For example, the 3112601 SA1 has 0% of people with no education, 31% with 12 years, 7% with certificate II, 1% with certificate IV, 8% with diploma, 53% with degree. Each simulation run assigns education level in different ways to households.
H	religious	Professed religion (no religion, catholic, others)	1/2/3	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned the religion to each household. Specifically, the households are clustered in three different class no religion, catholic and others. In "others" are contained all the other professed religion. For example, the 3112601 SA1 has 47% of people with no religion, 35% catholic, 18% others. Each simulation run assigns education level in different ways to households.
H	parents-origin	Household parents' origin (both parents Australian, both parents born overseas, one parent Australian)	1/2/3	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned the parents' origin. For example, the 3112601 SA1 has 55% of people with both parents Australian, 33% with both parents overseas, 12% with one parent Australian. Each simulation run assigns parents' origin in different ways to households.
H	employment	Sector of employment. For this	0/1	2016 Australian Census Data (ABS, 2016)	Based on the data provided by AUS census dataset, per

		analysis, only two sectors were considered (i.e. healthcare and higher education), since an hospital and university campus are inside the neighborhoods			each SA1 it was randomly assigned the healthcare or high education sectors (1) as an employment to a set of households. For example, the 3112601 SA1 has 14 households that works in the healthcare sector and 0 in the higher education one; all the others have an employment equal to 0.
H	Travel to work	Household transport mode to go to work (car, public transport, walk, work at home, bike, scooter, taxi)	1/2/3/4/5/6/7	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned transport mode to each household. For example, the 3112601 SA1 has 76% of people using private car, 13% public transport, 3% that go by walk, and 0% for all the others transport mode (i.e. work at home, bike, scooter, taxi). Each simulation run assigns transport mode in different ways to households.
H	language	Household language (English only spoken and non-English spoken)	1/2	2016 Australian Census Data (ABS, 2016)	Based on the percentage provided by AUS census data, per each SA1 it was randomly assigned the language to each household. For example, the 3112601 SA1 has 81% of people that spoke English and 19% of non-English spoken. Each simulation run assigns language in different ways to households.

* N = neighborhood; D = dwelling; H = household

The consistency of statistical data resulting from the procedures modelled in Netlogo for the initialization phase was verified through a set of simulation runs. Specifically, the median mortgage and median rent are compared with real data contained in the 2016 Australian Census Data and with the real-estate prices in each SA1 contained in the AUS real-estate website (https://www.realestate.com.au/buy). Then, the household weekly incomes are checked with the original data contained in the 2016 Australian Census datasets, as well as the number of people with low and high weekly incomes in each SA1. The simulation results verified the robustness and reliability of the procedures modelled compared with the real data. As it is possible to see in Figures 7.8, 7.9, 7.10, exemplary simulation runs show how the modelled data follows the same trends as real-world ones for each statistical area.

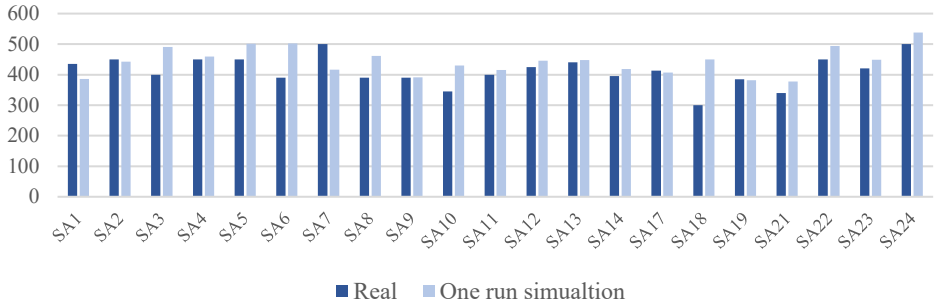


Figure 7.8. Median weekly rent

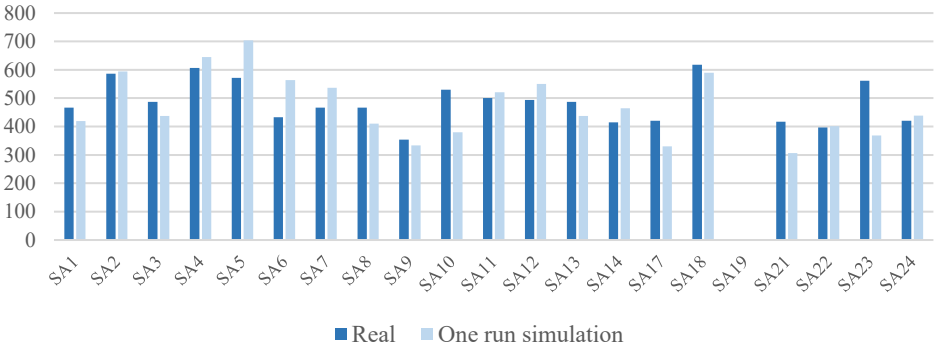


Figure 7.9. Median weekly mortgage

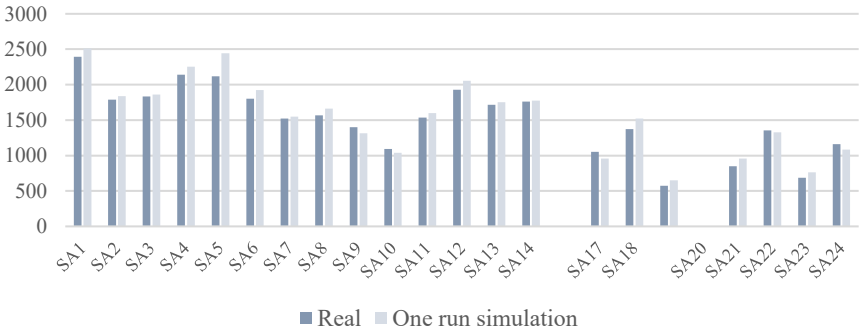


Figure 7.10. Median weekly household income

After the initialization phase, a set of procedures were implemented in order to simulate the dynamical actions of households and the real estate market. These procedures are executed for 20 years (from 2021 to 2041).

7.4.2 Dwelling price variations through spatial HPM

Dwelling prices and rents are modelled to change during the simulation runs in Netlogo. These changes follow the price trends in Brisbane, differentiating between houses (i.e., 3.71) and units (i.e., 0.14) (QBE, 2021).

Also, they eventually happen due to events or projects, as in our case study where a new urban park is realised, i.e., the Victoria Park. Predicting the effects of this transformation on real estate prices is a site-specific and hard task without a proper model. Therefore, a spatial HPM is conducted in the inner-city of Brisbane to understand the contribution of recreational parks to the real-estate market (see Bottero et al. 2022 in press). The spatial HPM conducted in the inner Brisbane is detailed in the following paragraphs: firstly, it was illustrated how green areas are classified before the analysis; secondly, it was shown the data and variables considered in the spatial HPM; thirdly, the results of spatial HPM are described looking at the relationship between housing prices and the proximity of parks; finally, the estimated value uplift due to the Victoria Park transformation is presented. The results of all these steps give an estimated value uplift equal to 3% of the property prices within 750 meters to recreational parks. This percentage is applied as a one-time increase in 2022 to the ABM gentrification model in Netlogo.

According to Brisbane City Council (2014) and, in particular, secondary data sources related to public parks and land for community facilities network, there are seven types of parks in the city of Brisbane, and most of them are subcategorised into other specific types. However, it was out of the scope of this study to consider all park types specified within the Brisbane City Council (2014) documentation on parks. There are two reasons for this limitation in scope. Firstly, the spatial open dataset contained on the Brisbane City Council website[36] only contains information about the location of each park in the city, without any references to these typologies. As a result, this would have required us to manually define the specific subcategories for each green area. Secondly, some subcategories can be considered equivalent to more general ones, and some functions can be contained in many types of parks, in particular, in those more general, such as *Sports Parks* or *Recreational Parks*.

For these reasons, the analysis, instead, considered a previous classification scheme found in the Brisbane Priority Infrastructure Plan of 2011. This document classifies urban parks into two main categories: *Sports Parks* and *Informal Recreation Parks*, which are both subcategorised based on the park size and location in the city. Starting from the open dataset with the park functions and

[36] https://www.data.brisbane.qld.gov.au/data/dataset

assets[37], it has been possible to define the main use of each park by dividing them into informal recreation or sports parks and taking into account whether they are local or district/metro-sized parks.

Then, the sale prices of 15,330 single residential property sold between 2016 and 2019 were identified within the Inner Brisbane study area. Each property has also detailed with the numbers of bedrooms, bathrooms, and garage space house attributes, available from the CoreLogic[38] RP Data set. Moreover, accessibility variables were calculated using GIS by measuring the Euclidean distances to the nearest public park, considering the different typologies of sites. Table 7.4 presents a summary of the variables used in the analysis. It is worth mentioning that, following Wen et al. (2015) and Sohn et al. (2020), in the first version of the model, the full range of variables, including location, neighbouring, environmental, and structural variables, were included. However, as the Inner Brisbane area considered in the present study is a homogeneous area described by similar features from the point of view of the presence of the sporty and educational facilities, commercial areas, and transport routes, the location and neighbouring variables were not significant, being the same for most of the sample. Therefore, by a backward elimination process, the current set of variables, which is composed of structural variables and environmental variables, has been identified. This approach is aligned with other studies in the context of hedonic models, which do not include location or neighbouring variables in the model because these variables do not vary as much within each area as to be included in the evaluation (Anthon et al., 2005; Mulley et al. 2016; Rajapaksa et al., 2016; Rambaldi et al., 2013).

Table 7.4. Variables used in the spatial HPM analysis

Variables		Unit	min	max	Mean	Standard Deviation
Apartment characteristics	Price	[AUS $]	1,099	2,365,0000	840,893,355	740,052,483
	Bedroom	[number]	0	20	2,643	1,370
	Bathroom	[number]	0	16	1,711	0,896
	Car	[number]	0	17	1,462	1,019
Distance	Urban park	[meter]	3,262	5,789,337	282,086	168,731
	Recreational urban park	[meter]	3,262	5,789,337	310,515	186,042
	Sport urban park	[meter]	8,841	6,627,113	636,947	344,772

Based on the residential property sale prices and the variables considered, several models have been tested according to HPM (see Section 3.5.1), including the Ordinary Least Square (OLS) model, the Spatial Error Model (SEM), and the Spatial Autocorrelation Model (SAR). Following the most commonly used approach in the hedonic model literature (Rosen, 1974), this study adopts the natural log of price as the dependent variable in the multiple regression function, as represented in equation 7.2:

[37] https://www.data.brisbane.qld.gov.au/data/dataset/park-facilities-and-assets

[38] https://www.corelogic.com.au/

$$ln(P) = \alpha BED + \beta BATH + \gamma CAR + \delta PARK + \varepsilon \quad (7.2)$$

In this model, *P* is the vector of the transaction price of apartments; *BED, BATH,* and *CAR* are, respectively, the numbers of bedrooms, bathrooms, and car parking spaces; *PARK* is a Boolean variable, which assumes the value 1 if the apartment is located within 750 m of a park and the value 0 otherwise. It has to be noted that, according to the design standards for urban park spaces in the city of Brisbane (Brisbane City Council, 2014), 750 m corresponds to the walking distance to urban parks. Indeed, the desired accessibility standard for parks is up to 750 m walking distance, meaning that all residents should be able to walk 750 m or less to access a park. The variable PARK has been further detailed in the different versions of the model, in order to estimate the role of the different park typologies on housing prices. Specifically, following the Municipal Plan of the City of Brisbane, two typologies of urban parks have been considered, recreational parks and sport parks, which were further specified according to their extension, leading to the analysis of four types of parks: small recreational parks (surface less than 0.5 hectares), large recreational parks (surface greater than 0.5 hectares), small sport parks (surface less than 1 hectare) and large sport parks (surface greater than 1 hectare). The symbols α, β, and γ represent the regression coefficients for the corresponding terms, whereas ε represents the random error. The error is calculated as the difference between the observed and predicted value and represents all of the variations in the dependent variable not explained by the considered independent variables.

In the development of the estimation, the OLS model was tested first, and the results are reported in Table 7.5. As it is possible to see, most of the housing characteristic variables significantly affect housing prices.

Table 7.5. Results of the OLS model considering the different typologies of urban parks in Brisbane

REGRESSION RESULTS – LINEAR MODEL (OLS) – OBSERVATIONS NUMBERS = 15,334						
	All parks	Recreational/ Sport Parks	Local Recreational / District Recreational Parks	Local Sport / District Sport Parks	Recreational Parks and Local / District Sport Parks	Sport Parks and Local / District Recreational Parks
Variables	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE
Constant	12.650***	12.628***	12.686***	12.733***	12.692***	12.694***
	(0.034)	(0.030)	(0.020)	(0.012)	(0.020)	(0.020)
Bed	0.211***	0.211***	0.2106***	0.210***	0.210***	0.211***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Bath	0.026***	0.025***	0.0266***	0.026***	0.026***	0.026***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Car	0.076***	0.076***	0.0766***	0.076***	0.076***	0.076***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Urban parks	0.068**					
	(0.033)					
Recreational parks		0.105***				
		(0.029)				
Sport parks		-0.021**				-0.018*
		(0.010)				(0.014)
Recreation parks						-0.0002
						(0.014)

< 0.5 ha			-0.003			0.040***
			(0.014)			(0.009)
> 0.5 ha			0.037***		0.0026	
			(0.014)		(0.014)	
Sport parks					0.045***	
					(0.014)	
< 1.0 ha				-0.045***	-0.049***	
				(0.013)	(0.013)	
> 1.0 ha				-0.013	-0.015	
				(0.010)	(0.010)	
S.E. of regression	0.535	0.535	0.535	0.535	0.535	0.535
R Squared	0.308	0.309	0.308	0.309	0.309	0.308
Adjusted R-squared	0.308	0.308	0.308	0.309	0.309	0.308

**** indicates probability p < 0.01; ** indicates probability p < 0.05; * indicates probability p < 0.1;*

In addition to the OLS model, two types of spatial regression models were developed to control spatial autocorrelation: the spatial autoregressive (SAR) model and the spatial error model (SEM). In particular, the software GeoDa was employed (Anselin et al., 2006). GeoDa addresses the problem of spatial dependence through distance weight matrices, calculating contiguity weights. In the present application, the Queen's contiguity method was used to create the weight matrix W assuming that all adjacent houses affect the value of a given house (Sohn et al., 2020). The Queen criterion determines neighbouring units as those that have any point in common, including both common boundaries and common corners. Accordingly, the weight of the surrounding houses assumed the value of 1 if they shared a border or vertex with a given house, and 0 if not.

After the contiguity weight matrix calculation, the Moran's Index (MI) was computed to measure the spatial autocorrelation effect. In detail, the MI was calculated by relating the natural logarithm of the total price (ln Price) of each transaction to the average value of the neighbouring ones (lagged ln Price) (Figure 7.11). The results confirmed that the autocorrelation phenomenon occurred in the area under investigation as the MI which shows a discrete level of spatial autocorrelation.

The four quadrants in the graph provide a classification of four types of spatial autocorrelation: high-high, low-low, high-low, and low-high. Spatial autocorrelation analysis can also be visualised in a specific cluster map where the high-high, low-low, high-low, and low-high clusters are shown (Figure 7.12). This map is based on the so-called LISA (Local Indicators of Spatial Association) that allows to delineate hot spots and cold spots in the real estate market that represent specific submarkets of housing prices. The LISA map, in particular, shows a significant spatial clustering of high and low prices in Brisbane; additionally, the map clearly shows segmented housing markets between inner city and outer city areas. The map shows that most of the high price clusters are concentrated in the area of East Brisbane, with New Farm being the most expensive suburb in the city.

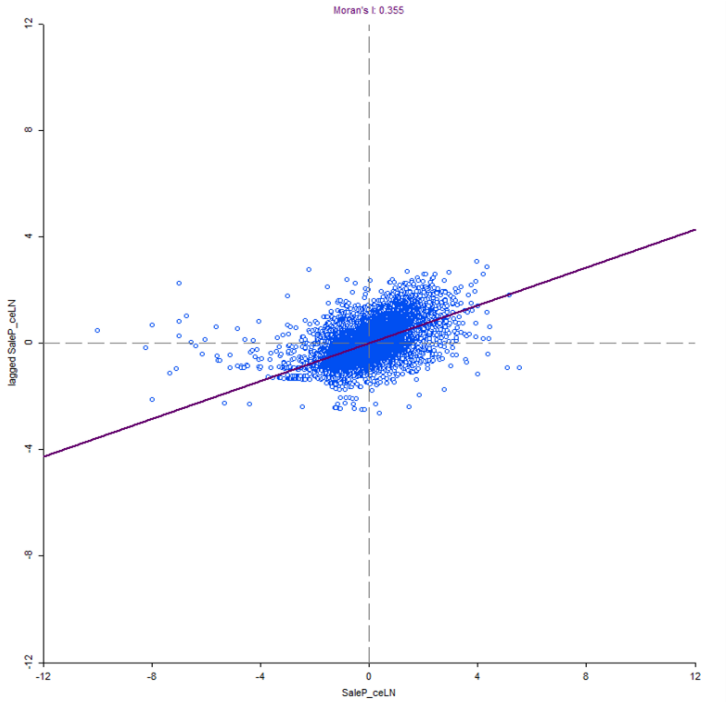


Figure 7.11. Moran Index

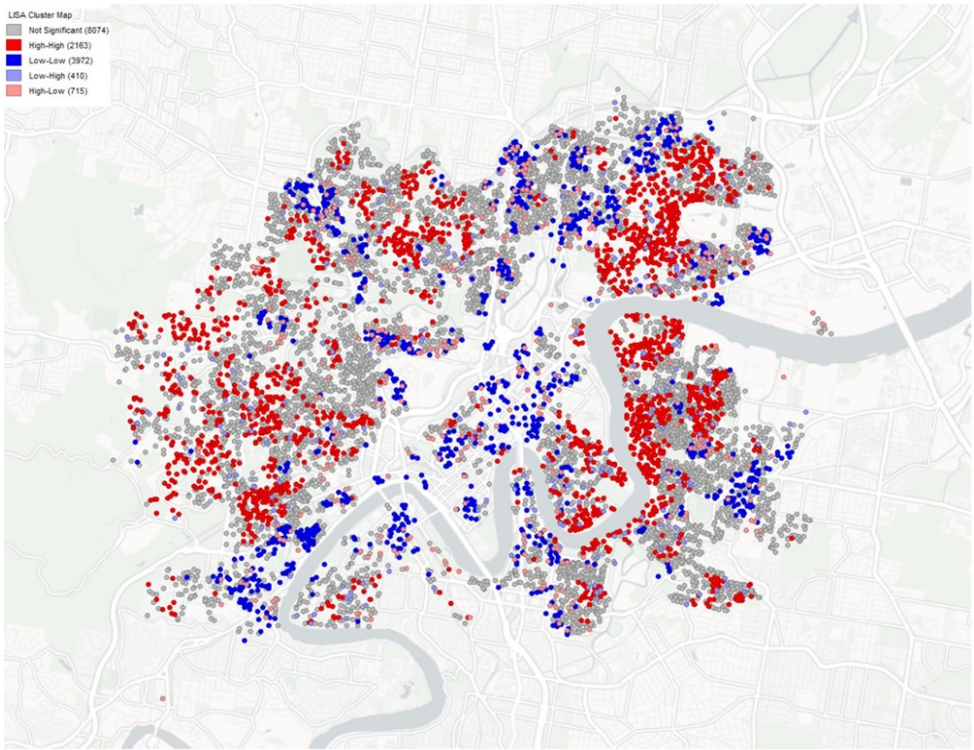


Figure 7.12. Cluster map of hot spots and cold spots in Brisbane real estate market

Subsequently, the SAR and SEM models have been developed, and the results of the estimations are reported in Tables 7.6 and 7.7, respectively. Following Anselin et al. (2008), specific tests have been developed to determine the choice of

models, including Log-Likelihood value, Akaike criterion (AIC) and Schwarz criterion (SC). According to the literature, the best performing spatial model has the Log-Likelihood value closer to zero, and the lowest values of AIC and SC. Moreover, the Lagrange Multiplier (LM) statistical index was also calculated in order to further verify the results of the model.

Table 7.6. Results of the SAR model considering the different typologies of urban parks in Brisbane

REGRESSION RESULTS – SPATIAL LAG MODEL (SAR)– OBSERVATIONS NUMBERS = 15,334						
	All parks	Recreational/ Sport Parks	Local Recreational / District Recreational Parks	Local Sport / District Sport Parks	Recreational Parks and Local / District Sport Parks	Sport Parks and Local / District Recreational Parks
Variables	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE
W_Sale Price	0.508***	0.508***	0.509***	0.507***	0.508***	0.509***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	0.010
Constant	6.025***	6.009***	5.994***	6.085***	6.012***	6.001***
	(0.131)	(0.130)	(0.130)	(0.127)	(0.130)	(0.130)
Bed	0.140***	0.141***	0.14***	0.140***	0.141***	0.141***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Bath	0.048***	0.047***	0.048***	0.048***	0.048***	0.048***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Car	0.063***	0.063***	0.063***	0.063***	0.063***	0.063***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Urban parks	0.043					
	(0.030)					
Recreational parks		0.077***				
		(0.027)				
Sport parks		-0.020**				0.034***
		(0.009)				(0.013)
Recreation parks						0.033***
						(0.012)
< 0.5 ha			0.031**			-0.020**
			(0.013)			(0.009)
> 0.5 ha			0.031**		0.034***	
			(0.012)		(0.013)	
Sport parks					0.035*	
					(0.012)	
< 1.0 ha				-0.013	-0.018	
				(0.012)	(0.012)	
> 1.0 ha				-0.013	-0.017*	
				(0.009)	(0.009)	
LN_PRICE (mean)	13.429	13.429	13.429	13.429	13.429	13.429
R Squared	0.432	0.432	0.432	0.432	0.433	0.433
Akaike criterion	21783.2	21775.5	21773.6	21782.6	21770.1	21770.1
Schwarz criterion	21829	21828.9	21827.1	21836.1	21838.8	21831.2
Log Likelihood	-10885.6	-10880.7	-10879.8	-10884.3	-10876	-10877
S.E. of regression	0.485	0.484	0.484	0.485	0.484	0.484
Lag coefficient (Rho)	0.508	0.508	0.510	0.507	0.508	0.509
LM (lag)	4033.884***	4034.743***	4057.174***	4014.007***	4008.491***	4062.729***
Robust LM (lag)	525.397***	539.921***	532.241***	516.867***	536.948***	537.183***

**** indicates probability p < 0.01; ** indicates probability p < 0.05; * indicates probability p < 0.1*

Table 7.7. Results of the SEM model considering the different typologies of urban parks in Brisbane

REGRESSION RESULTS – SPATIAL ERROR MODEL (SEM) – OBSERVATIONS NUMBERS = 15,334						
	All parks	Recreational/ Sport Parks	Local Recreational / District Recreational Parks	Local Sport / District Sport Parks	Recreational Parks and Local / District Sport Parks	Sport Parks and Local / District Recreational Parks
Variables	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE	Coefficient (β) with SE
Constant	12.886*** (0.057)	12.839*** (0.034)	12.815*** (0.024)	12.854*** (0.015)	12.817*** (0.025)	12.825*** (0.025)
Bed	0.168*** (0.005)	0.168*** (0.005)	0.168*** (0.005)	0.168*** (0.005)	0.168*** (0.005)	0.168*** (0.005)
Bath	0.027*** (0.007)	0.027*** (0.007)	0.027*** (0.007)	0.027*** (0.007)	0.027*** (0.007)	0.027*** (0.007)
Car	0.066*** (0.0047)	0.066*** (0.005)	0.066*** (0.005)	0.066*** (0.005)	0.066*** (0.005)	0.066*** (0.005)
Urban parks	-0.039 (0.057)					
Recreational parks	-	0.020 (0.032)				
Sport parks	-	-0.016 (0.011)				0.016 (0.017)
Recreation parks						0.022 (0.015)
< 0.5 ha	-		0.016 (0.017)			-0.016 (0.011)
> 0.5 ha	-		0.021 (0.015)		0.018 (0.017)	
Sport parks					0.025 (0.015)	
< 1.0 ha	-			-0.031** (0.015)	-0.034** (0.015)	
> 1.0 ha	-			-0.003 (0.011)	-0.004 (0.011)	
LAMBDA	0.594*** (0.011)	0.593*** (0.011)	0.594*** (0.011)	0.593*** (0.011)	0.593*** (0.011)	0.594*** (0.011)
LN_PRICE (mean)	13.429	13.429	13.429	13.429	13.429	13.429
R Squared	0.434	0.434	0.435	0.434	0.435	0.435
Akaike criterion	21922.7	21923	21922.1	21920.6	21920.6	21922
Schwarz criterion	21960.8	21968.8	21967.9	21966.5	21981.7	21975.5
Log Likelihood	-10956.330	-10955.477	-10955.058	-10954.315	-10952.321	-10954.021
S.E. of regression	0.483	0.483	0.483	0.483	0.483	0.483
Lag coefficient (Lambda)	0.594	0.593	0.594	0.593	0.593	0.594
LM (error)	3937.743***	3907.118***	3942.073***	3930.653***	3880.150***	3937.442***
Robust LM (error)	429.257 ***	412.295***	417.141***	433.514***	408.607***	411.896***

*** indicates probability p < 0.01; ** indicates probability p < 0.05; * indicates probability p < 0.1;

The results indicate that all the variables related to the intrinsic characteristics of properties have a significant relationship with the price. As expected, these characteristics are positively correlated to the price, meaning that the higher the number of bathrooms, bedrooms, or car parking, the higher the price. As far as urban parks are considered, the results of the model show that their role is slightly different across the considered categories. For urban parks in general, the results show that the presence of a park contributes to a value uplift of around 4-6% in

property value (second column of Tables 7.5, 7.6, and 7.7). An in-depth analysis, taking into account the characteristics of the urban park, revealed that recreational parks are positively associated with housing prices, whereas sports parks are negatively associated (third column of Tables 7.5, 7.6, and 7.7). In particular, the proximity to recreational parks correlates with a predicted increase of 7% in housing prices, whereas, by comparison, the presence of a sports park translates into a 1% decrease. This opposite effect could be related to the real or perceived negative impact that sports parks can have on the surrounding neighbourhoods in relation to noise, traffic, and other negative impacts that might be present. Unexpectedly, when considering the dimensions of urban parks, the findings of the model did not show any divergence between large and small parks. Both showed an expected increase of 3% in housing prices (fourth column of Tables 7.5, 7.6, and 7.7). By comparison, for sports parks, the differences in the dimensions were not appreciated by the market and their effects turned out to be not significant according to the performed analysis.

The results described above allowed to understand how the presence of urban parks affects the housing prices in the city of Brisbane. Findings indicate that quantifying the impact of new urban parks on residential property prices in terms of creation of externalities can lead to useful insights.

For the purpose of the evaluation, Figure 7.13 shows the Victoria Park Golf Course and the distribution of apartment sales data used in the analysis within the considered area. Based on the results of HPM developed for the entire inner Brisbane, it was possible to estimate that the transformation of the golf course into a recreational green park would lead to a 3% average increase in housing prices for assets located within a 750m radius of the park. If these findings were applied to the new Victoria Park development, the predicted average value uplift for the area would be estimated at around 63 million AUS$ (Table 7.8).

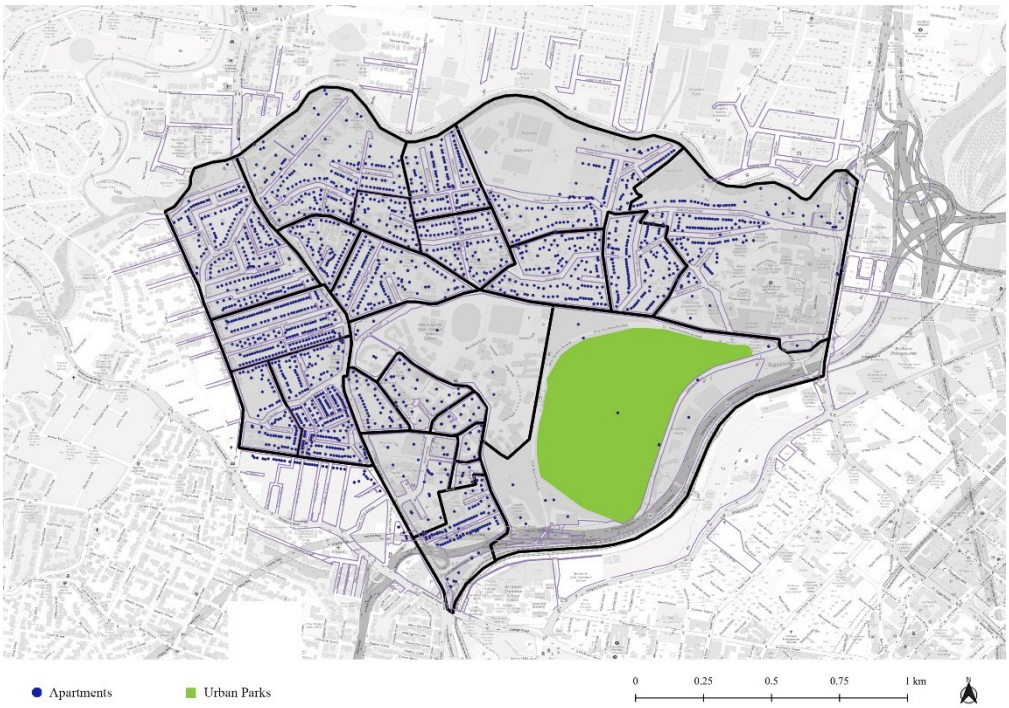


Figure 7.13. The Victoria Golf Course Park and the distribution of the apartment sales data used in the analysis in the considered area

Table 7.8. Synthetic data and results for the Kelvin-Grove and Herston districts

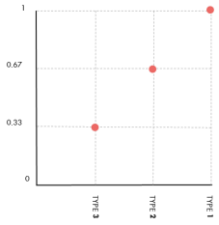
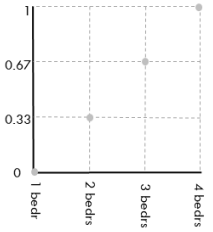
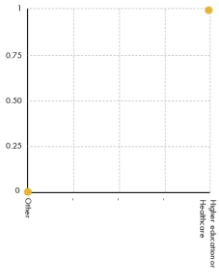
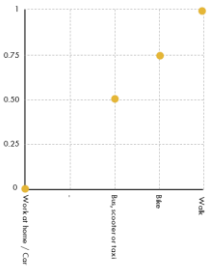
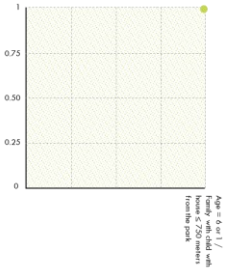
Variables	Measure	Unit	Value
Average housing price	in the 750m radius area	[AUS $]	614,187
Dwellings	in the 750 m radius area	[number]	3,430
Uplift	in the housing price due to the new park	[percentage]	3
Total uplift in the 750 m area		[AUS $]	**63,199,842.3**

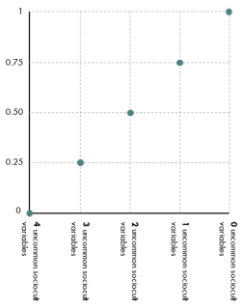
7.4.3 Household decision-making process through MCDA

The model executes the decision-making process of households over time (see Section 7.2.2). For this specific case study, a group of local experts (i.e., QUT professors and staff) was asked to support the definition of household preferences and perform the AHP weighting phase. On the one hand, household preferences were defined through specific calculation procedures for each variable in the likelihood equation, then standardized to make variables comparable. Specifically, the focus group among experts resulted in the calculation procedures and standardization contained in Table 7.9.

Table 7.9. Calculation and standardization of the sub-criteria

Sub-criteria	Variables considered	Calculation	Standardization
Price suitability (Ps)	Weekly price (D) (mortgage and rent)	Tenure 1: Ps = 1 Tenure 2: Ps = (1 - (mortgage / income-weekly))	-

	Tenure (D) Weekly income (H)	Tenure 3: Ps = (1 - (rent / income-weekly))	
Type preference (Tp)	Dwelling type (D)	single-family house (type = 1) is better than semi-detached house (type = 2), which are better than apartment (type = 3): IF type 1, then Tp = 1 IF type 2, then Tp = 0.67 IF type 3, then Tp = 0.33	
Size preference (Sp)	Bedroom (D) Household composition (H)	<u>For single households:</u> IF n-bedrs = 1 or 2, then Sp = random 0.67 or 1.00 IF n-bedrs = 3 or 4, then Sp = 0 <u>For group households / For family households – couple with child / For family households - other:</u> IF n-bedrs = 1, then Sp = 0 IF n-bedrs = 2, then Sp = random between 0.33 IF n-bedrs = 2, then Sp = random between 0.67 IF n-bedrs = 2, then Sp = random between 1.00 <u>For family households – couple without child:</u> IF n-bedrs = 1 or 2 or 3, then Sp = random 0.33, 0.67 or 1.00 IF n-bedrs = 4, then Sp = 0	Example: couple with child 
Work preference (Wp)	Employment (H) Travel to work (H)	IF employment = higher education or healthcare, then Wp = 1 IF employment = other, then: IF travel to work by WALK, then Wp = 1 IF travel to work by BIKE, then Wp = 0.75 IF travel to work by BUS or SCOOTER or TAXI, then Wp = 0.50 IF travel to work by CAR, then Wp = 0 IF work at home, then Wp = 0	 
Amenity preference (Ap)	Park proximity (D) Age (H) Household composition (H)	For households with AGE = 6 (≥ 65 years) or AGE = 1 (15-24 years): IF dwelling distance ≤ 750 meters from the park, then Ap = 1 OTHERWISE dwelling distance > 750 meters from the park, then Ap = random value between 0 and 1 For family households – with child and a house that is a maximum of 750 meters from the park: IF house distance ≤ 750 meters from the	

		park, then Ap = 1 OTHERWISE house distance > 750 meters from the park, then Ap = random value between 0 and 1 For group households / For family households - other / For family households – without child, with AGE = 2, 3, 4 or 5: Ap = random value between 0 and 1 For SINGLE households with AGE = 2, 3, 4 or 5: Ap = random value between 0 and 1	
Economic status (Ecs)	Weekly income (H)	For each SA1 area: Calculation of min income of households Calculation of max income of households Calculation of mean income of households Each household standardized his/her weekly income with the mean, max and mix income in his/her SA1:	-
Sociocultural status (Scs)	Language (H) Parents origin (H) Religion (H) Education (H) Gender (H) + Household composition (H) Aboriginal	Scs is a combined measure based on a set of own attributes of the households (education, religion, parents' origin, and language) and fragility conditions. Specifically, Scs is the combination of Socio-cultural (Sc) and Fragility (Fp). Socio-cultural (Sc) measures if there are minority or not in each SA1 in terms of education, religion, parents' origin and/or language. For example: if REL = 3 (often least frequent in the neighbourhoods) is higher than 33% of the total of residents in the SA1, the religious is no more uncommon IF all 4 variables are uncommon, then Sc = 0 IF 3 variables are uncommon, then Sc = 0.25 IF 2 variables are uncommon, then Sc = 0.50 IF 1 variable is uncommon, then Sc = 0.75 IF 0 sociocultural variables are uncommon, then Sc = 1.00 <u>Fragile people (Fp):</u> IF household is a single female with child, then Fp = 0.50 IF household is an aboriginal, then Fp = 0.50 IF household is a single female with child and aboriginal, then Fp = 1.00 Then, Sc and Fp are combined and normalized	
Accessibility	Services (D)	Standardization of the value of each	-

preference (Accp)	service / infrastructure in the dwelling's SA1 (small services, big services, road distance, bicycle path distance, bus stops distance) based on the minimum and maximum values in the neighbourhoods. Example: accessibility-road = ((min_dist_road_KG&H - distance_road_SA1) / (min_dist_road_KG&H - max_dist_road_KG&H)

* D = dwelling; H = household

On the other hand, the weighting method adopted in the AHP is based on a pairwise comparison of each couple of elements at one level of the hierarchy with respect to each element placed at the higher level. For more details, see Chapter 3, Section 3.4.1. The experts assigned the weights for the criteria and the sub-criteria levels. The complete questionnaire can be consulted in Appendix B.1. The results are reported disaggregated in Figure 7.14, disaggregated, and aggregated in Figure 7.15. The only aggregated results are reported in Table 7.10.

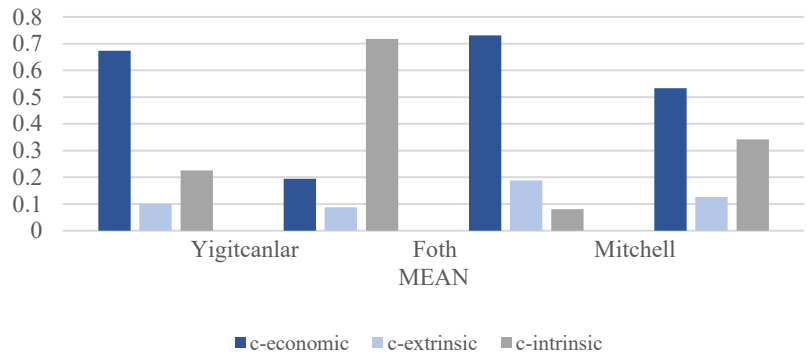


Figure 7.14. Criteria weights

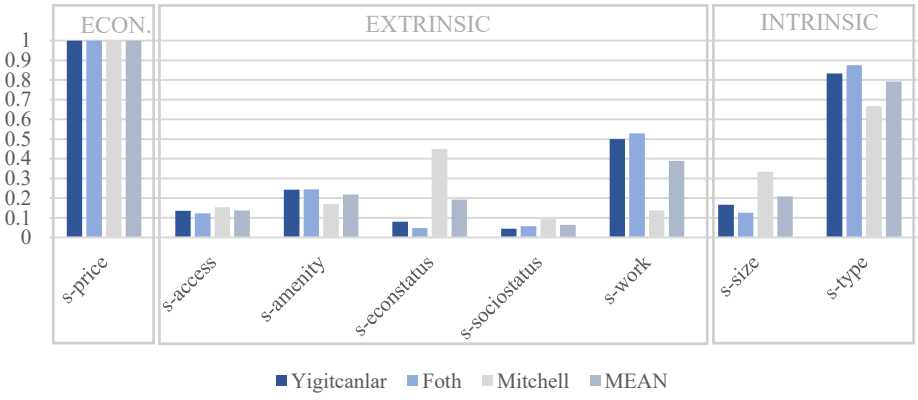


Figure 7.15. Sub-criteria weights

Table 7.10. Weights assigned by the local experts

Criteria	Criteria Weights	Sub-criteria	Sub-criteria weights
Economic aspects (EA)	0.533	Price suitability (Ps)	1.000
Intrinsic characteristics (IC)	0.341	Type preference (Tp)	0.792
		Size preference (Sp)	0.208
		Work preference (Wp)	0.388
		Amenity preference (Ap)	0.219
Extrinsic quality (EQ)	0.126	Economic status (Ecs)	0.192
		Sociocultural status (Scs)	0.064
		Accessibility preference (Accp)	0.137

7.4.4 Stress level, behavioural threshold, and decision rules

Step 4 of the proposed simulation process considers five different rules for modelling who and how many people each year decide to stay or leave their properties after the individual decision-making process calculation. It is important to notice that the number of rules and the percentage of people that leave the neighbourhoods each year are defined based on the specific real-estate market under investigation and the population considered.

(1) In the first rule, 25% of the households with a level of stress higher than 50% go away each year, without considering if they like or dislike the house where they live (i.e., without calculating the housing mobility likelihood). (2)-(3) The second and third rules refer to people with a level of stress higher than 30% but lower than 50%. (2) However, the second rule states that 25% of the households leave their properties since they have a housing mobility likelihood lower than the defined threshold, (3) whereas the third rule forces 10% of households to leave their property, even if the housing mobility likelihood is higher than the defined threshold. This lower percentage is due to the fact that some people prefer higher expenses in exchange for a home that matches their expectations. (4) In the fourth rule, 10% of the households with no stress but low housing mobility likelihood go away. If the number of people in the neighbourhood belonging to each category (from rule 1 to rule 4) is less than 10, all of them go away. (5) In the fifth rule, nobody goes away since they have no stress and a high housing mobility likelihood. However, homeowners can decide to sell or rent their property as an investment if a high number of students or visitors starts to arrive in the districts. In this case, they leave the neighbourhood in a quantity that depends on the increasing number of students or visitors recorded the previous year.

7.4.5 Gentrification experiments

The gentrification experiments are designed in order to test the resilience of the neighbourhood to gentrification phenomena eventually occurring due to the in-flow of a low, moderate, or high number of high-income households, students, visitors, or diverse ethnic groups.

The model assumes that the number of occupied and unoccupied houses and units remains stable in all simulations, meaning that for every household that leaves the neighbourhood, a new household comes in. Another assumption of the model is related to the property state. The new household coming into the neighbourhood acquires the same property state as the previous household. In other words, the dwelling maintains the same type of property for all simulation runs and for all the years of simulation. This agent variable is also stored by the house/unit that will host a new household with the same property status as the previous one. In other words, if the past household was a renter, the new household will also be a renter, whereas if the past household was a homeowner, the new household will be a buyer. The only exception happens when a homeowner belonging to the rule 5 category (see Section 7.4.3) decides to rent his/her property to make a profit.

Once the households leave the neighbourhood, new households arrive in the districts. Two different procedures for households' state variables are proposed and compared. In the first procedure, the household state variables (such as family composition, age, and income) are assigned randomly (random procedure). In the second procedure, households assume the dominant characteristics of the statistical area where they go to live (the dominant procedure). As an example, if in the statistical area most of the people are young, there is a high probability that the new household will also be young.

Within these two procedures, it is also possible to stress gentrification through the in-flow of a certain percentage of potential gentrifies each year. The following gentrification scenarios are compared with the ones without gentrifiers (i.e., the random procedure and dominant procedure): high-income gentrifiers, dominant socio-ethnic status gentrifiers, students, visitors, high-income and dominant socio-ethnic status gentrifiers, a mix of gentrifiers.

7.5 Results

The model was run under each gentrification experiment for 20 simulation time steps, corresponding to the years from 2021 to 2041. The model contains a lot of information that needs to be investigated in order to understand gentrification dynamics. The number of households that each year decide to leave the neighbourhoods was first tested. It was investigated using both random and dominant procedures, as well as various threshold values (0.5, 0.6, and 0.7). The 0.7 threshold was excluded after the first simulations since they show unreasonable

(too high) mobility trends and are useless for studying gentrification in the neighbourhoods under analysis. Simulations with 0.6 and 0.5 thresholds and with random and dominant procedures (Figures 7.16 and 7.17) have similar values in the number of people who go away each year. This could suggest that the transformation of the park does not affect the creation of the gentrification phenomenon. However, the number of people leaving their neighbourhoods is lower in dominant procedures. This result makes sense since minorities decrease over time and people who have arrived are satisfied with their neighbours and their similar characteristics. Looking at socio-cultural diversity trends over the years, the average socio-cultural diversity level increase (passing from 0.1185 in 2021 to 0.1566 in 2041) in the random procedure and no gentrification experiment. This indicates that economic reasons essentially affect the individual mobility choice. Conversely, the socio-cultural diversity slightly decreases in the dominant procedure with no gentrification experiment. People who do not speak English pass from an average of 68 to 65; people who have both parents abroad pass from an average of 104 to 100; people who practice a minor religion pass from an average of 40 to 38; and low-education households pass from an average of 86 to 85.

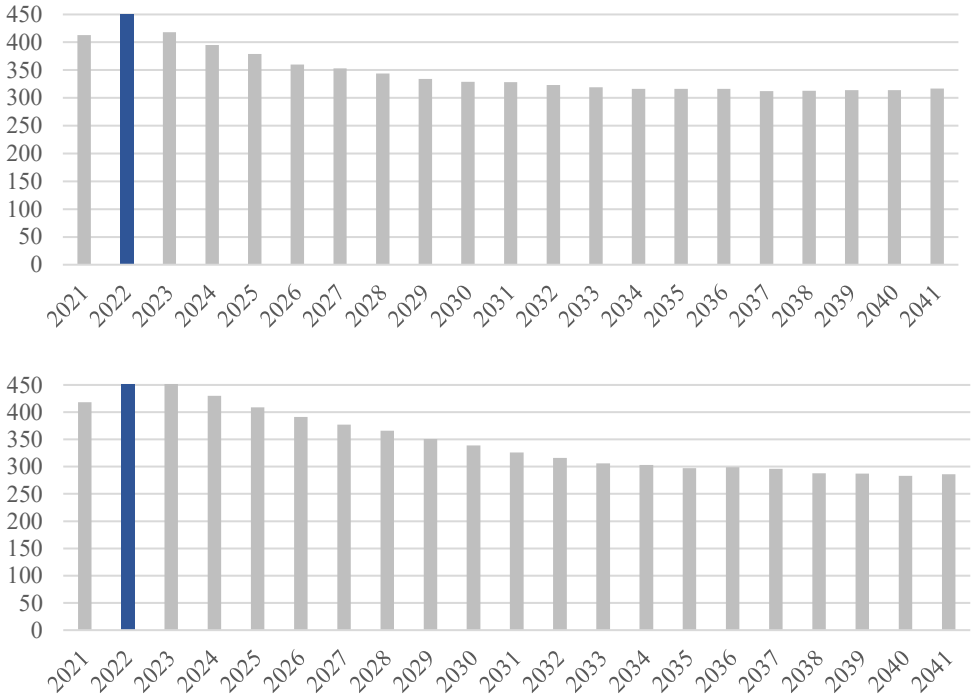


Figure 7.16. Simulations with 0.5 threshold, random (up) and dominant (down) procedures, and no gentrification experiment

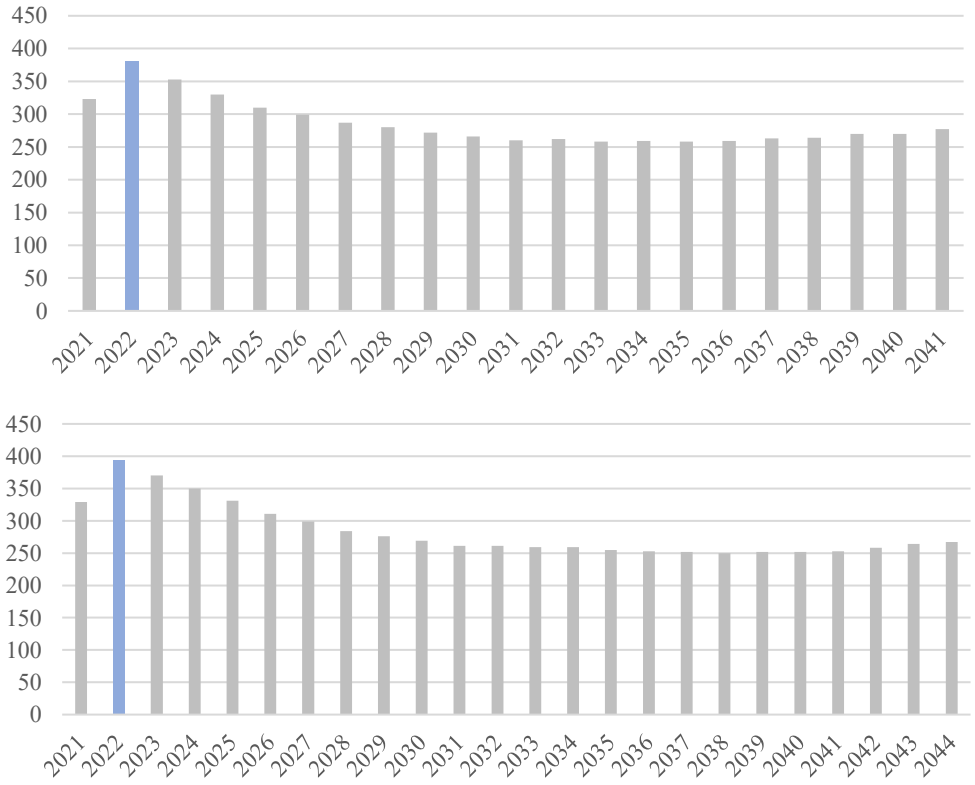


Figure 7.17. Simulations with 0.6 threshold, random (up) and dominant (down) procedures, and no gentrification experiment

Figure 7.18 shows another interesting phenomenon. Simulating the inflow of 25% of new residents with high income both with random and dominant procedures and a 0.6 threshold, it is possible to notice that after a certain point, the number of households that go away decreases significantly, showing a tendency to stay. This tendency could suggest the creation of an "*elite* neighbourhood", where new households push out minorities and create an environment characterized by people with similar economic and socio-cultural characteristics.

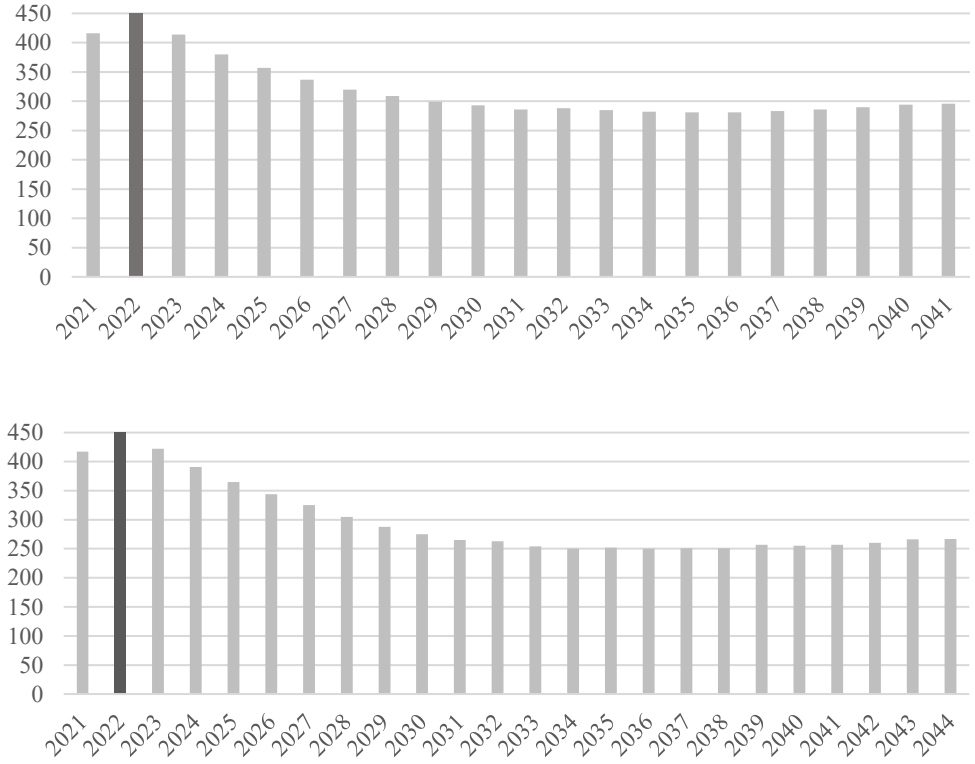


Figure 7.18. Simulations with 0.6 threshold, random (up) and dominant procedures (down), and 25% of new residents with socio-cultural dominant characteristics

The socio-cultural trends justify these hypotheses: the average socio-cultural diversity slightly decreases, passing from 0.116 in 2021 to 0.114 in 2041. However, the income differences are more disruptive, as it is possible to see in Figure 7.19. The comparison of average income values between 2021 and 2041 (Figure 7.19) clearly shows that, especially for low-income SA1, the average income increases significantly. This happens not only with gentrification experiments but simply with the dominant procedure. This indicates that the presence of the park itself affects the creation of gentrification in the neighbourhoods. It is therefore obvious that significant price increases happen for the dominant procedure with or without gentrifiers.

For the 0.5 threshold and 25% of high-income households (Figure 7.20), the decrease is lower than for the 0.6 threshold. This can be explained by the higher acceptability (i.e., lower threshold) and preferences of residents concerning the property and neighbourhood where they live.

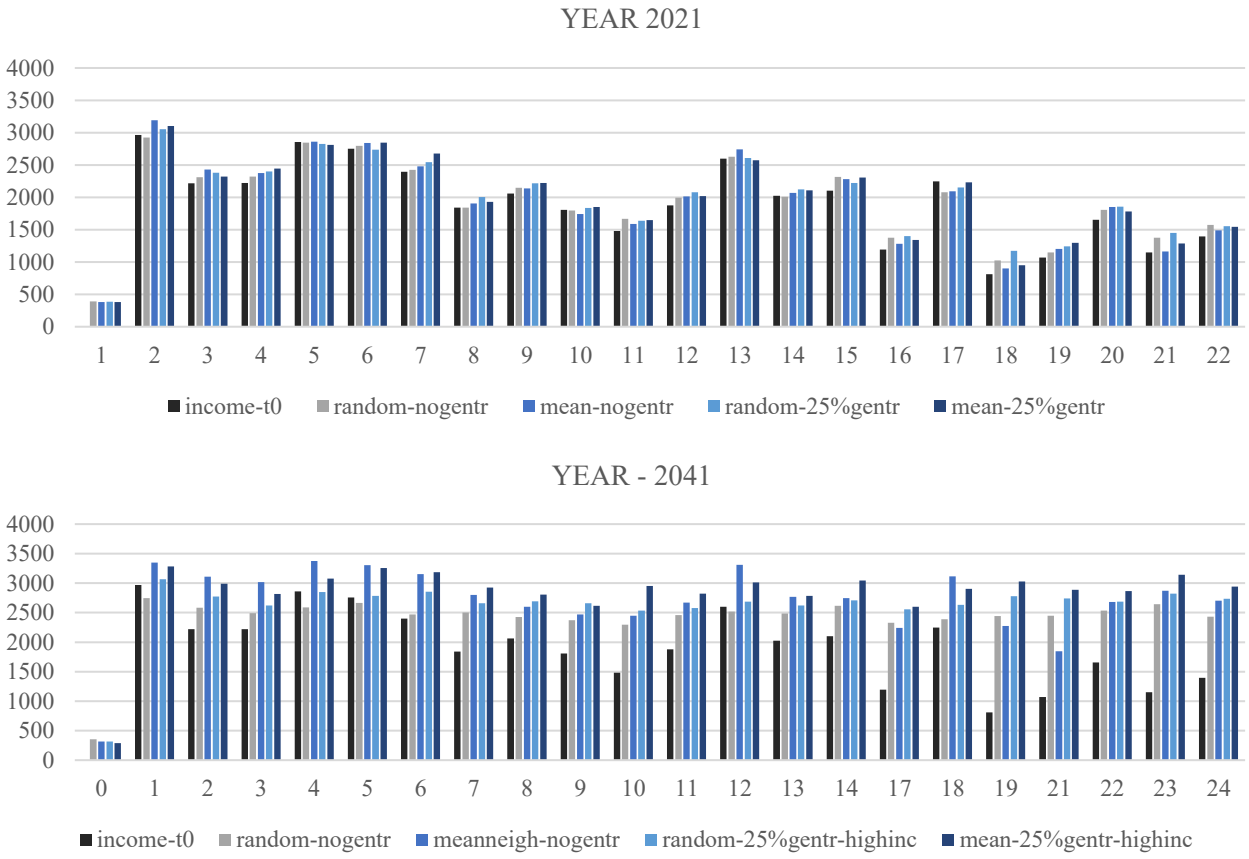


Figure 7.19. Comparison of initial average weekly-incomes (2021) and the ones in 2041 for each SA1 and different gentrification experiments

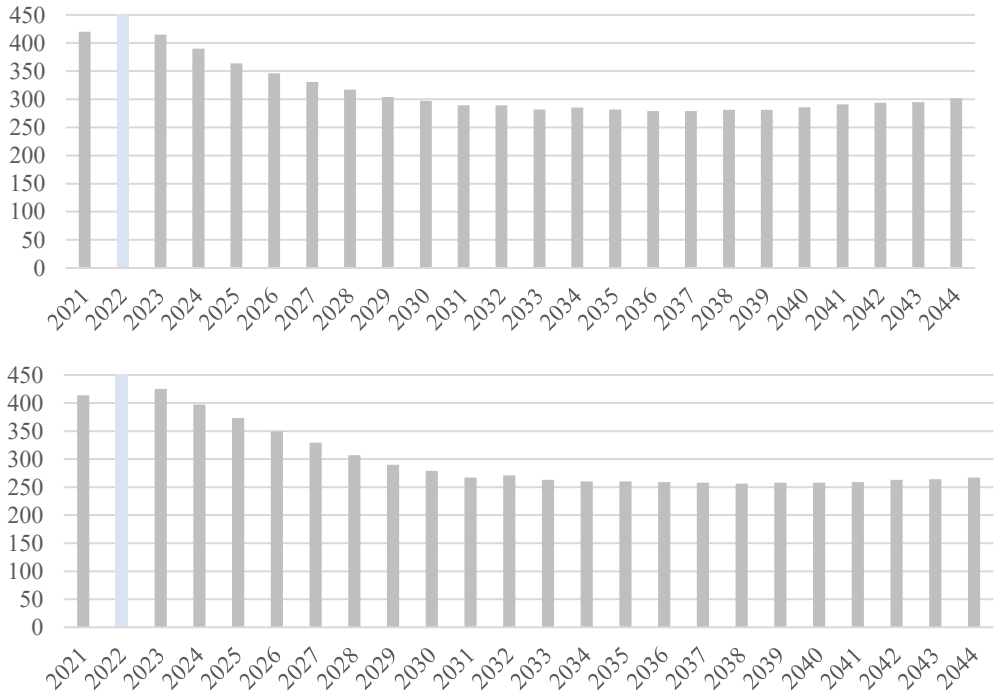


Figure 7.20. Simulations with 0.5 threshold, random (up) and dominant (down) procedures, and 25% of new residents with high income

Then, comparing the different gentrification experiments with the 0.6 threshold, the effect of the "*elite* neighbourhood" continues to be accentuated precisely in the mean neighbourhood scenarios. This is strongly visible in the dominant socio-ethnic status experiment (Figure 7.21), suggesting a high likelihood of diversity loss in the neighbourhoods. In this gentrification experiment, a significant decrease in all the socio-cultural components is detectable, as it is possible to see in Table 7.11. People with low education levels are the most affected. Therefore, without adequate control and preventive policy measures, the neighbourhoods are seriously at risk after the transformation of Victoria Park and due to the general price increase and demand for properties in the inner area.

Table 7.11. Average socio-cultural diversity trends for dominant socio-ethnical status experiments and 0.6 threshold

	2021	**2031**	**2041**
No-English speakers	66.048	50.952	44.714
Both parents born overseas	103.381	101.429	101.476
Religion minority	38.333	28.286	24.762
Low education level	82.190	65.571	57.429

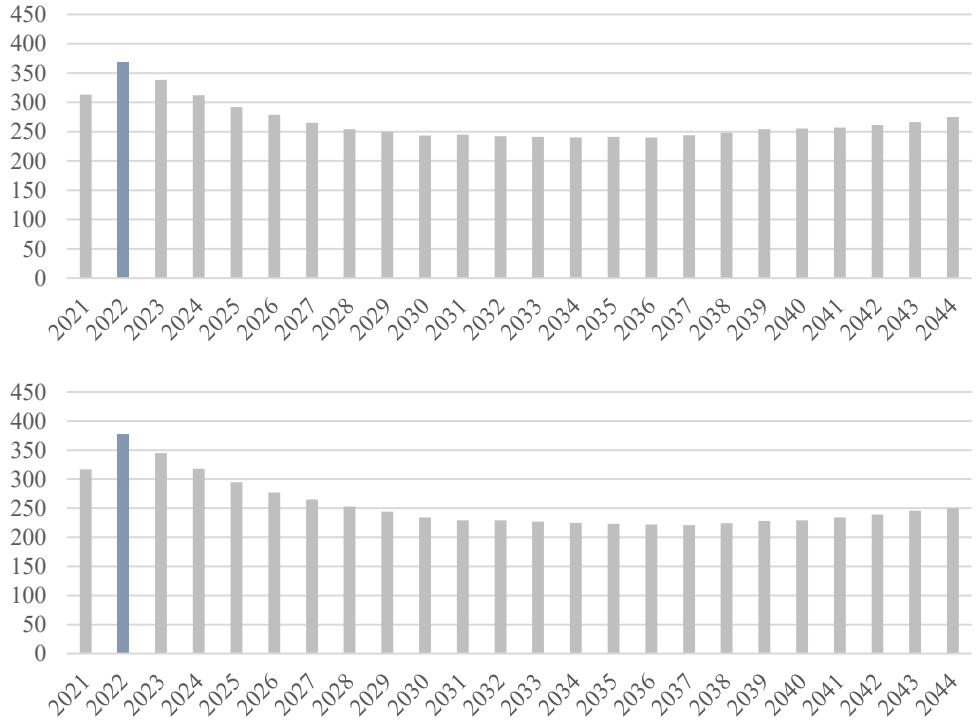


Figure 7.21. Simulations with 0.6 threshold, random (up) and dominant procedures (down), and 25% of new residents with socio-cultural dominant characteristics

Conversely, a significant increase in students does not seem to have a disruptive effect (Figure 7.22). This can be explained by the long presence and coexistence of these temporary residents.

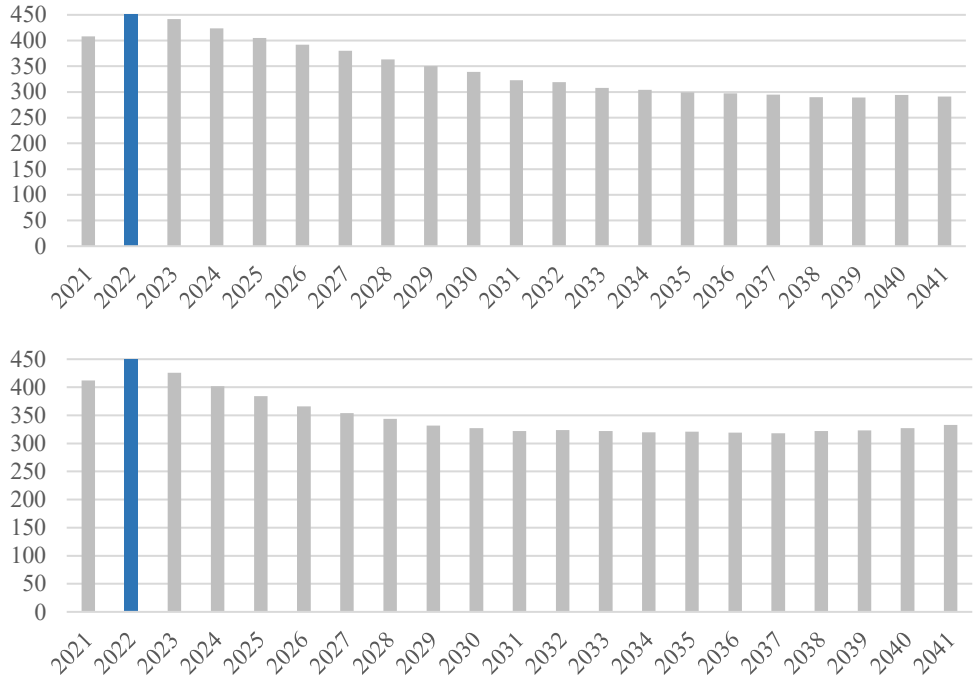


Figure 7.22. Simulations with 0.6 threshold, random (up) and dominant (down) procedures, and 25% of student gentrifiers

The mix of gentrifiers experiment (Figure 7.23) shows more rapidly the stabilization of the inflow household trend. On one hand, this can mean that the mix of gentrifiers does not provoke a consistent abandonment of the current inhabitants, maintaining the diversity of the neighbourhood. On the other hand, it can reveal a more rapid creation of an "*elite* neighbourhood" for all the gentrification components (i.e., income, socio-cultural, ethnic, educational diversity, etc.). Looking at socio-cultural trends, it is possible to state that the second hypothesis is true. All socio-cultural and ethnic diversities decrease with 0.5 and 0.6 thresholds. For example, with the 0.6 threshold, no-English speakers pass from 65.524 in 2021 to 47.810 in 2041; people with both parents born overseas from 102.190 to 99; minority religion people from 38.190 to 25.048; and particularly for low-education people (from 77.381 to 36.714).

In the mix of gentrifiers experiment, similar trends are detectable for 0.5 threshold simulations. Conversely, the other gentrification experiments with the 0.5 threshold are less clear than the 0.6 threshold in tracing gentrification.

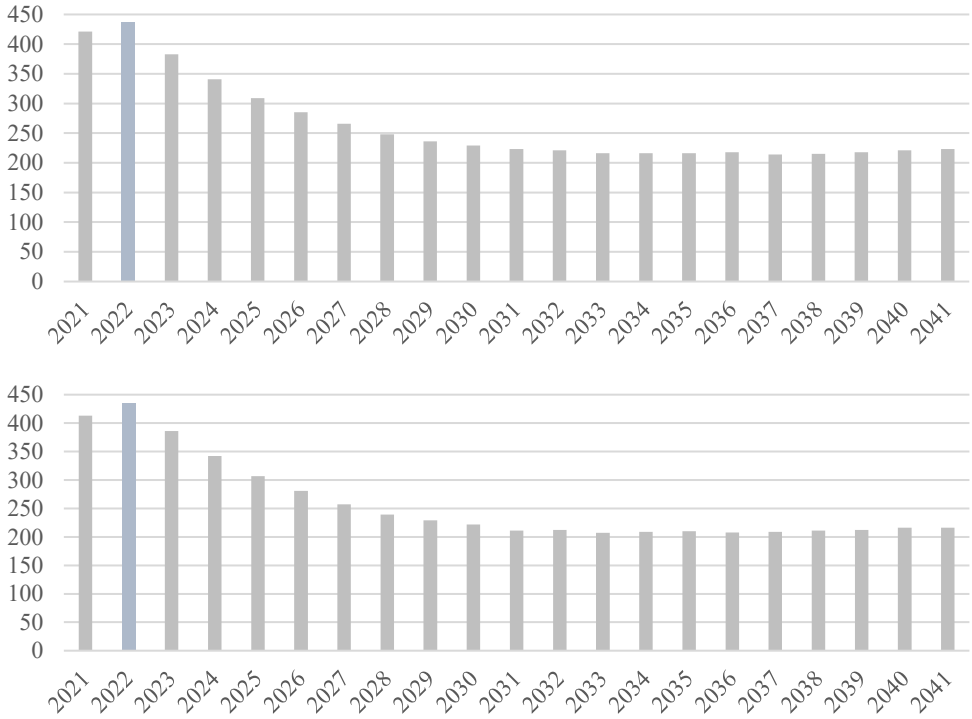


Figure 7.23. Simulations with 0.6 threshold, random (up) and dominant (down) procedures, and 25% of a mix of gentrifiers

The increasing value is very similar and generally concentrated in those SA1s with lower initial income. The student gentrification experiments are the only ones that assume different features with 0.6 and 0.5 thresholds. With 0.6 threshold, it is possible to notice a higher income than in the other experiments. This reveals that students under these conditions acerbate the income differences and, therefore, the economic inequalities. Socio-cultural and ethnic diversity are not affected by student gentrifiers. The average socio-cultural-ethnic diversity in the neighbourhoods initially decreases from 0.113 in 2021 to 0.112 in 2031, but then it slightly increases from 0.112 in 2031 to 0.114 in 2041. With a 0.5 threshold, students do not have a high impact on the income increase, meaning that higher acceptability (i.e., lower threshold) makes students a peaceful group of inhabitants of the area and not a repulsive force.

The impact of a green gentrification process should then be considered and planned for with appropriate policy and regulation. In particular, precautionary policies should be considered, such as the low provision of public affordable housing in future developments. Similarly, taxation mechanisms should be analysed to help existing homeowners to keep their properties, avoiding an immediate capitalization of the increase in their property values, and to help tenants to continue to be able to afford their rents.

7.6 Conclusions

This chapter presents a mixed method that combines a spatially explicit ABM, MCDA, and spatial HPM to investigate gentrification dynamics in real-world contexts. Specifically, the proposed method investigates gentrification from a bottom-up perspective, where both supply and demand sides have a role in the definition of residents' preferences. The real-estate market and neighbourhood features, as well as individual preferences, contribute to the decision to stay or leave the neighbourhood; then, the inflow of new residents can result in gentrification over the time.

The conceptual framework can be applied to other case studies and represents the first attempt to explore gentrification in a real-world application, taking into account more tangible and less tangible factors (such as social biases, cultural factors, age preferences, etc.). Its applicability was tested in the city of Brisbane (Australia) and the transformation project of the golf park into a new urban park in the districts of Kelvin-Grove and Herston. In particular, spatially explicit data with a level of detail at the micro-scale was used.

The results can support DMs and PMs in envisioning possible effects on the real estate market and household mobility, caused by transformation and regeneration processes in cities. Accordingly, they can monitor the phenomenon or provide adequate policies and measures to limit it.

However, some improvements can be made. In the ABM, one of the key issues is that it is necessary to simulate gentrification without considering the transformation of Victoria Park. This can highlight if gentrification can occur without this transformation, due to the general increase in real estate prices and housing demand in Brisbane, particularly between 2020 and 2021 when housing prices are highly increased due to COVID-19. Moreover, alternative simulations will be performed, changing the set of weights defined by the experts and used in the mobility likelihood calculation. These can be used as a sensitivity and robustness analysis of the model and of the results obtained.

Further exploration will also consider the application of the general framework proposed to a real-case study where gentrification occurred in the past. Using historical data, it is possible to verify under what conditions gentrification occurred and which factors are more important. Specifically, various simulation runs can experiment with different configurations of the mobility likelihood function by incrementally adding components. In this way, it is possible to understand the contribution of each variable considered in the mobility calculation. This can also be applied to the case study of Brisbane, to highlight what happens with or without some factors.

Moreover, several opportunities for expanding the results of the present study can also be related to the spatial HPM. First, it could be interesting to add more cases to the initial dataset of housing prices. This could lead to a refined analysis of homogeneous market segments. Further development of the study could consider

a better characterization of the urban parks included in the model, broadening the parks' typologies. Moreover, future improvement of accuracy in the analysis would entail measuring actual travel distance by various modes of transport (e.g., walking, biking, public transport, etc.) and comparing the distance and time to get to the park. For simplicity, the actual analysis only considered the Euclidean distance between housings and different types of parks. Additionally, the analysis could be further explored by including other variables which affect the amenities of urban parks, such as the view of the park. Consideration of this latter variable may reveal more precisely differences between properties near urban parks and those lacking this last feature.

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Chapter 8

III CASE STUDY – The Basse di Stura area, Turin (ITA)[39]

The third case study aims to build and evaluate alternative strategies for the development of a new urban park in the area of Basse di Stura (Turin, Italy). Due to the complexity of this site, characterized by abandonment and high pollution of the soil, as well as the various aspects to be considered for the generation of alternative participative scenarios, a mixed method approach has been proposed. Firstly, SWOT and SA support the collection of the relevant information about the area under analysis and the different perspectives of the stakeholders interested in this decision-making process. Secondly, a panel of experts is involved in the selection of alternative actions to be implemented in the area. Then, using two different methods (a combined RP+SP survey and BWM, respectively), citizens and key stakeholders are asked to elicit their preferences about this set of possible actions. Finally, MAS supports the scenario building phase, taking into account both the satisfaction of citizens and stakeholders' preferences and the overall sustainability of the site, according to

[39] Part of this chapter has been developed in the following paper:

- Bottero, M., Assumma, V., Caprioli, C., & Dell'Ovo, M. (2021). Decision making in urban development: The application of a hybrid evaluation method for a critical area in the city of Turin (Italy). *Sustainable Cities and Society*, *72*, 103028. https://doi.org/10.1016/j.scs.2021.103028
- Bottero, M., Caprioli, C., & Berta, M. (2020). Urban Problems and Patterns of Change: The Analysis of a Downgraded Industrial Area in Turin. In *Values and Functions for Future Cities* (pp. 385–401). Springer, Cham. https://doi.org/10.1007/978-3-030-23786-8_22
- Bottero, M., Bravi, M., Caprioli, C., Dell'Anna, F. (2022). Using Revealed and Stated Preferences to design a new urban park in a metropolitan area of North-Western Italy. (under review)

a set of multi-dimensional indicators. The creation of alternative scenarios is strongly based on preferences and sustainable performance, but also on the suitability of current and new land uses (i.e., actions), which are based on a rich set of GIS data. According to the general scheme contained in Chapter 5 (Figure 5.1) about the three main elements of ABM/MAS, Figure 8.1 details how these three elements are declined and how the different methods are used in this third case study to inform and structure them.

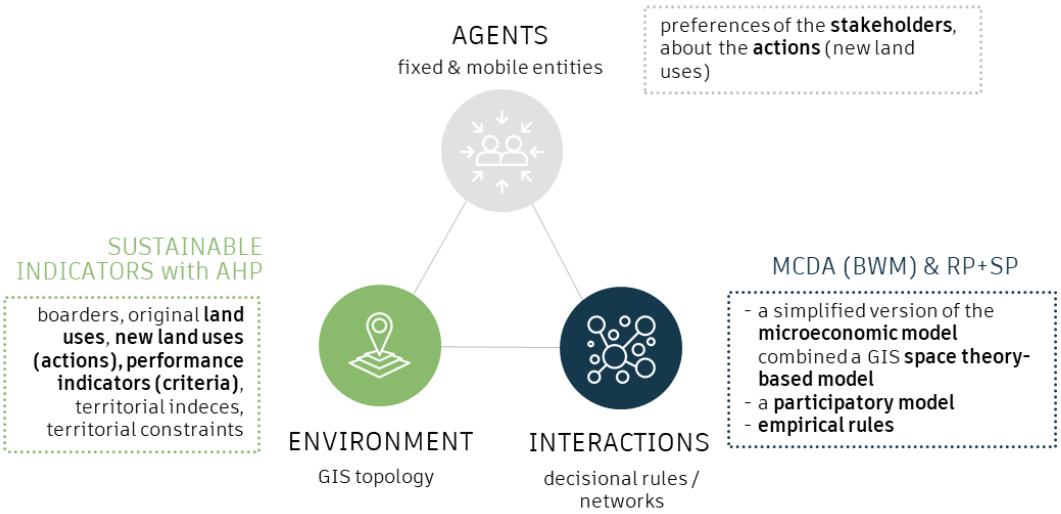


Figure 8.1. ABM/MAS main pillars as developed in this case study application

8.1 An integrated evaluation model for supporting SOCIO-ENVIRONMENTAL scenarios

Cities in Western countries are experiencing negative effects due to decentralization and deindustrialization. It has generated an economic crisis and an urban decline. Within this context, urban regeneration has become a widespread solution to many urban political agendas. Many positive outcomes can be achieved through urban regeneration, including building restoration, increased well-being and life quality for residents, valorisation of cultural resources, environmental protection, and economic development. Urban regeneration looks at urban areas as complex and dynamic systems, where social, environmental, economic, and design processes drive the transition to important changes (Cerreta & Panaro, 2022). Nowadays, urban transformation and planning have to deal with these aspects, which are becoming increasingly important and urgent. It is well known that cities worldwide are responsible for more than 70% of energy-related emissions (Thring, 1977) and that 60%-80% of final energy use is consumed there (Bottero et al., 2019a). The United Nations predicts that by 2050, over 70% of the world population will live in urban areas (Brockerhoff & Nations, 1998). Conversely, cities are the main places of attraction for technological, economic, and socio-

cultural development (Kourtit & Nijkamp, 2018). In that context, public space and its planning represent an important occasion in this transition, not only to improve the quality of the urban environment but also to generate social cohesion (Giuffrida et al., 2016; Madanipour, 2013). Some urban projects, such as the requalification of the Porto Vecchio in Genoa (Italy) or the Clyde Waterfront in Glasgow (UK), have focused strictly on public spaces, as a driver of image and changes in the quality of life of urban areas, with significant implications for their revitalization and regeneration (Bottero et al., 2020; Lecroart, 2007). The quality of the urban environment in deprived neighbourhoods and the building of high-level public spaces lead to fairer and more democratic cities, in which equal treatment and investment do not mean displacement and gentrification (Madanipour, 2013).

At the same time, the COVID-19 pandemic has shown that cities are not completely equipped to respond to the new needs emerging. New long-term strategies are required to make cities more resilient, inclusive, green, circular, and smart through a new approach to urban spaces (Caprioli et al., 2021). In particular, in major cities, green spaces are the only chance citizens have to experience nature, thus contributing to an improved quality of life and the wellbeing of citizens (D'Alpaos & Andreolli, 2020). Evidence of positive externalities provided by the development of green strategies and the presence of green urban infrastructures (GUIs) has been deeply discussed by several scholars and classified by (Demuzere et al., 2014) into: i) Physical benefits, e.g. CO2 reduction, thermal comfort and energy use reduction, and ii) Psychological and social benefits, e.g. health and restorative benefits, social and individual coping capacities, and education (Caprioli et al., 2021). Moreover, considering the lockdown period experienced nationally and internationally, many citizens have expressed a need for outdoor spaces where to have fun. Accordingly, cities with a good availability of green spaces have reduced the mental and physical stress experienced during that period (Stockholm Environment Institute, 2020).

Urban regeneration, beyond the triple-bottom-line approach (i.e., the interaction of social, economic, and environmental aspects) (Sala et al., 2015), requires the consideration of the land take and the reuse of abandoned sites to preserve the scarce land resource and to reduce the criticalities generated by urbanization (Bottero et al. 2019b; Cerreta & Panaro, 2022; Sdino et al., 2021). A crucial issue is represented by the presence of abandoned industrial sites, located in peripheral and not attractive locations (Dell'Ovo et al., 2020). Their reuse implies remediation costs, but their neglect may entail ecosystem degradation and thus a loss of ecosystem services (Assumma et al. 2021; Caprioli et al. 2021). Here, externalities, both positive and negative, have to be managed, as well as a trade-off among the multiple dimensions and stakeholders involved in selecting the most sustainable alternative for requalification (Cerreta & Panaro, 2022; Giuffrida et al., 2016).

The application presented in this chapter aims to investigate the complexity involved in urban regeneration (Blecic et al., 2009), focusing in particular on the role of integrated evaluation tools for supporting decision-making processes and

the construction of participative scenarios among the stakeholders involved. Starting from the analysis of a real case study related to the regeneration of a highly polluted and abandoned industrial area in the city of Turin (Italy) (Basse di Stura) in a new urban park, the research proposes a combination of evaluation tools able to produce a complete picture of the problem and to define possible long-term visions for the site. Specifically, the integrated framework combines SA, SWOT analyses, RP+SP survey, and BWM into a spatially explicit MAS. In this context, the adoption of integrated methodologies is strategic to analyse each phase of the decision problem from its early stages to the selection of the most suitable scenario according to the context and the stakeholders engaged. The development of a multi-methodological framework allows DMs to guide the regeneration by considering different perspectives and satisfying the demands of society and the city (Cerreta & Panaro, 2022; Shen et al., 2012). The identification of priority actions and transformational changes requires a complete and structured understanding of the overall urban system and its subsystems (Webb et al., 2018). As in most regeneration processes, DMs are mainly the public administration, policy makers, and public bodies, that work for city transformation with a comprehensive sustainable view, spanning environmental protection, social cooperation, technological advancement, and cultural preservation. However, DMs are not always able to consider properly the needs of citizens in real-world contexts, as well as the different perspectives and behaviours of other key stakeholders in regeneration processes, such as environmental agencies, developers, and owners, among others. These key stakeholders have a central role in the success of a regeneration project. The integrated framework exactly proposes the co-construction among stakeholders and the evaluation of the sustainable performance of the scenarios, which are, therefore, salient, credible, evident, and legitimate (Bottero et al., 2021; Cash et al., 2003). Surprisingly, the topic of alternative construction is almost ignored in literature, and very few contributions are available on this, as recently examined by Colorni & Tsoukiàs (2020). Within this context, the present application represents therefore an innovative exploration both in the field of ABM/MAS research and, more in general, in decision analysis and operational research.

8.2 A multi-methodology perspective: RP + SP + BWM + MAS + GIS

Decision-making problems, particularly in regeneration and planning processes, often involve multiple conflicting objectives/criteria that should be considered (Jürgen et al., 2008). However, it is possible to distinguish between problems where a predefined and discrete set of alternatives has to be evaluated and those where, conversely, the set of suitable solutions is not explicated in advance but requires constraint functions for its definition (Ferretti et al., 2019). Solving this latter group of problems means supporting DM in finding the most preferred

solution (Jürgen et al., 2008). This can only be accomplished by directly involving them in the evaluation by asking for their preferences regarding the transformation. However, alternative generation for choice problems is a vital activity in decision analysis that is sometimes overlooked and undeveloped (Colorni & Tsoukiàs, 2020).

Within this context, the presented chapter proposes a multi-methodological approach (Figure 8.2) for supporting a stakeholder participatory process of scenario planning. Specifically, the information provided by context analysis through SWOT and SA, and the elicitation of preferences expressed by the main stakeholders involved in the planning process through BWM and the RP+SP survey are combined into a spatially explicit ABM. In this phase, a focus group with a panel of experts is also organized to support the definition of the possible strategies to be implemented in the area under investigation.

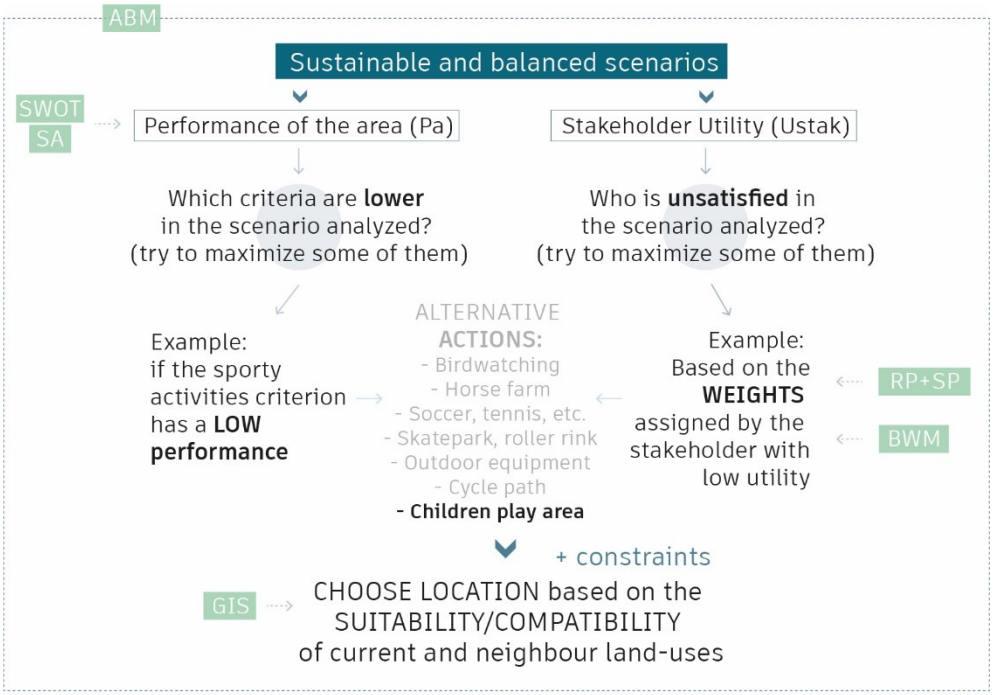


Figure 8.2. Framework of the multi-methodology model

In the first stage, SWOT and SA are adopted to acquire all the relevant information about the case study and the different perspectives of stakeholders involved in the decision-making process. In this phase, it was also organized a focus group with a panel of experts that support the definition of the possible strategies to be implemented in the area under investigation.

The second stage has the aim of defining a complete set of criteria to assess the sustainability of the regeneration process through an overall index of scenario performance. The list of criteria is the result of the knowledge acquired during the implementation of SWOT and SA, as well as of a literature review developed in Scopus on the main indicators used in MCDA for evaluating sustainable urban regeneration. Specifically, the list of criteria was hierarchically structured and allows to calculate the sustainable performance index of the simulated scenario.

In the third stage, two methods are used for the elicitation of stakeholder preferences about the possible strategies to be implemented in the area. BWM (see Chapter 3, Section 3.4.2) is used to collect the preferences of four different key stakeholders: the developers, the environmental agency, the municipality, and the owners of the area. Conversely, the preferences of citizens are obtained through a RP+SP survey (see Chapter 3, Sections 3.5, 3.5.2, 3.5.3). The results of this elicitation of preferences are then used for the estimation of each stakeholder utility. These two methods were differently selected for citizens and stakeholders for the following reason. On one hand, CE helps citizens envision possible scenarios without asking them to abstractly reason about the strategies one at a time. However, CE requires the collection of a broad number of surveys for the accuracy and precision of its outcomes. On the other hand, BWM is more adapted to obtaining information about the preferences of the stakeholders, but, conversely, it is more abstract than CE. For that reason, direct interaction between the analyst and the stakeholder was carried out in BWM, which was impossible with CE.

All the previous stages are useful to inform ABM. Firstly, the main GIS maps are included in the software. Secondly, the agents are created. Thirdly, the simulation runs make possible the creation of scenarios, which are the balance between the achievement of scenario sustainability and the satisfaction of the stakeholders, as well as the spatial compatibility among land uses.

8.3 Case study description

The case study is a large area of 150 hectares located in the northern part of the city of Turin and called Basse di Stura (Figure 8.3). The name comes from the high difference in the level of the ground between the Stura riverbed and the surrounding roads. The Stura stream is the only natural boundary of the area, the others are high-traffic roads (Via Reiss Romoli, Raccordo Autostrale Torino-Caselle and Strada dell'Aeroporto). This set of infrastructures underlines the relevant role of the area in terms of accessibility for the metropolitan city, but at the same time, it results in a high-traffic area. Moreover, these roads strongly divide Basse di Stura from the neighbouring areas.

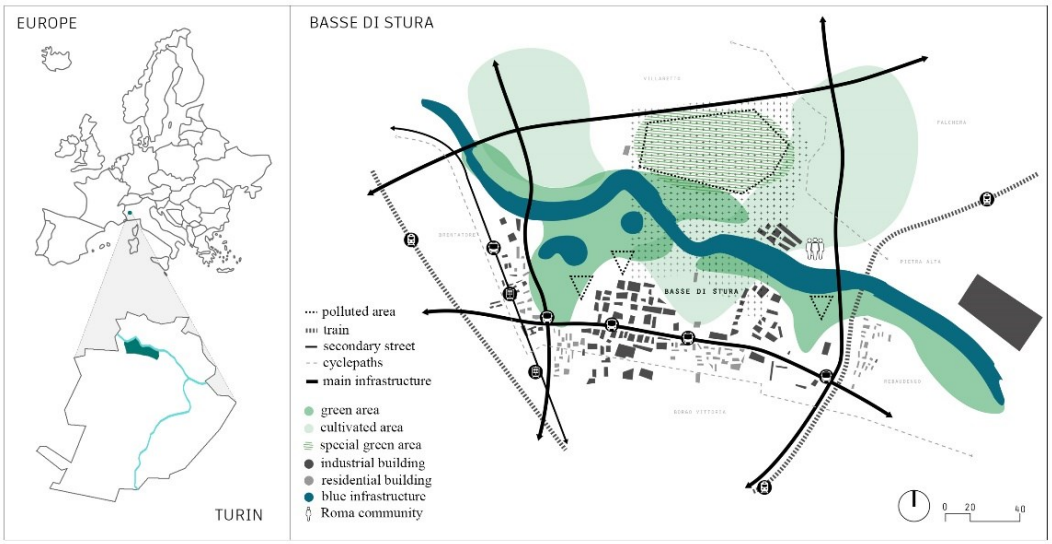


Figure 8.3. Localization and the main characteristics of Basse di Stura area

Its location at the edge of the city has determined the uses of the area in the past and in the present. Originally, rural land use characterized the entire surface. The extensive fields and the closeness of the Stura stream encouraged the diffusion of farmhouses and rural jobs. However, the agricultural use of land has recently been lost because of the high pollution of land due to the past heavy factories and the illegal disposal of industrial waste. Even today, a huge number of factories and car dealerships occupy the area, showing the industrial vocation of the area.

Recently, the local administration has expressed its interest in the development of this area, both for the natural potential of this site and for its strategic location. The proximity to the municipalities of Venaria Reale, Borgaro Torines, and Settimo Torinese is strategic for the different policies proposed by local authorities geographically connected to Basse di Stura: the project Tangenziale Verde, Torino Città d'Acque, and Corona Verde. These projects provide for the creation of a blue-green infrastructure in the city of Turin and the neighbouring municipalities where existing and new green areas create a network along the rivers with a system of cycle paths on a large scale. Another relevant occasion for the area is the infrastructural project of the second line of the Turin underground. From the preliminary studies of the route, the Rebaudengo area (1.5 km away from Basse di Stura) is supposed to be the northern terminal of the line (Comune di Torino – Divisione Infrastrutture e Mobilità, 2008), easily connecting this part of the city with the central one.

As mentioned before, the area has changed its uses over the years, passing from an agricultural vocation to an industrial one. This transition has resulted in soil contamination and an increase in the vulnerability of groundwater and watercourses because of illegal industrial waste disposal. For that reason, until 2013, the area was included in the list of contaminated sites of national interest (SIN = Sito di Interesse Nazionale) by the Italian Ministry of Environment and Sea. However, after 2013, the competence of the area passed, first to the Piedmont Region and then to the Municipality of Turin.

As a consequence, the Municipal Plan represents the main document to understand most of the dynamics and future visions of this area, at least those provided by the Municipality. The main use planned for the area is classified as P17, i.e., an urban and fluvial park, with a small buildable surface of about 0.10 sqm/sqm. However, until now, no actions in this direction have been developed, due to the high level of contamination of the soil and the limits prescribed by the Hydrogeological Risk Plan. In some cases, the small buildable surface is not enough for the owners to cover the high cost of remediation, which is in some cases caused by the actions of others.

The Municipal Plan directives need to face with other plans:

- the Regional Territorial Plan for the transformation of the area to create advanced productive and tertiary functions;
- the Landscape Regional Plan for an integration with the Corona Verde project;
- the Coordination Plan of the Turin Metropolitan area;
- the Plan for the Po river basin;
- the Hydrogeological Risk Plan (Bottero et al., 2020)

The complex dynamics of Basse di Stura also led to the realization of a specific executive plan for environmental requalification, called P.E.R.A., which identifies in-depth the necessary actions to be taken (Comune di Torino, 2003).

8.4 Application of the multi-methodology approach

8.4.1 Preliminary context analysis: SWOT and SA

The case study description has underlined the complex situation in Basse di Stura, where social, environmental, and economic problems strongly affect the transformation of the area. Within this context, the adoption of SWOT and SA is fundamental to conducting the preliminary analysis of this complex area. For methodological details about SWOT and SA, see Chapter 3, Section 3.3.

In the first stage of the preliminary analysis, a SWOT Analysis is developed. Instead of the common 2x2 matrix, which contains the strengths, weaknesses, opportunities, and threats in four sections, a different design of the SWOT Analysis is performed, which allows to analyse each element in Basse di Stura from both a natural and an anthropic point of view (Figure 8.4).

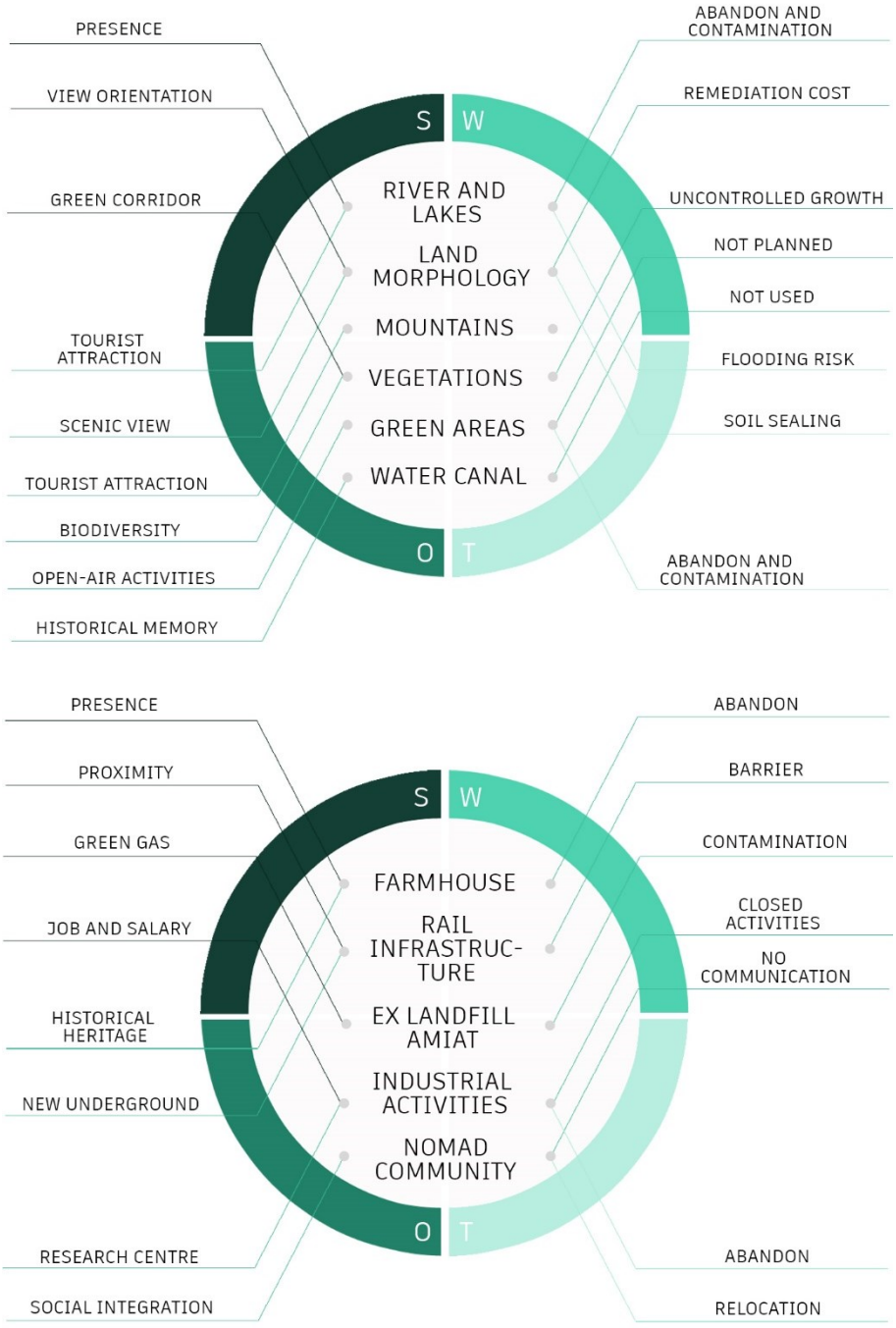


Figure 8.4. SWOT Analysis for the natural (up) and anthropic elements (down) (Bottero et al. 2020)

The results of SWOT highly show the unexpressed potential of the area. Soil contamination and water pollution may cause problems for Basse di Stura workers and residents who live nearby. Informal allotments and Roma camps provoke social marginality and the abandonment of vulnerable people. The non-intervention could trigger irreversible impacts in the area. Its location benefits from strategic accessibility, such as the highway, railway, airport, and the future underground line. The vast green areas and the river Stura could connect this area with the green and blue infrastructures of the Metropolitan City. Possible inclusion of the area within environmental projects could facilitate the restoration and enhancement of its

habitats. Education has the power of sensibilization and awareness of present and future generations about the area (e.g., social justice, or waste recycling). River flooding is a threat that could further damage the area. The local economy is affected by the progressive abandonment of the farmhouses and industries. Some opportunities could be the adaptive reuse of industrial buildings for green energy production (see EU project Together2020 in Turin) and the creation of new job demand through the design of co-working spaces. Taxes and subsidies for green technology may attract investors and facilitate the implementation of energy policies, even if the long-term transformations and large amounts of economic resources may be a deterrent to their interest. The ongoing revision of the Municipal Plan is thus an opportunity to regenerate Basse di Stura.

In the second stage of the preliminary analysis, SA is applied in order to understand who can contribute to the decision-making problem and whose outcomes could affect the results of this process (Dente 2014). The analysis starts with listing all stakeholders interested in the Basse di Stura project and underlines for each of them the competence level, the resources they carry out, and the types of actors they are (Table 8.1). In fact, every stakeholder is motivated by some particular interest related to their goals, values, or preferences, which will determine their support for or rejection of a strategy.

Table 8.1. Types, resources, and action level of each stakeholder

Stakeholder	Level	Resource	Type
EU (European Union)	international	economic	political, bureaucrats
Italy government	national	legal, political, economic	political, bureaucrats
Piedmont Region	regional	legal, cognitive, political, economic	political, bureaucrats
ARPA (environmental agency)	regional	legal	bureaucrats, expert
Designers (architects, planners…)	national, regional, municipal, local	cognitive, economic	expert
Big landlords (Poste, Italgas)	national	legal, political, cognitive, economic	special interest
Investors	national, regional, municipal, local	economic	special interest
Metropolitan city of Turin	municipal	legal, cognitive, political, economic	political, bureaucrats
Municipality of Turin	municipal	legal, cognitive, political, economic	political, bureaucrats
Neighbourhood municipalities	municipal	legal, cognitive, political, economic	political, bureaucrats
AMIAT (Municipal waste management company)	municipal	cognitive	special interest
GTT (transport agency)	municipal	political	special interest
Environmental groups	local	cognitive, political	general interest
Small landlords	local	cognitive	special interest
Local commercial activities	local	cognitive	special interest
Citizens	local	cognitive	special interest
Nomad community	local	cognitive	special interest

Owners of industrial activities	local	economic, cognitive	special interest
Juventus FC	municipal	economic	special interest

For this case study, a specific stakeholder technique was developed: the Social Network Analysis (SNA) (Rhodes, 1997; Shrimpton Masson, 2015). For methodological details, see Chapter 3, Section 3.3. This approach is particularly suitable to highlight the stakeholders' influences through a network representation, in which each stakeholder has different ties with others. These connections and relations can affect the overall performance of the decision network. With this approach, it is also possible to visually understand the size and form of the network. Figure 8.5 shows the stakeholder network for the present case study. The nodes are the stakeholders, listed in Table 8.1, while the arrows are the connections among them. The dimension of the circles is related to the power of the stakeholders, while the proximity to the centre represents the stakeholders' interest with respect to the transformation of the area.

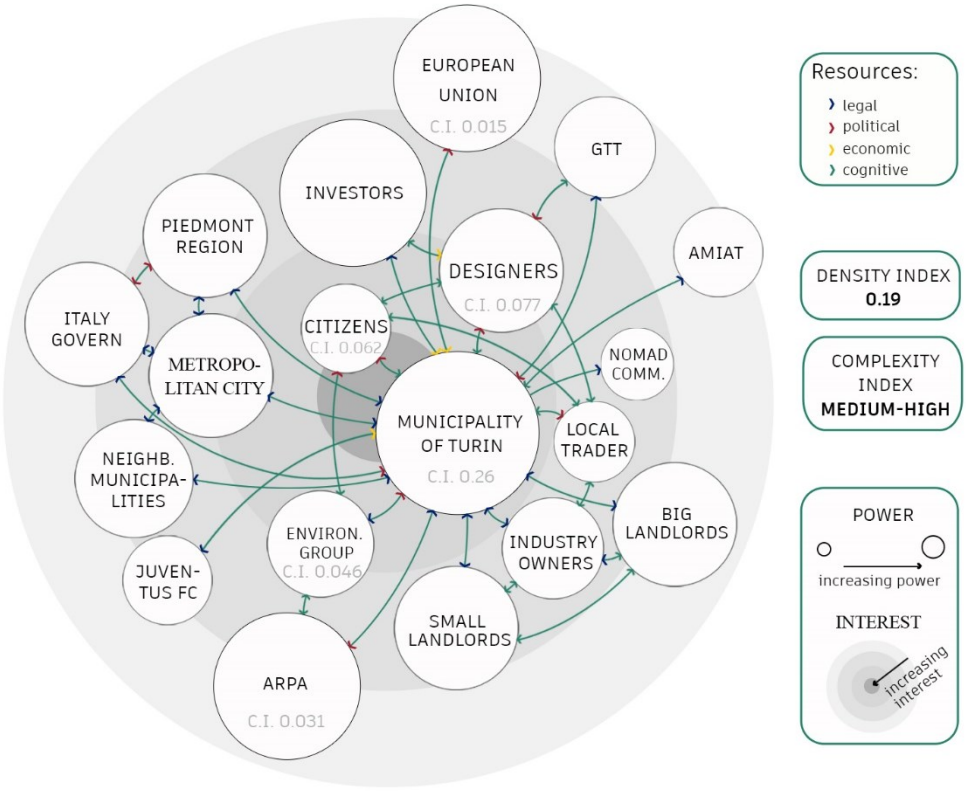


Figure 8.5. Stakeholders map for the Basse di Stura case study

According to this method, the calculation of specific indexes helps in the comprehension of the dynamics that regulate the network (Berta et al., 2018). The analysis highlights the centrality of the Municipality of Turin, which is the most central actor with 17 relations (a centrality index of 0.26). It is not surprising because the city of Turin is the main promoter of the process and the owner of some lands. Instead, the others have a lower capacity to direct the process. In fact, all of them have a maximum of five 5 relationships (such as the designers) and a minimum of 1 (such as the nomad community or the waste management company).

However, the transformation is not possible without the help of many of these actors. For example, landowners of the area and investors are crucial in the development of the transformation, as shown by their position close to the centre and with quite a large dimension. Another important stakeholder is represented by the citizens, whose power is limited but whose interest is very high.

8.4.2 Selection of the actions and elicitations of preferences

The construction of the SWOT analysis and the consideration of values and preferences emerging from the SA have provided a deep understanding of the area, supporting a preliminary definition of the possible future scenarios. Specifically, the real actions to be implemented in the area emerge after a focus group where different experts are involved. The municipality of Turin (architect Giacomo Leonardi), some urban planners (Professors Cotella and Santangelo), an applied economist (Professor Scarpa), and an environmental expert (Professor Mondini), participated at the discussion table. The focus group was structured into three parts. Firstly, all the experts were informed about the area, the data, and the information acquired during the preliminary analysis. Secondly, they start a brainstorming phase in which ideas and perspectives are discussed. This phase results in a preliminary list of possible strategies. Thirdly, the most appropriate actions (19) are defined all together and clustered into 5 different groups of activities, as reported as follows and hierarchically shown in Figure 8.6:

- social and educational activities: (SE1) Farm school, (SE2) Educational tour on the natural and industrial history of the area, (SE3) Social centre («casa del quartiere»), (SE4) Allotments;
- activities in nature: (NA1) Nature trails along the river, (NA2) Birdwatching, (NA3) Butterfly farm, (NA4) Horse farm;
- technological activities: (BE1) Cultivated areas of no-food crop, (BE2) Bio-energy areas, (BE3) Research centre;
- sport activities: (SA1) Soccer/tennis/basket/volley (etc) fields, (SA2) Skatepark/Roller rink, (SA3) Outdoor equipment, (SA4) Cycle path;
- organised sites: (OS1) Children's play area & pic-nic area, (OS2) Dog park, (OS3) Study spaces, (OS4) Organised beaches along the river.

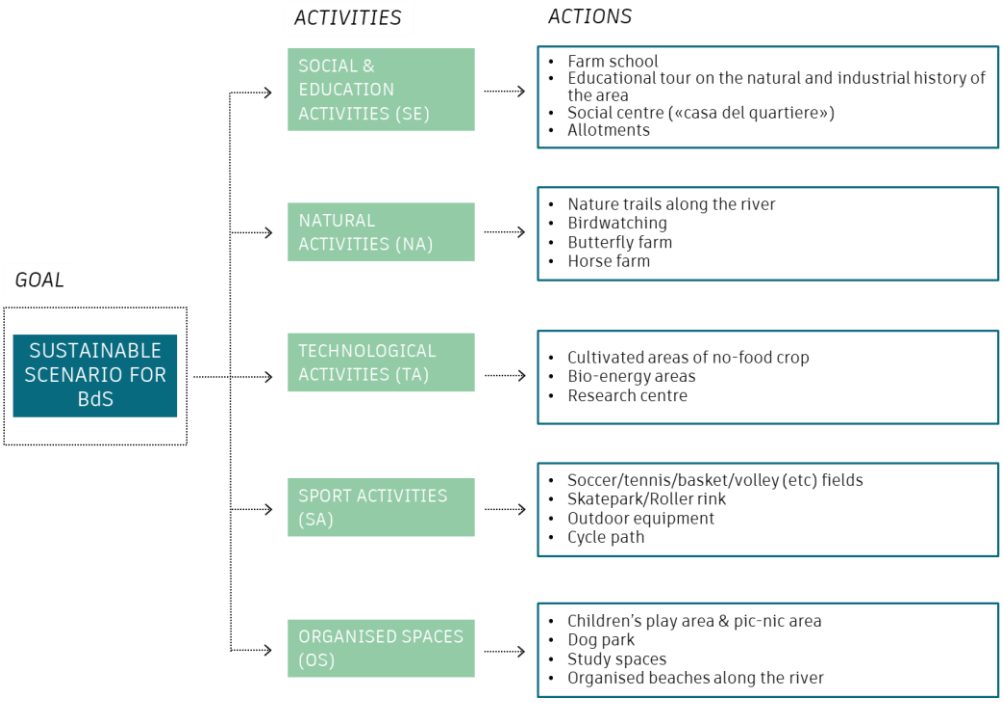


Figure 8.6. The hierarchic structure of alternative activities and related actions

The use of a focus group, strongly based on preliminary evaluation analysis, keeps tightly connected the two phases of the scenario building (i.e., the analysis of the context through SWOT and SA, and the outline of different physical alternatives for the masterplan). The two parts have alimented the development of the final proposed strategies through continuous feedback, reinforced by the brainstorming and discussion among experts. The result is the application of a formal approach able to support the design of alternative solutions for solving a complex decision-making process (Colorni & Tsoukiàs, 2013).

Therefore, the analysis of the context and the consultation of experts have supported the creation of knowledge related to the area under investigation, as well as the development of alternative strategies. However, the crucial point of this case study, but generally of most transformation and regeneration processes, is represented by the achievement and satisfaction of stakeholders' needs, expectations, and objectives. The analysis has thus considered the direct inclusion of stakeholders' preferences regarding the hypothetical scenarios for Basse di Stura through the adoption of two methods. Five stakeholders are considered in the analysis: the municipality of Turin, the owners of the area, a potential developer, an environmental expert, and citizens. These five stakeholders represent, as it is possible to see in the SNA (Figure 8.5), the most interest in the Basse di Stura regeneration and, some of them, also very powerful. A MCDA method, specifically BWM (for methodological details see Chapter 3, Section 3.4.2), is used to elicit the preferences of the first four stakeholders. Conversely, the pooling method with RP+SP (see Chapter 3, Sections 3.5, 3.5.2, and 3.5.3) is used to collect the citizens' preferential actions to be implemented.

For the four stakeholders, the relative importance of activities and actions was gathered using an individual online survey sent to each stakeholder using the BWM linear model (for details see Chapter 3, Section 3.4.2). The survey was developed using Google Form (https://www.google.it/intl/it/forms/about/). A pre-test was sent to a group of experts who validated the comprehensiveness and clarity of the survey. Then, the final version of the survey was sent to each stakeholder. During face-to-face meeting, each stakeholder answered to the survey with the help of the analyst. The survey is composed of seven different sections. Section 1 is a preliminary section devoted to the presentation of the case study, a description of the contents and objectives of the survey, with a brief explanation of BWM, and the illustration of activities and actions to be evaluated. In this section, it was also asked to specify the stakeholder represented (if the developer, the environmental expert, the municipality, or the owner). In Section 2, the stakeholders indicate the most important (BEST) and least important (WORST) ACTIVITY for the development of a sustainable transformation of the Basse di Stura Park. Moreover, he/she assigns the preference ratio of the BEST ACTIVITY over the other ACTIVITIES and all the activities over the WORST ACTIVITY. The preference ratio between two activities was assigned by the stakeholder through a pairwise comparison that used the fundamental scale of Saaty. Sections 3, 4, 5, 6, and 7 ask the stakeholder to indicate the most important (BEST) and least important (WORST) ACTIONS for the implementation of each activity, respectively: socio-educational activities, activities in nature, technological activities, sporty activities, and organised sites. This means that for each section, a set of actions related to a single activity are compared through BWM.

The complete questionnaire can be consulted in Appendix B.2.

The weights obtained from the survey and the elaboration through the linear BWM are reported in Tables 8.2 and 8.3, respectively, for the level of the activities and the level of the actions. In the two tables, ξ^{L*} represents the consistency ratio [0-1] where values close to 0 show more consistency, while values close to 1 show less consistency (Rezaei, 2016). Moreover, the chosen best and worst activities and actions are highlighted in green and red, respectively.

Table 8.2. Relative importance assigned by the stakeholders to the activities

	Socio-educ activities	**Natural activities**	**Technological activities**	**Sport activities**	**Organised sites**	ξ^{L*}
Developer	0.229	0.066	0.229	0.361	0.115	0.098
Environmental expert	0.150	0.505	0.200	0.059	0.086	0.094
Municipality	0.060	0.158	0.158	0.236	0.388	0.085
Owner	0.428	0.156	0.234	0.117	0.065	0.043

Table 8.3. Relative importance assigned by the stakeholders to the actions

	SOCIO-EDUCATIONAL ACTIVITIES				
	Farm school	**Educational tour**	**Social centre**	**Allotments**	ξ^{L*}
Developer	0.319	0.080	0.550	0.051	0.089
Environmental expert	0.489	0.261	0.057	0.193	0.091
Municipality	0.145	0.079	0.487	0.289	0.092
Owner	0.196	0.196	0.090	0.518	0.071
	NATURAL ACTIVITIES				
	Nature trails	**Birdwatching**	**Butterfly farm**	**Horse farm**	ξ^{L*}
Developer	0.286	0.048	0.190	0.476	0.095
Environmental expert	0.518	0.196	0.196	0.090	0.071
Municipality	0.182	0.091	0.273	0.454	0.091
Owner	0.466	0.259	0.172	0.103	0.051
	TECHNOLOGICAL ACTIVITIES				
	Cultivated areas of no-food crop	Bio-energy areas	Research centre		ξ^{L*}
Developer	0.542	0.292	0.166		0.042
Environmental expert	0.244	0.111	0.645		0.089
Municipality	0.166	0.292	0.542		0.042
Owner	0.575	0.325	0.1		0.075
	SPORT ACTIVITIES				
	Soccer/ tennis etc. fields	**Skatepark/Roller rink**	**Outdoor equipment**	**Cycle path**	ξ^{L*}
Developer	0.041	0.443	0.258	0.258	0.072
Environmental expert	0.518	0.196	0.196	0.090	0.071
Municipality	0.076	0.245	0.245	0.434	0.057
Owner	0.278	0.463	0.074	0.185	0.093
	ORGANISED SITES				
	Children & picnic area	**Dog park**	**Study spaces**	**Organised beaches**	ξ^{L*}
Developer	0.258	0.041	0.258	0.443	0.072
Environmental expert	0.197	0.089	0.196	0.518	0.071
Municipality	0.153	0.231	0.231	0.384	0.077
Owner	0.059	0.5	0.147	0.300	0.088

As expected, Tables 8.2 and 8.3 show different results among the stakeholders. Regarding the activities, the stakeholders completely disagree on the choice of the best and worst ones. The developer prefers activities able to produce income, such as sporty areas, compared to activities in nature. Conversely, the environmental expert is interested in the promotion of natural activities in opposition to impermeable areas, such as the sports. In the same way, the municipality prefers an

organization of spaces for all citizens, whereas the owner understands the need to include people with socio-educational activities as the only chance to increase interest in this area.

As for the actions related to the socio-educational activities, the municipality and the developer agree on the potential of creating a social centre in the area, as a priority to involve them in other socio-cultural activities in the area. Older people, for example, could be involved in the creation of educational tours or the use of allotments. The environmental expert instead prefers the farm school as an opportunity to build both an amenity environmental place unique in the city and a space for increasing the awareness of people, and particularly children, about the topic of ecosystem services, among others. The owner prefers allotments among the socio-educational activities, since it is the easiest way to sell their properties. An agricultural cooperative has already bought some portions of the area and a reclaim of the soil could quickly foresee the return of the area to its original function.

For the actions related to the activities in nature, some coalitions can be predicted. On one hand, both developer and municipality agree on the realization of a horse farm, while they consider it less important or less attractive as a birdwatching space. On the other hand, the environmental expert and the owner have declared respectively more sustainable and feasible the organization of natural trails in the area, compared to the strong impact of a horse farm.

Other coalitions emerge when actions for technological improvement are evaluated by the stakeholders. In this case, the environmental expert and the municipality agree on the potentiality of realizing a research centre, since it can gain from the expertise that is already there and, consequently, it can generate positive externalities in terms of socio-economic mixite in this northern part of the city. Conversely, the developer and the owner have declared the need for remediation actions before any other technological improvement. This is also in line with what the owner prefers for the agricultural strategy of Basse di Stura.

The partnership between owner and developer is maintained for sporting events as well. They affirmed that a skatepark or a roller rink can be more attractive, as it happened in the regeneration of the industrial area of Parco Dora in Turin. The environmental expert, instead, imagines an area characterized by green spaces where different people can enjoy them. Soccer, tennis, or basket fields can be used freely by young people who live in the surroundings, as it happens, for example, in the Parco Ruffini in Turin. However, the municipality thinks that the priority action should be the realization of cycle paths, also in line with the other projects that the city of Turin has with the other municipalities, such as Corona Verde, Tangenziale Verde, or Torino Città d'Acque.

For the organized sites, the developer, municipality, and the environmental expert agree on the potential to exploit the river Stura and its banks for the development of organized beaches for people daily relax or occasional events. The owner is the only one who prefers a dog area, since it is faster and easier to implement.

Since one of the main objectives of this application is to support the municipality in building strategies able to effectively attract Turin citizens to the new Basse di Stura Park, also citizens are involved in the elicitation of their preferences. A survey was implemented with the specific aim of collecting the habits of Turin citizens in the use of green areas and urban parks, as well as preferential functions to be placed in Basse di Stura. A pre-test was administered to a group of 20 respondents, who gave their suggestions to implement and ameliorate the experiment. Then, the final version was implemented through the Limesurvey tool (www.limesurvey.org/) and distributed online through different social media platforms to reach a more heterogeneous sample. The data collection lasted a year to obtain answers from a mixed population who uses green areas and urban parks in different ways, seasons, and times. In its final version, the questionnaire is composed of 5 sections plus a section 0, as follows:

1. Section 0 contains a brief explanation of the case study and the aim of the survey. Moreover, in this part, the sample is targeted at citizens of legal age (≥18 years old) and who have lived the entire last year in the metropolitan city of Turin;
2. Section 1 collects the attitude of the respondent in the way he/she uses different green areas in the city, i.e., parks (urban, historical, hilly, river, agricultural), greenery in the neighbourhood, neighbourhood play area, dog area, and other green spaces (e.g., green space in the place of study or work). Here, it is asked to the interviewee to approximately locate on the map his/her home and/or his/her workplace, depending on the place from which he/she reaches the green spaces of the city, and to specify the number of visits per year of the green areas most frequently visited. These two data support the estimation of the random parameters in terms of the costs of each person going to some green areas (see the methodological explanation of Travel Cost in Chapter 3, Section 3.5.2);
3. Section 2 investigates the habits of the respondents towards a specific green area in the city, i.e., the urban park. Specifically, it is asked to the interviewee to select the park most used in the last year and specify the main activities performed there. This last RP information is in fact used for designing the SP part (contained in Section 4) where CE is proposed (for methodological details about RP, SP, and CE, please see Chapter 3, Sections 3.5, 3.5.2, and 3.5.3);
4. Section 3 examines the interests of the respondents in the future urban park in Basse di Stura. In this part, it is also asked to the interviewee to express his/her Willingness to Pay (WTP) for the implementation of an urban park in this area (see the methodological explanation of WTP in Chapter 3, Section 3.5.2);
5. Section 4 collects through a CE the preferences of the respondents in the alternative transformation scenarios for the area of Basse di Stura through binary options with the park mostly used. The different

configurations of Basse di Stura proposed to the interviewee emerged from an orthogonal design performed in SPSS[40] for the 19 actions presented in Chapter 8.4.2.1. The orthogonal design proposed 32 scenarios. Four binary options are presented to each respondent, where the park usually visited maintains the same features throughout the experiment, whereas the Basse di Stura scenarios change. In fact, the Limesurvey tool, although not directly programmed for CE, is able to generate random scenarios for each interviewee according to the different choice sets obtained from the orthogonal design;

6. Section 5 contains a set of questions aimed at obtaining the demographic and socio-economic characteristics of each interviewee.

The final version of the questionnaire is attached in Appendix B.3 in its English version.

In 12 months, 492 respondents completed the questionnaire, but it was used only by those who entirely answered the survey (i.e., 369 answers, 75% of total). It is not in the scope of this section to illustrate all the results obtained from the analysis. More details about socio-economic data of respondents, their habits, and preferential activities in green areas and parks most visited are reported in Bottero et al. 2022 (under review). This section contains the results of citizen preferences concerning the actions to be implemented in Basse di Stura. A Random Parameter Logit (RPL) is used to combine information from RP and SP (for methodological details, see Chapter 3, Section 3.5.3). The hypothesis behind this application is related to the correlation among the choices that each individual expresses in different choice tasks. Additionally, there is a correlation in the choice between the most used green areas and the potential new Basse di Stura park, as well as in the travel costs and number of visits to the most visited park. In Table 8.4, the results of RPL are reported, only considering the variables with an acceptable level of significance.

Table 8.4. Estimations from Random Parameters Multinomial Logit Model

Dep. Var. = Choice (0,1)	Coeffic.	St. Error	z	Prob.	95% Conf. Int.	
Random parameters in utility function						
Travel cost	-0.09369	0.03685	-2.54	0.011	-0.16591	-0.02147
Visit frequency	0.00217	0.001	2.17	0.0302	0.00021	0.00413
Nonrandom parameters in utility function (choice-set variables)						
Farm school	0.27491	0.14982	1.83	0.0665	-0.01873	0.56856
Educational tours	0.67532	0.12585	5.37	0.0000	0.42865	0.92198
Horses farm	0.29892	0.13685	2.18	0.0289	0.03069	0.5714
Cultivated no-food areas	0.47727	0.13761	3.47	0.0005	0.20756	0.74698

[40] https://www.ibm.com/it-it/analytics/spss-statistics-software

Research centre	0.46804	0.13694	3.42	0.0006	0.19965	0.73698
Skatepark/Roller rink	-0.29490	0.12480	-2.36	0.0181	0.19965	0.73643
Children play area	0.42323	0.12167	3.48	0.0005	-0.53951	-0.05029
Dog area	0.43211	0.12067	3.58	0.0003	0.18477	0.66169
Study spaces	-0.31711	0.12539	-2.53	0.0114	0.1956	0.66862
Organised beach	-0.47734	0.14175	3.37	0.0008	-0.56287	-0.07135
Constant (my park)	-0.39589	0.21644	-1.83	0.0674	-0.75515	-0.19952
Std. Devs. Of Random Parameters						
Travel cost	0.27664	0.27664	7.09	0.0000	0.20021	0.35307
Visit frequency	0.00712	0.00712	5.43	0.0000	0.00455	0.00969
Log Likelihood Function		-864.14206	Chi squared			316.5
Restricted LLF		-1022.3921	Significance level			0.0000
McFadden Pseudo R^2		0.1547841	Inf. Cr. AIC			1758.3

Among the 19 actions proposed to the respondent in the choice sets, 7 present a positive coefficient. Specifically, the answers of the citizens provide this ranking of actions (from the most to the least important): Educational tour on the natural and industrial history of the area (2), Cultivated areas of no-food crop (9), Research centre (11), Children play area (16), Dog park (17), Horse farm (8), Farm school (1). Instead, 3 are highlighted as undesirable activities: Skatepark/Roller rink (13), Organised beaches along the river (19) and Study spaces (18).

8.4.3 Identification of a set of criteria to evaluate the sustainability of the scenarios

To achieve high sustainable performance, a set of criteria has to be considered for the evaluation of the scenarios that are gradually created during the simulation process and the interactions among the stakeholders in ABM. The list of criteria is the result of the combination of a literature review developed in Scopus on the main indicators used in MCDA for evaluating urban transformation and the knowledge acquired during the implementation of SWOT and SA. The list of criteria and sub-criteria selected is then hierarchically structured.

Concerning the literature review, the analysis was conducted by consulting the database Scopus on October 2021 and using the following keywords: TITLE-ABS-KEY ("multicriteria" AND "sustainability" AND ("urban development" OR "urban transformation" OR "urban regeneration")). 211 documents result from this research, but only those written after 2015 are investigated more in-depth (i.e., 131 documents). This temporal limit has the aim of considering only manuscripts that can be influenced by the SDG framework set up in 2015. Another selection is then made according to the topic. It was specifically excluded those articles that dealt with the spatial location of facilities, or whose topic was completely different

(hazard, coastal flow, etc.), or when they considered other scales of analysis (e.g., buildings or entire cities). The final list of consulted papers is reported in Table 8.5.

Table 8.5. Papers consulted for the criteria identification

	Authors	Title	Year	Journal
[1]	Caldatto, F.C., Bortoluzzi, S.C., de Lima, E.P., Gouvea da Costa, S.E.	Urban sustainability performance measurement of a small brazilian city	2021	Sustainability
[2]	Della Spina, L., Rugolo, A.	A multicriteria decision aid process for urban regeneration process of abandoned industrial areas	2021	Smart Innovation, Systems and Technologies
[3]	Ustaoglu, E., Aydınoglu, A.C.	Suitability evaluation of urban construction land in Pendik district of Istanbul, Turkey	2020	Land Use Policy
[4]	Nikoloudis, C., Aravossis, K., Strantzali, E., & Chrysanthopoulos, N.	A novel multicriteria methodology for evaluating urban development proposals	2020	Journal of Cleaner Production
[5]	Bisello, A.	Assessing multiple benefits of housing regeneration and smart city development: The european project sinfonia	2020	Sustainability
[6]	Ali-Toudert, F., Ji, L., Fährmann, L., Czempik, S.	Comprehensive Assessment Method for Sustainable Urban Development (CAMSUD) - A New Multi-Criteria System for Planning, Evaluation and Decision-Making	2020	Progress in Planning
[7]	Della Spina, L.	Adaptive sustainable reuse for cultural heritage: A multiple criteria decision aiding approach supporting urban development processes	2020	Sustainability
[8]	Feleki, E., Vlachokostas, C., Moussiopoulos, N.	Holistic methodological framework for the characterization of urban sustainability and strategic planning	2020	Journal of Cleaner Production
[9]	Bottero, M., Oppio, A., Bonardo, M., Quaglia, G.	Hybrid evaluation approaches for urban regeneration processes of landfills and industrial sites: the case of the Kwun Tong area in Hong Kong	2019	Land Use Policy
[10]	Berta, M., Bottero, M., Ferretti, V.	A mixed methods approach for the integration of urban design and economic evaluation: Industrial heritage and urban regeneration in China	2018	Environment and Planning B: Urban Analytics and City Science
[11]	Bottero, M., D'Alpaos, C., Oppio, A.	Multicriteria evaluation of urban regeneration processes: An application of PROMETHEE method in northern Italy	2018	Advances in Operations Research
[12]	Nogués, S., Arroyo,	Alternative approach to	2016	Journal of Urban

	N.L.	prioritization of brownfield reclamation attending to urban development potentialities: Case study in a depressed industrial district in Northern Spain		Planning and Development
[13]	Della Spina, L., Ventura, C., Viglianisi, A.	A multicriteria assessment model for selecting strategic projects in Urban areas	2016	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)

To take into account the contextual factors defining Basse di Stura, the stakeholders interested in the transformation, and the aim of the evaluation, the final list of sub-criteria is the result of some additional considerations. Firstly, the list of sub-criteria obtained from the literature review is screened based on the results of the case study analysis, specifically through SWOT and SA. Secondly, it was deliberatively chosen to not consider some aspects that are related to the way in which actions are implemented, even if strongly connected to sustainability achievement, such as how to manage waste collection, water re-use, or the installation of eco-products. Thirdly, it was excluded from the evaluation all elements connected to the distance and proximity to services and means of transport, since they are independent from the transformation of Basse di Stura. The list of criteria and sub-criteria resulting from this process is presented in Table 8.6. Table 8.6 also reports the stakeholders satisfied by the consideration of the specific sub-criterion and the elements of the SWOT which are achieved or solved by the inclusion of the related sub-criterion, as well as the references from the literature review. It is composed of 24 sub-criteria, clustered into 5 criteria, as follows:

- Environmental quality: collects the aspects that exert a positive influence on the environmental quality of the area;
- Economic performance: considers the economic aspects to be taken into account for the implementation of the scenarios;
- Social quality: contains the aspects with an influence on the perception of quality and well-being of the site for citizens/stakeholders;
- Technological improvement: takes into account the aspects able to increase the technological performance of the area;
- Urban quality: measures the structural design of the urban development;

Table 8.6. List of sub-criteria resulting from the literature review and the preliminary analysis

	Sub-criteria	SWOT*[1]	SA*[2]	References
Environm	Prevention extreme events	W, O, T	M, E	[2, 6, 11]
	Green areas	S, O	C, E, M	[2, 6, 8, 9, 10, 11,

	organized			13]
	Rehabilitation of polluted areas	W, T	C, E, M	[2, 6, 10, 11, 12]
	Local air quality	W, T	E, M	[4, 5, 6, 7, 8]
	Biodiversity	O	E	[6]
	Local economic development (e.g. paid activities)	S, W, O, T	C, D, M, O	[1, 5, 6, 10]
	Public Investments	W	D, O	[2, 4, 6, 7, 9, 10, 11]
Economic	Private Investments	W	M	[2, 4, 7, 9, 10, 11]
	Maintenance costs limited	W	D, M	[2, 4]
	Activities for UE funds attraction (e.g. Piano Nazionale di Ripresa e Resilienza - PNRR)	W, O	D, M	[5, 6, 7, 8]
	Recreational activities	W, O	D, M, O	[2, 4, 6, 7, 8, 10, 11, 13]
	Sports activities / Health	W, O	C, M	[1, 2, 4, 5, 10, 13]
Social	Historical-cultural activities	S, W, O	C, M	[6, 7, 10, 13]
	Job	S, W, O	C, M	[1, 2, 4, 5, 6, 10, 11]
	Enhanced neighbourhood identity	W, O	C, D, M, O	[4, 5, 6, 10]
	Energy consumption		D, E, M	[5, 6, 7, 8, 10]
Technology	Natural resources and renewable energies	S, T	D, E, M	[1, 2, 5, 6, 7, 8]
	Technological innovation	O	D, O	[5, 6]
	Agriculture production	O	D, M, O	[6]
	Functional mixite		D, C, M, O	[2, 6, 7, 8, 11, 12]
	Natural amenities integration	S, W, O	C, E, M	[3, 6, 9, 12]
Urban quality	Integration of existing structure	S, W, O	D, O, M	[6, 9, 10]
	Safety against degradation	W, T	D, E, M, O	[6, 7, 10]
	Flexibility		D, M, O	[6, 7]
	Urban/Region plans coherence		D, M, O	[5, 6, 12]

***[1] S = strength, W = weakness, O = opportunity, T = threat**

***[2] D = developer, C = citizen, E = environmental agency, M = municipality, O = owner**

Then, the hierarchical structure of the evaluation is presented in Figure 8.7, showing the goal/objective of the evaluation, the criteria, and the sub-criteria.

According to AHP, an important step is constituted by the weighting phase. However, in this application, a neutral scenario was adopted, which gives all the criteria and sub-criteria the same influence. This choice was made considering that the preferences of the stakeholders are included in the selection of the actions during the ABM simulation and the construction of the utility functions (see Section 8.4.4.3).

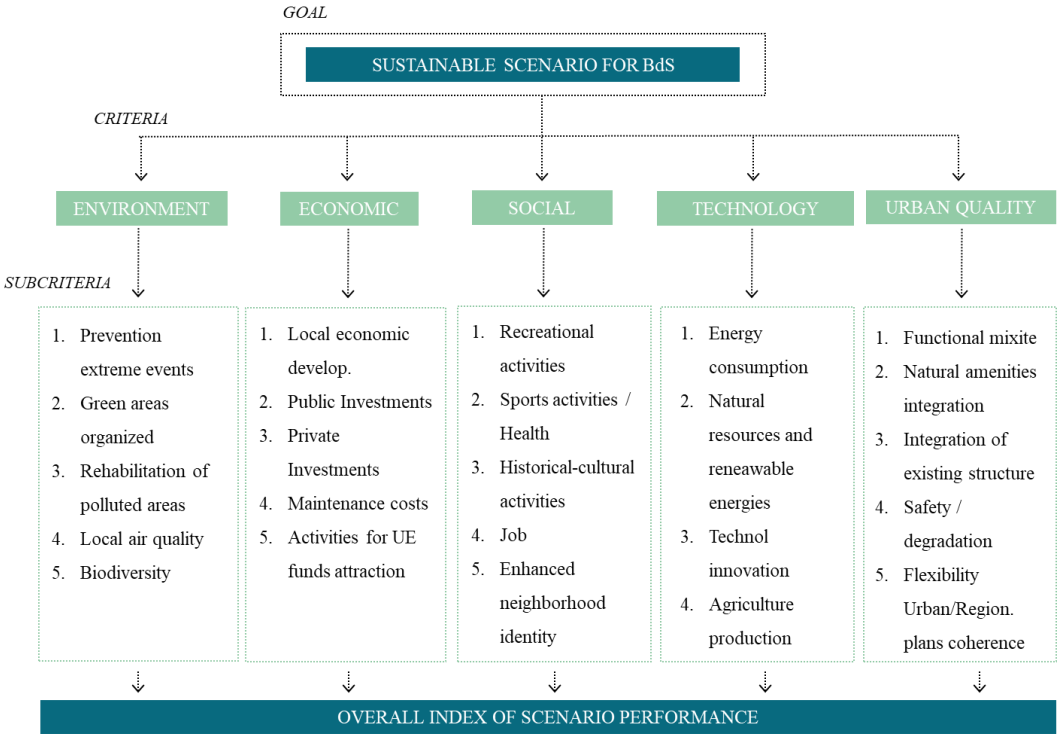


Figure 8.7. The hierarchic structure of criteria and sub-criteria

8.4.4 The spatially explicit MAS

The ABM simulation was developed in Netlogo 6.1.1 (see Appendix A.3). Netlogo software is generally composed of two phases for the implementation of the simulations, i.e., the setup and the go, respectively. On one hand, the setup is devoted to the initialization of agents and of the environment. Since the application uses spatially explicit data, the maps created in GIS are also included in the first lines of the code. On the other hand, the go contains all the procedures that are simulated over time. In this application, each simulation run is based on these 5 main steps.

In the first step, criteria performances and their related standardized values are updated. In fact, once an action is activated, a change in one or more criteria performances is detectable. The criteria are measured by specific mathematical formulas that are based on a set of spatial indicators.

In the second step, the stakeholders calculate their own utilities, which are

based on the types of actions activated in the previous step and the weights assigned through the BWM or the RP+SP survey. At this stage, the stakeholder with the lowest utility value has priority in the choice of the action to be activated.

In the third step, the stakeholder with the lowest utility can choose one of his/her preferential actions that is able to increase a low performance criterion.

In the fourth step, the action finds its suitable location, based on the BAU land uses and the compatibility with the surrounding land uses. The compatibility of land uses is defined both between actions and land uses of the BAU scenario and between actions and land uses developed during the simulation runs (i.e., once actions are activated). Moreover, the extension of each action is randomly defined for each simulation, in a range between the minimum and maximum surface extension defined in the first stage by the panel of experts.

The last step is devoted to the update of all dynamic variables in the model and the calculation of the sustainable performance index of the scenario.

The following paragraphs will present one by one the procedures implemented in the model, both in the setup and in the go phase. The result of setup and go allows, at the end of the simulation run, the creation of sustainable balanced scenarios that combine stakeholders' preferred actions and sustainable performances for transforming area of Basse di Stura.

The initialization phase is composed of the set of procedures needed for setting the environment and the agents into ABM. In spatially explicit simulations, the first group of codes is constituted by the integration of all the GIS extensions required in the model. In this application, the most relevant maps contain information related to the land uses of the business-as-usual scenario (BAU) (i.e., the state of the art of the area before any hypothetical transformation). The initialization phase contains 11 land uses: lake, road and built area, wood, green areas, uncultivated pasture, agricultural area, commercial and industrial area, riverbank, landfill, and residential area. The land uses are now assigned to each patch of 10x10 that composes the model. Moreover, additional maps are included in Netlogo to take into account some constraints related to the ownership, the morphology, and the buildable limits of the areas. These latter maps are useful in determining the suitable locations of the actions selected by the stakeholders (see Section 8.4.4.4).

Firstly, the PAI (Piano di Assetto Idrogeologico) limits indicate the area with major risks of landslides and floods, with the aim of safeguarding the safety of people and minimizing damage to goods around them. Therefore, the model excluded for buildable actions (such as the research centre) all the areas in the first band, i.e., the riskiest. Secondly, another important piece of information for the implementation of building actions is contained in the map with the classification of the areas according to the territorial index. As mentioned in the description of the case study, Basse di Stura presents a low level of buildability, that spans from 0.01 to 0.15 sqm GFA (gross floor area) over sqm of buildable area. Thirdly, the ownership map contains the information about the areas of public and private property. Some activities and their related actions require that the areas have been already of public bodies for their more rapid implementation (such as cycle paths

or children playground); others, instead, take advantages from the direct sales between private entities.

After the inclusion of GIS extensions, the model can create the agents. In this application, three types of agents (also called breeds) are defined: i) criteria; ii) actions; and iii) stakeholders. Only the latter breed is a real agent, in the meaning that this PhD research gives to this word. However, in this application, criteria and actions are considered agents in order to allow the connections through links among these three entities. In the software adopted the only way to connect with links is having elements as agents. This is due to the many procedures in the simulation runs that require the execution of criteria and actions, according to the performance of the area and the preferences of the stakeholders. Specifically, the links between actions and criteria describe whether the action is able to increase the performance of one or more criteria. The links between actions and stakeholders contain the information about higher or lower preference of the stakeholders for the actions. The three groups of agents have their own specific variables, as illustrated in Table 8.7.

Table 8.7. Detailed description of static and dynamic variables used in the present application

Agent group	Number	Variables	Static/Dynamic	Description
Criteria	25	Name	Static	Name of each criterion (e.g., E1, E2…, E25)
		Performance	Dynamic	Performance contains the result of the specific calculation to measure each criterion (e.g., E1 performance is equal to the sum of all permeable land uses in the area).
		Standardized performance	Dynamic	This variable translates the performance value in a standardized value between 0 and 1
Actions	19	Land use	Static	The land use variable is used to distinguish the actions (e.g., Allotments, Dog area, Beach, etc.)
		Activation	Dynamic	Activation indicates if the action is activated or not in the scenario (yes/no)
Stakeholders	5	Name	Static	Name defines to which group the stakeholder belongs (i.e., citizen, municipality, developer, owner, environmentalist)
		Utility	Dynamic	Utility expresses the utility value of each stakeholder based on the actions activated in the scenario (0-1)
		Order-chooser	Dynamic	Order-chooser assigns the order of choice among the stakeholders. It is defined per each step based on the utility value calculated in the previous step
Links	499	Priority	Static	Priority indicates how much importance the stakeholders assign to each action.

Once the model is initialized, it is possible to model the other main steps that constitute the proposed model (as described at the beginning of this section). In

particular, steps 1 and 5 jointly support the calculation of the sustainable index.

The calculation of the sustainable index is done for each simulation step. However, a distinction is needed between the sustainable index calculated in the first step (named P_0) and the ones assessed in the following steps (P_1). In fact, for the first step, no actions have been implemented yet, and the sustainable index P_0 is calculated for the BAU scenario. While, for steps higher than 1, the indexes P_1 are measured according to new land uses, where the new uses are based on the actions implemented in each step and the surface covered by these actions. Therefore, P_1 do not consider the old land uses already there for its calculation.

For the calculation of P_0 and P_1, the performance of all the sub-criteria has to be assessed. Also, in this case, the performance is measured in different ways according to the step of the simulation. In fact, the calculation of the sub-criterion performance is based on the land uses that are present in each step. This stage is important since the selection of the action to be implemented is not only in charge of the stakeholder preferences but also depends on the low level of performance of some sub-criteria both in the BAU scenario (step = 1) and the ongoing transformation (step > 1). In fact, the model selects for each run one sub-criterion that has the lowest performance level among the entire list of sub-criteria. To do this, a standardization of all sub-criteria is needed to compare performances that originally have different units of measurement with the same value scale, i.e., between 0 and 1.

Table 8.8 presents for each sub-criterion its unit of measurement and how its performance is calculated respectively in step 1 (T0 performance) and a step higher than 1 (T1 performance). Moreover, it presents the standardization of the sub-criterion performances.

Table 8.8. Performance table

	Sub-criteria	u.m.	T0 performance	T1 performance[a]	Standardization
Environmental	Prevention extreme events	sqm permeable	Agriculture + Green Area + UncPasture + Wood + Riverbank + Lake + River	((SE1surf*80%) + (SE4surf*100) + (NA1surf*100%) + (NA2surf*100%) + (NA3surf*100%) + (NA4surf*70%) + (BE1surf*100%) + (BE2surf*80%) + (SA3surf *100%) + (SA4surf*100%) + (OS1surf*100%) + (OS2surf*100%) + (OS3surf*100) + (OS4surf*100%))	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = total BdS surf
	Green areas organized	sqm	0	((NA1surf*100%) + (NA2surf*100%) + (NA3surf*100%) + (NA4surf*80%) + (SA3surf *100%) + (SA4surf*100%) + (OS1surf*100%) + (OS2surf*100%) + (OS3surf*100) + (OS4surf*100%))	$(X - x_{min}) / (x_{max} - x_{min})$ areas $x_{min} = 0$ x_{max} = total BdS surf
	Rehabilitation of polluted areas	sqm	500092[b]	Surface modified	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = total BdS surf
	Local air quality	CO_2 * sqm actions	(Agriculture*surf + GreenArea*surf + UncPasture*surf + Wood*surf + Riverbank *surf + Lake*surf + River*surf) – (Lanfill *surf + RoadBuilt*surf + Residential*surf + Farmhouses*surf + Commercial-Industrial*surf)	- SE1surf + SE2surf*0 – SE3surf + SE4surf + NA1surf*0 +NA2surf*0 + NA3surf*0 + NA4surf + BE1surf + BE2surf – BE3surf + SA1surf*0 + SA2surf*0 + SA3surf + SA4surf + OS1surf + OS2surf + OS3surf + OS4surf*0	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = total BdS surf
	Biodiversity	Number of species attractor actions	Agriculture*1 + GreenArea*1 + UncPasture*1 + Wood*1 + Sponda*1 + Lake*1 + River*1 – Lanfill*1 – RoadBuilt*1 – Residential*1 – Farmhouses*1 – Commercial-Industrial*1	SE1*1 + SE2*0 – SE3*1 + SE4*1+ NA1*1 +NA2*1 + NA3*1 + NA4*1 + BE1*1 + BE2 0 – BE3*1 + SA1*0 + SA2*0 + SA3*1 + SA4*1 + OS1*0 + OS2*0 + OS3*1 + OS4*1	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = 6 (max possible with intervention)
Economic	Local economic development (e.g., paid activities)	Number of actions (excluded industrial and commercial)	0	SE1 + SE2 + SA4 + NA1 + NA2 + NA3 + NA4 + TE2 + SA1 + OS4	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = 10 (max possible interventions)
	Public Investments	Number of actions attracting	0	SE1 + SE2 + SE3 + SE4 + NA1 + BE1 + BE3 +	$(X - x_{min}) / (x_{max} - x_{min})$

		public investments		SA1 + SA2 + SA3 + SA4 + OS1 + OS2 + OS3 + OS4	$x_{min} = 0$ $x_{max} = 15$ (max possible interventions)
	Private Investments	Number of actions attracting private investments	0	SE1 + SE4 + NA2 + NA3 + NA4 + BE2 + BE3 + SA1 + OS4	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 9$ (max possible interventions)
	Maintenance costs	Qualitative: costs (high 1, medium 0.5, low 0)	Agriculture (med) + GreenArea (low) + UncPasture (low) + Wood (low) + Riverbank (low) + Lake (low) + River (low) + Lanfill (high) + RoadBuilt (low) + Residential (med) + Farmhouses (low) + Commercial–Industrial (high)	SE1 (low) + SE2 (low) + SE3 (low) + SE4 (low) + NA1 (low) + NA2 (low) + NA3 (med) + NA4 (med) + BE1 (med) + BE2 (med) + BE3 (high) + SA1 (med) + SA2 (low) + SA3 (low) + SA4 (low) + OS1 (low) + OS2 (low) + OS3 (low) + OS4 (low)	$(X - x_{min}) / (x_{max} - x_{min})$ x_{min} = sum of all possible actions with med or high maintenance costs $x_{max} = 0$
	Activities for UE funds attraction (e.g. Piano Nazionale di Ripresa e Resilienza - PNRR)	Number of actions attracting UE funds	0	SE1 + SE2 + SE3 + SE4 + NA1 + BE1 + BE2 + BE3	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 8$ (max possible interventions)
Social	Recreational activities	Number of recreational actions	0	SE1 + SE2 + SE3 + SE4 + NA1 + NA2 + NA3 + NA4 + SA1 + SA2 + SA3 + SA4 + OS1 + OS2 + OS3 + OS4	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 16$ (max possible interventions)
	Sports activities / Health	Number of sporty actions	0	NA2 + NA4 + SA1 + SA2 + SA3 + SA4 + OS1	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 7$ (max possible interventions)
	Historical-cultural activities	Number of historical-cultural activities	0	SE1 + SE2 + NA1 + BE3	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 4$ (max possible

					interventions)
	Job	Qualitative: number of job created (likert scale 1-5)	Agriculture (0) + GreenArea (0) + UncPasture (0) + Wood (0) + Riverbanck (0) + Lake (0) River (0) + Lanfill (0) + RoadBuilt (0) + Residential (0) + Farmhouses (0) + Commercial-industrial (5)	SE1 (1) + SE2 (1) + NA1 (1) + NA3 (2) + NA4 (2) + BE1 (2) + BE2 (1) + BE3 (5) + SA1 (3) + OS4 (1)	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = 14 (max possible with intervention with an average job level equal to 2)
	Enhanced neighbourhood identity	Qualitative: level of enhanced of each action (high 1, medium 0.5, low 0)	0	SE1 (0.5) + SE2 (1) + SE3 (0.5) + SE4 (1) + NA1 (1) + NA2 (1) + NA3 (0) + NA4 (0) + BE1 (1) + BE2 (0) + BE3 (0.5) + SA1 (0.5) + SA2 (0.5) + SA3 (0) + SA4 (0) + OS1 (0) + OS2 (0) + OS3 (0) + OS4 (1)	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = 8 (max possible interventions)
Technology	Energy consumption	sqm actions * kWh Non-residential buildings are on average 40% more energy intensive than residential buildings (250 kWh/m^2 compared to 180 kWh/m^2)	Residentialsurf * 180 + Commercial-industrial * 250	SE1surf * 180 + SE3surf * 180 + NA3surf *180 + NA4surf * 180 – BE2surf * 250 + BE3surf * 250 + SA1surf * 180	$(X - x_{min}) / (x_{max} - x_{min})$ x_{min} = - BdS surface * 250 (as all industrial) x_{max} = + BdS surface * 250 (as all reneawable energy)
	Natural resources and renewable energies	sqm	0	BE2surf	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = BdS surface
	Technological innovation	Number of technological actions	0	BE1 + BE2 + BE3	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = 3 (max possible interventions)
	Agriculture production	sqm	0	SE1surf + SE4surf + BE1surf	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = max possible surface
Ur	Functional mixite	Number of different actions			

Natural amenities integration	Qualitative: high (if more than 2 actions integrated), medium (if 2 actions integrated), low (0)	0	SE1 + SE4 + NA1 + NA2 + NA3 + NA4 + BE1 + OS4	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 4$ → half of the max possible number with intervention
Integration of existing structure	sqm redeveloped of existing structures	0	Sqm redeveloped of existing structures	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = Residential + Industrial-Commercial + RoadBuilt
Safety against degradation	sqm transformed	197.030 (Residential + Commercial-industrial) * 70% (70% and not 100% because some areas are abandoned)	sqm with actions	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = BdS surface
Flexibility	sqm changeable	Agriculture + GreenArea + UncPasture + Wood	SE2surf + SE4surf + NA1surf + NA2surf + BE1surf + BE3surf + SA3surf + SA4surf + OS1surf + OS2surf + OS3surf + OS4surf	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ x_{max} = BdS surface
Urban/Region plans coherence	Number of compatible actions	0	SE2 + SE4 + NA1 + NA2 + BE1 + BE3 + SA3 + SA4 + OS1 + OS2 + OS3 + OS4	$(X - x_{min}) / (x_{max} - x_{min})$ $x_{min} = 0$ $x_{max} = 12$ (max possible actions)

a 0 means neutral

b Already reclaimed areas, calculated in QGIS

Another important piece of information is related to the types of actions that are able to increase the performance of each sub-criteria. This is useful both for the calculation of P_1 and the creation of the connections between actions and sub-criteria. This latter aspect allows the stakeholders to select the most preferential action among the set of possible actions able to increase the low performance of the sub-criteria. The model highlights the set of sub-criteria with the lowest performance and the stakeholder with the lowest utility in each simulation. This latter stakeholder first chooses the action that can improve one of the sub-criteria with the lowest performance, from a set of preferential actions.

For this purpose, a matrix (Table 8.9) was jointly built with the help of the expert panel to appropriately connect actions and sub-criteria.

Table 8.9. Relation between actions and sub-criteria

	Sub-criteria	SE1	SE2	SE3	SE4	NA1	NA2	NA3	NA4	BE1	BE2	BE3	SA1	SA2	SA3	SA4	OS1	OS2	OS3	OS4
Environmental	Prevention extreme events	80%	0	0	100%	100%	100%	100%	70%	100 %	80%	0	0	0	100 %	100 %	100 %	100 %	100 %	100 %
	Green areas organized	80%	0	0	0	100%	100%	100%	70%	0	0	0	0	0	100 %	100 %	100 %	100 %	100 %	100 %
	Rehabilitation of polluted areas	100%	0	100%	100%	100%	100%	100%	100%	100 %	0	100%	100%	100 %	100 %	100 %	100 %	100 %	100 %	100 %
	Local air quality	80%	0	-100%	+100 %	+100 %	+100 %	+100 %	+70%	100 %	100%	-100%	100%	100 %	100 %	100 %	100 %	100 %	100 %	100 %
	Biodiversity	1	0	-1	1	1	1	1	1	1	0	-1	0	0	1	1	0	0	1	1
Economic	Local economic development (e.g. paid activities)	x	x		x	x	x	x	x		x		x							
	Public Investments	x	x	x	x	x				x		x	x	x	x	x	x	x	x	x
	Private Investments	x			x		x	x	x		x	x	x							x
	Maintenance costs limited	low	low	low	low	low	low	med	med	med	med	high	med	low	low	low	low	low	low	low
	Activities for UE funds attraction (e.g. Piano Nazionale di Ripresa e Resilienza - PNRR)		x	x	x	x				x	x	x								
Social	Recreational activities	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x
	Sports activities / Health						x		x				x	x	x	x	x			
	Historical-cultural	x	x			x						x								

	activities																			
	Job	1	1			1		2	2	2	1	5	1							1
	Enhanced neighbourhood identity	med	high	med	high	high	high	low	low	high	low	med	med	med	low	low	low	low	low	high
Technology	Energy consumption	20%*180		100%*180					30%*180		100%*250	100%*250	-20%*180							
	Natural resources and renewable energies									x	x	x								
	Technological innovation							x		x	x	x								
	Agriculture production	80%			100%					100%										
Urban quality	Functional mixite	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Natural amenities integration	x			x	x	x	x	x	x										x
	Integration of existing structure		x		x	x	x			x					x	x	x	x	x	x
	Safety against degradation		x		x	x	x			x		x			x	x	x	x	x	x
	Flexibility																			
	Urban/Region plans coherence																			

8.4.4.3 Stakeholders' utility functions

Then, steps 2 and 3 allow to calculate the stakeholders' utility functions and to establish the stakeholder least satisfied for each simulation step. The least satisfied stakeholder will be given priority in deciding which action to take in the next step. In fact, the utility depends on a personal utility likelihood function of the stakeholders that considers the actions activated in the previous step of the simulation and the weights assigned by stakeholders through BWM and RP+SP.

Therefore, in order to obtain the utility of each stakeholder, the model needs to record the actions activated in each simulation step. This happens in the model by assigning a binary value to the action variable named "activation", equal to 1 if the action has been activated in previous steps, while 0 if it has never been activated. Obviously, this code is only executed when the number of simulation steps is greater than 1. In fact, in the first run, no stakeholders have calculated their utility, since the area is still characterized by the BAU scenario. In this application, it is therefore chosen to randomly choose the first stakeholder who selects the action to be developed in Basse di Stura in the simulation step equal to 1.

The stakeholder utility is calculated as follows (eq. 8.1):

$$U_j = \sum_{i=1}^{n} W_{ij} * \left(\sum_{z=1}^{m} w_{zj} * a_z\right) \quad (8.1)$$

Where U_j is the utility of the stakeholders *j*, calculated as the weighting sum of all the activities (n = 1, 2, …, 5) and related actions (m = 1, 2, …, 19) when activated in the area ($a_z = 1$). The utility is equally calculated for the developer, the environmental expert, the municipality, and the owner. The differences in the utilities of the stakeholders are given by the weights W_{ij} (i.e., the relative importance) assigned by the stakeholder *j* through BWM to the activity *i*, and w_{zj} the relative importance assigned to the action *z*. This equation is like the mobility likelihood calculation in the previous application (Chapter 7), calculated as an individual weighting sum.

For the citizens, the utility is calculated in a very similar way, but the weighting sum is only constituted by those actions considered important in the RP+SP survey, i.e., Farm school, Educational tours, Horses farm, Cultivated areas of no-food crop, Research centre, Skatepark/Roller rink, Children's play area, and Dog area. Since the number of sub-criteria is lower than for the other stakeholders, the weighting sum is then normalized to translate the value into the range between 0 and 1. Therefore, the utility of the citizen (U_j) is calculated as follows (eq. 8.2):

$$U_j = \frac{\left(\sum_{z=1}^{m} w_{zj} * a_z\right)}{p} \quad (8.2)$$

Where p is used to standardize the utility, based on the maximum value

deriving from the sum of the weights w_{zj} in the case where all actions preferred by the citizen are activated.

At this stage, the model is able to highlight the stakeholder with lower utility function and the sub-criteria with lower performances. The stakeholder therefore selects his/her preferential action, which is also the one that increases the low performance of one of the sub-criteria. Theoretically, the selected action can be implemented in Basse di Stura. Practically, it should find a suitable location (step 3 of the model). The selection of a suitable location is based on five aspects or constraints.

The first constraint refers to the possibility of developing new land uses. This aspect implies that areas already implemented with actions are no longer available options.

The second aspect regards the locational suitability of new land uses (i.e., actions) according to the previous land uses of the BAU scenario. With the help of the expert panel, the highest (green), medium (yellow), and lowest (red) suitable original land uses were defined for each action. The result of this discussion is synthetized in Table 8.10.

The third aspect considers the suitability of land uses around the potential new action implemented. To do this, the action finds the parcel around which the highest number of suitable land uses can be counted. Each action calculates this latter value according to a specific radius. This specific radius is based on the surface assigned to the action at the beginning of the simulation step. More details about the definition of the radius are given below, when the fourth aspect is described. As for the second step, a table with the land uses suitable to be around the new actions was jointly developed with the support of the expert panel, as shown in Table 8.11. In Table 8.11 the sign "+" means good compatibility, "0" neutral, and "-" negative match.

The fourth aspect that the action has to consider is the surface to be covered. This surface is assigned randomly between the minimum and maximum values in each simulation run. For each action, these minimum and maximum surface values are grounded on an analysis of existing case studies and/or prototypes, as detailed in Table 8.12.

The fifth constraint eventually occurs in two circumstances. The first circumstance is when a buildable action must be implemented. In this case, two aspects need to be considered: the territorial index and the PAI bands. On the one hand, the action will select, but without excluding, the available areas with the highest territorial index. On the other hand, all the areas inside the PAI bands are excluded from the selection. The second circumstance happens when private or public ownership is required. In this case, the action will prefer, but without excluding, the parcels that are not characterized by the desired ownership. It is the case of cycle paths that are more easily implemented if located in public property areas.

As it is possible to see in Table 8.12 by looking at the unit of measurement, it is worth mentioning that some actions are implemented as areal surfaces, such as the farm school or the research centre, others as lines, such as the cycle paths or the educational tours.

Table 8.10. Land uses suitability compared to the BAU scenario

LANDUSE	Agriculture	Green area	Unculture pasture	Wood	Riverbank	Lake/River	Landfill	Road/Built	Residential	Commercial/ Industrial
Farm school										
Educational tours										
Social hub										
Allotments										
Nature trails										
Birdwatching										
Butterflies										
Horse farm										
No food crops										
Bio-energies										
Research center										
Soccer/tennis fields										
Skatepark/roller rink										
Outdoor equipment										
Cycle paths										
Child area										
Dog area										
Study area										
Organised beach										

Table 8.11. Land uses suitability compared to the ongoing scenario

LANDUSE	SE1	SE2	SE3	SE4	NA1	NA2	NA3	NA4	BE1	BE2	BE3	SA1	SA2	SA3	SA4	OS1	OS2	OS3	OS4
Farm school		+	+	+	+	+	+	+	+	-	-	0	0	0	+	+	-	+	0
Educational tours	+		+	+	+	+	+	+	+	-	+	0	0	0	+	+	0	+	0
Social hub	+	+		+	+	+	+	+	+	-	0	+	+	+	+	+	+	+	+
Allotments	+	+	+		+	+	+	0	+	0	0	0	0	0	0	0	0	0	0
Nature trails	+	+	+	+		+	+	+	+	-	-	-	-	0	+	+	-	0	0
Birdwatching	+	+	0	+	+		+	+	+	-	-	-	-	0	+	+	-	0	0
Butterflies	+	+	0	+	+	+		+	+	-	-	+	+	+	+	+	+	0	+
Horse farm	+	+	0	+	+	+	+		0	-	-	+	+	+	+	+	-	0	0
No food crops	+	+	0	+	+	0	0	0		+	+	0	0	0	0	0	0	0	0
Bio-energies	0	0	0	0	0	0	0	0	0		+	0	0	0	0	0	0	0	0
Research center	+	+	0	+	+	0	+	0	+	+		+	+	+	+	0	0	+	+
Soccer/tennis fields	+	+	+	0	+	+	+	+	0	+	+		+	+	+	+	+	+	+
Skatepark/roller rink	0	0	0	0	0	0	0	0	0	0	+	+		+	+	+	+	+	+
Outdoor equipment	+	0	+	0	+	0	0	+	0	-	0	+	+		+	+	+	+	+
Cycle paths	+	+	+	+	+	+	+	+	+	-	+	+	+	+		+	+	+	+
Child area	+	+	+	+	+	+	+	+	+	-	0	+	+	+	+		+	+	+
Dog area	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	+		0	0
Study area	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	0	0		+
Organised beach	+	+	+	0	+	+	+	+	+	-	+	+	+	+	+	+	+	+	

Table 8.12. Identification of the minimum and maximum values for each action

Land uses	u.m.	Min-surf	Max-surf	Description	Explanation of min and max	Sources
Farm school	m^2	2000	400000	Analysed all farmhouses in the province of Turin	min: Mulino Sambuy (San Mauro Torinese) - 2400 m^2; max: Coop agricola il frutto permesso (Bibiana) - 40 hectares	http://www.piemonteagri.it/qualita/it/progetti-e-attivita/educazione-alimentare-e-fattorie-didattiche/cerca-fattorie%20%20
Educational tours	m	5000	15000	The average human walking speed at crosswalks is about 5.0 Km per hour	It is defined the minimum equal to 5 km of walk for the tour, the maximum as 15 km walk	Aspelin, K (2005) Establishing Pedestrian Walking Speeds. Portland State University
Social centre	m^2	1600		In the city of Turin, there are 8 Social Hub (called "Case del quartiere") with a total extension of 12700 sqm	Dividing 12700 sqm for the 8 "Case del quartiere", it is possible to obtain the average value equal to 1600	http://www.retecasedelquartiere.org/
Allotments	m^2	310	8000	Examination of national and international urban allotments, as well as the ideal surface for one person allotment. Examples: Officina Verde Tonolli in Turin (8000 smq), Giardin8 in Turin (100 smq), New York (6500 smq), Parigi (14.000 smq), Milan (500.000 smq – under develepoment)	Min: 10 people: (120 smq x 2) + 70 sqm = 310 smq; max: 8000 smq (based on the bigger case study of Turin)	https://ortiatuttogas.it/quali-sono-le-dimensioni-ideali-per-un-orto/ https://ormetorinesi.net/ and various web pages for the other case studies outside Turin
Nature trails	m	25% of the river extension	river extension	The minimum and maximum values were chosen proportionally to the extension of the river	river extension: 3000 smq	
Birdwatching	m	25% of the river extension	river extension	The minimum and maximum values were chosen proportionally to the extension of the river	river extension: 3000 smq	

Butterfly farm	m^2	370	8000	Examination of national and international butterfly farms. Examples: Butterfly farm d'Abruzzo (inside a big park) (10000 smq); Guinnes world record in Malaysia (8000 smq); Niagara Parks Butterfly Conservatory (1000 smq); Victoria Butterfly Gardens (1100 smq); Cali Zoo Colombia (450 smq); Butterfly Pavilion in Colorado (2800 smq); butterfly house in Western Colorado Botanical Gardens and Butterfly House (370 smq); Konya Tropical Butterfly Garden (7600 sqm); Kuala Lumpur Butterfly Park (7400 smq); Butterfly Garden or Jardin des Papillons in Grevenmacher in eastern Luxembourg (600 smq)	Min: 370 sqm (butterfly house in Western Colorado Botanical Gardens and Butterfly House); max: 8000 sqm (Guinness world record in Malaysia)	https://en.wikipedia.org/wiki/List_of_butterfly_houses and various web pages for surface details
Horse farm	m^2	800	1000	Examination of the minimum dimension of a common horse farm and chosen the maximum.	Min (space for 1 horse and dressing room for 2): 20 x 40 + 4 x 3 + 6.5 x 2 = 825 sqm; Max (10 horses + double dressing room for 2 people): 20 x 40 + 4 x 3 x 10 + 6.5 x 4 = 946 sqm	https://www.google.com/search?q=maneggio+dimensioni&rlz=1C1GCEB_itIT881IT881&oq=maneggio+dimensioni&aqs=chrome..69i57j0i22i30.3936j0j7&sourceid=chrome&ie=UTF-8
No food crops	m^2	310	Permeable area	Examination of national and international the ideal surface for one person allotment, and then proportioned to have an adequate surface of no food crops	Min (10 people: (120 x 2) + 70 = 310 sqm; Max: BdS green permeable area	https://ortiatuttogas.it/quali-sono-le-dimensioni-ideali-per-un-orto/
Bio-energies	m^2	50% of not permeable area	Entire surface	A typical photovoltaic system of 6 kWh covers around 50 sqm on a roof. This data was useful to identify the right proportion compared to the not permeable area in Basse di Stura	Min: 50% of not permeable area; Max: entire surface of Basse di Stura	https://www.fotovoltaiconorditalia.it/idee/costo-impianto-fotovoltaico-6-kw#:~:text=Un%20impianto%20fotovoltaico%20da%206%20kw%20realizzato%20sul%20classico%20tetto,di%20una%20famiglia%20%E2%80%9Cstandard%E2%80%9D
Research center	m^2	5% of industrial area	All industrial surface of Via Reiss Romoli	Industrial area in Via reiss romoli has an extension around 287000 sqm), a big building in the area covers about 15510 sqm	Min: 5% of industrial area; Max: All industrial surface of Via Reiss Romoli	

Soccer/tennis etc. fields	m^2	1920	4692	Soccer: 44-65 x 25-40 smq (50 x 30 sqm); tennis: 24 x 11 sqm; volleyball: 18 x 9 sqm; basket: 15 x 28 sqm	Min: 1920 sqm (Soccer + tennis/volleyball + basket); Max: 4692 sqm (all activities x 2)	various web pages for sporty surface, such as: https://www.federtennis.it/Giocare-a-tennis/Conosci-il-tennis/Il-campo#:~:text=Il%20campo%20da%20tennis%20ha,dei%20paletti%2C%20posizionati%20nei%20corridoi
Skatepark/roller rink	m^2		1600	Examination of national and international the ideal surface for a skatepark		https://www.google.com/search?q=skatepark+misure&source=lmns&rlz=1C1GCEB_itIT881IT881&hl=it&sa=X&ved=2ahUKEwiG2MqE46T0AhUtIMUKHW7rAsYQ_AUoAHoECAEQAA
Outdoor equipment	m^2	50	300	Examination of Turin outdoor equipment. Examples: Meisino (80 smq); Salvemini (50 smq); Colonnetti (50 smq); Valentino (300 smq); Giardino Luigi Firpo (130 smq); Giardini del Fante (150 smq)	Min: 50 smq (Colonnetti); Max: 300 smq (Valentino)	http://www.comune.torino.it/verdepubblico/sport-nel-verde/
Cycle path	m	1000	7000	Different measures are taken in GIS for identifying the minimum and maximum extension of the cycle path.	Min: 1000 (from Via Reiss Romoli to the river); Max: 7000 sqm (extension of the border of the area of Basse di Stura)	
Children's play area	m^2	250	500	It was considered as a minimum, the ideal surface for a complete children's play area, while for the maximum, a surface equal to the double, which can also have a picnic area	Min: 250 smq; Max: 500 sqm	https://www.mise.gov.it/images/stories/mise_extra/phpm1A8g6La%20sicurezza%20dei%20parchi%20gioco.pdf
Dog area	m^2	250	500	It was used the same proportion of a children's play area		
Study spaces	m^2	60	1000	Examination of Turin study spaces. Examples: Principe Amedeo (96 workstations); Verdi (143 workstation); Michelangelo Buonarroti (184 workstations); Ormea (134 workstations); Murazzi student zone (250 workstations). Moreover, it was examinate the regulation law (more than 60 smq and for each student 7 sqm)	Min: 60 sqm (minimum law); Max: 1000 sqm (around 150 workstations, as around the average of the number of study spaces in Turin)	https://www.miur.it/0002Univer/0105Valuta/0621Docume/2811Estrat_cf2.htm#:~:text=le%20aule%20non%20devono%20essere,corridoi%2C%20bagni%2C%20etc.) http://www.studyintorino.it/it/studiare-a-torino/sale-studio-biblioteche/
Organised beach	m	25% of the riverbank extension	Entire riverbank	The minimum and maximum values were chosen proportionally to the extension of the river	Min: 25% of the riverbank extension; Max: Entire riverbank	

8.5 Results

The model was run many times under the same experiment, but varying the stop conditions. In this application, the stop condition is not based on the flow of time, as in Chapter 6 and Chapter 7. Conversely, the ticks (i.e., the clock in Netlogo) refer to the accomplishment of the Basse di Stura transformation. This can happen in the model in different ways:

(i) when all the actions (i.e., 19) are developed;

(ii) if one or more stakeholders are satisfied by the transformation;

(iii)when the area has been completely transformed;

(iv)the combination of (i), (ii) and (iii).

For all the stop conditions, the simulations always produce the same graphical representation and output of data. For the graphical representation, at the end of each simulation, the model is asked to show in the interface of Netlogo where the actions are located and their extensions, through the use of a specific colour. Specifically, the following colours are assigned to each action (Table 8.13):

Table 8.13. Colour assigned to each action in Netlogo

Action	Netlogo colour number	Colour
Farm school	6	
Educational tours	16	
Social hub	26	
Allotments	36	
Nature trails	46	
Birdwatching	56	
Butterflies	66	
Horse farm	76	
No food crops	86	
Bio-energies	96	
Research center	106	
Soccer/tennis fields	116	
Skatepark/roller rink	126	
Outdoor equipment	136	
Cycle paths	24	
Child area	34	
Dog area	44	
Study area	64	
Organised beach	94	

Then, the interface produces the representation shown in Figure 8.8. The yellow lines represent the links that connect actions and sub-criteria, and stakeholders and actions. The colors of the areas help the visualization of the

actions in their locations and approximately their extension. In fact, the position of actions in the area of Basse di Stura is not sufficient to represent the new configuration of the area. Firstly, they are not able to show the extension of the actions developed in the areas. Secondly, for graphical reasons and link connections, after a certain time in the model, some actions are located again in the bottom part of the interface.

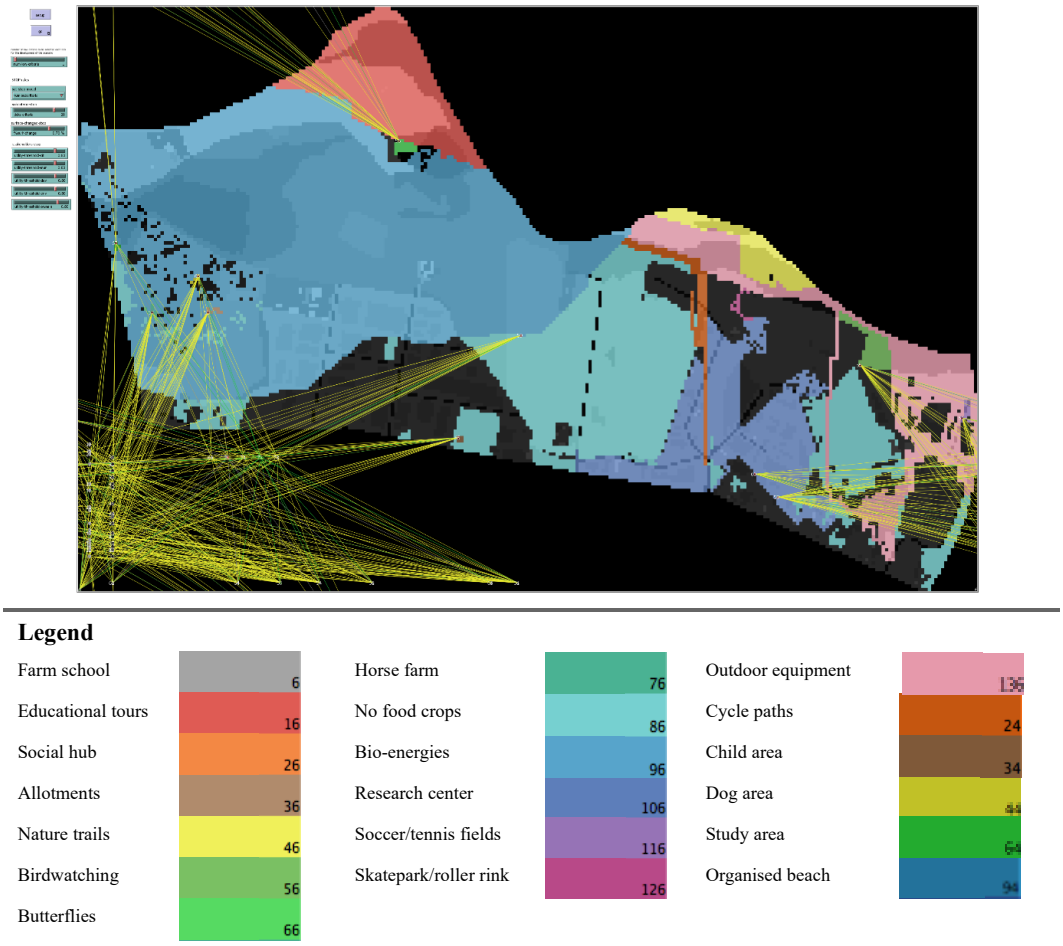


Figure 8.8. Graphical representation of an exemplary scenario in Netlogo

Concerning the output data, the information collected for each step is the following:

- the BAU sustainable performance index (P_0);
- the scenario sustainable performance index (P_1);
- the utilities of the stakeholders;
- the stakeholder who decides on the action in the step;
- the action activated in the step;
- the surface covered by the activated action.

These data are useful to monitor the ongoing simulation process characterized by the interaction among stakeholders, sustainable performances, and

environmental contexts and, at the same time, to have a complete view of the effectiveness of the scenarios generated in the different runs. This model, in fact, does not give a unique optimal solution, but proposes alternative sustainable and balanced scenarios among the stakeholders. These scenarios, therefore, need to be examined more in-depth, based on their final performances in terms of stakeholder satisfaction and sustainable achievement of the transformation. In the next few lines, some examples will provide an overview of the results obtained from this data analysis.

Firstly, the common result among all runs is related to the BAU sustainable performance index (P_0), which is equal to 0.137. The objective of each step that composes all simulations is to increase this value, proposing transformation scenarios for the achievement of the global sustainability of Basse di Stura. Table 8.14 presents an exemplary simulation run, where it is possible to appreciate the trend of P_1 compared to P_0. This simulation run is neither the most performant in terms of P_1 nor the lowest one, but it simply shows a common result of the model developed.

Table 8.14. Performances obtained for an exemplary scenario in each tick

Tick	Performance	Tick	Performance
1	0.137 (P_0)	11	0.328 (P_1)
2	0 (P_1)	12	0.377 (P_1)
3	0.02 (P_1)	13	0.424 (P_1)
4	0.046 (P_1)	14	0.467 (P_1)
5	0.102 (P_1)	15	0.518 (P_1)
6	0.128 (P_1)	16	0.535 (P_1)
7	0.150 (P_1)	17	0.591 (P_1)
8	0.193 (P_1)	18	0.648 (P_1)
9	0.240 (P_1)	19	0.670 (P_1)
10	0.271 (P_1)		

As it is possible to see in Table 8.14, P_1 overcomes P_0 only after tick 7. This happens, as mentioned in 8.4.4.2, because P_1 is calculated only considering the action contribution without the one from BAU land use. Moreover, the table shows how each step contributes to the increase in the overall sustainability of the area. At the same time, this means that only the creation of a complete scenario constituted by the combination of actions can really improve the quality of the area.

For the same simulation run, the results of stakeholder utilities along the ticks can also be analysed (Table 8.15).

Table 8.15. Stakeholder Utilities obtained for an exemplary scenario in each tick

Tick		Utility	Tick		Utility
1	(Uc)	0	11	(Uc)	0.763
	(Ue)	0		(Ue)	0.741

	(Ud)	0		(Ud)	0.486
	(Um)	0		**(Um)**	0.452
	(Uo)	0		(Uo)	0.531
2	(Uc)	0.221	12	(Uc)	0.763
	(Ue)	0.122		(Ue)	0.831
	(Ud)	0.018		(Ud)	0.497
	(Um)	0.005		**(Um)**	0.469
	(Uo)	0.084		(Uo)	0.753
3	(Uc)	0.221	13	(Uc)	0.861
	(Ue)	0.144		(Ue)	0.847
	(Ud)	0.163		**(Ud)**	0.528
	(Um)	0.063		(Um)	0.541
	(Uo)	0.138		(Uo)	0.769
4	(Uc)	0.363	14	(Uc)	0.861
	(Ue)	0.146		(Ue)	0.871
	(Ud)	0.176		**(Ud)**	0.607
	(Um)	0.152		(Um)	0.690
	(Uo)	0.144		(Uo)	0.802
5	(Uc)	0.363	15	(Uc)	0.861
	(Ue)	0.241		(Ue)	0.881
	(Ud)	0.195		**(Ud)**	0.691
	(Um)	0.181		(Um)	0.793
	(Uo)	0.216		(Uo)	0.824
6	(Uc)	0.520	16	(Uc)	1.000
	(Ue)	0.286		(Ue)	0.895
	(Ud)	0.319		**(Ud)**	0.721
	(Um)	0.207		(Um)	0.852
	(Uo)	0.351		(Uo)	0.837
7	(Uc)	0.610	17	(Uc)	1.000
	(Ue)	0.514		(Ue)	0.922
	(Ud)	0.392		**(Ud)**	0.847
	(Um)	0.216		(Um)	0.882
	(Uo)	0.435		(Uo)	0.875
8	(Uc)	0.610	18	(Uc)	1.000
	(Ue)	0.551		(Ue)	0.943
	(Ud)	0.404		(Ud)	0.931
	(Um)	0.259		(Um)	0.940
	(Uo)	0.462		**(Uo)**	0.884
9	(Uc)	0.610	19	(Uc)	1.000
	(Ue)	0.608		(Ue)	0.980
	(Ud)	0.418		(Ud)	0.933
	(Um)	0.277		(Um)	0.954
	(Uo)	0.495		**(Uo)**	0.924
10	(Uc)	0.610			
	(Ue)	0.622			
	(Ud)	0.448			
	(Um)	0.366			
	(Uo)	0.507			

In this exemplary case study, stakeholders' satisfaction (Table 8.15) and the sustainable index achieve high levels (Table 8.14). Generally, these two aspects go hand in hand, because the first one is connected to the second. The lower-satisfied stakeholder selects an action that he/she prefers, but he/she chooses the one that is able to increase the performance of one of the lowest sub-criteria.

The same phenomenon can be also appreciated in Table 8.16, where, as opposed as before, the low value of the sustainable index also means low utilities of the stakeholders.

Table 8.16. Utility and performance values for a low balancing scenario

Tick	Performance		Utility
1	0.137	(Uc)	0
		(Ue)	0
		(Ud)	0
		(Um)	0
		(Uo)	0
2	0.02	**(Uc)**	0
		(Ue)	0.024
		(Ud)	0.079
		(Um)	0.149
		(Uo)	0.034
19	0.263	**(Uc)**	0.345
		(Ue)	0.419
		(Ud)	0.409
		(Um)	0.387
		(Uo)	0.363

However, a few case studies present such low efficiencies. The majority have a sustainable index higher than 0.50 and an average utility higher than 0.70.

Considering the different stop models, they do not provoke very different outcomes. For the first stop model, the number of actions activated is generally no less than 17. This happens only when actions 58 and 59 are activated as last choices, and they do not find sufficient surfaces to locate the entire extension requested. This also happens for the third stop model, where the reason for interrupting the simulation is related to the accomplishment of a quite large percentage of the entire area of Basse di Stura (precisely, 70%). For the second stop model, related to the satisfaction of the stakeholders, the levels of utility are not so high to stop the simulation run in one of the first ticks. In fact, the way in which the ABM was created allows a balance among the utilities of the stakeholders and does not increase one of them over another. Therefore, also in this case, the simulation goes at least 14/15 ticks. As a consequence, the fourth model, which is the combination of the second and the fourth stop models, produces very similar outcomes.

In Table 8.17, all the outcomes of the most performing scenario are presented,

both in terms of the sustainable index achieved and the stakeholder satisfaction. It is worth mentioning that this scenario is the best among the simulation runs performed. This means that other scenarios could be more efficient, but they are simply not simulated. This implies that the more simulations are performed, the lower the likelihood of excluding the optimal scenario.

Table 8.17. Results from the most performing scenario simulated

Tick	Performance		Utility
1	0.137	(Uc)	0
		(Ue)	0
		(Ud)	0
		(Um)	0
		(Uo)	0
19	0.695	**(Uc)**	1.000
		(Ue)	0.943
		(Ud)	0.987
		(Um)	0.982
		(Uo)	0.968

The actions implemented in the area and their extension are summarized in Table 8.18. From this table, it can also be appreciated when the actions are activated in the simulation run.

Table 8.18. Actions implemented in the most performing scenario simulated

Tick	Action	Surface (sqm)	Tick	Action	Surface (sqm)
1	Outdoor equipment	65600	11	Farm school	46000
2	Bio-energies	215700	12	Study area	500
3	Horse farm	900	13	Birdwatching	18400
4	Butterflies	3100	14	Educational tours	155200
5	Organised beach	26600	15	Cycle paths	52900
6	No food crops	1067400	16	Child area	300
7	Nature trails	8200	17	Skatepark/roller rink	1700
8	Dog area	300	18	Social hub	1600
9	Research centre	84500	19	Soccer/tennis fields	250000
10	Allotments	4600			

8.6 Conclusions

This chapter presents a mixed method that combines a spatially explicit ABM, informed by preliminary analysis (SWOT and SA), a pooled RP and SP survey, and BWM. This approach allows the analyst to not simply evaluate alternatives but to generate them during the decision-aiding process. The aim is, in fact, to explore

regeneration scenarios built according to stakeholder preferences and from a sustainable perspective. This bottom-up perspective, based on stakeholder preferences, contributes to making the decision salient, credible, evident, and legitimate. At the same time, the separation of attributes and the identification of their performance and values make possible the achievement of sustainable options. This methodological proposal represents one of the first attempts in which the focus is on the design of alternatives rather than their evaluation, starting from a predefined set of them.

The conceptual framework proposed in this chapter can be applied easily to other case studies by simply adapting criteria, spatial data, and stakeholders' values to the specific case study, as generally happens in all MCDA. The applicability of the mixed method is tested in the city of Turin and, specifically, in the case study of Basse di Stura, where many social, environmental, and economic problems affect its transformation.

However, some improvements can be made. As for ABM, the choice of a suitable area to develop an action can be made through probability functions as proposed by Tian et al. (2011). Accordingly, some opportunities for expanding the results of the present study can be found in the estimate of action frequencies in the scenarios generated, as well as the identification of parameter costs for each action. Another useful improvement can be limiting the number of actions implemented. In this way, more reliable scenarios can be presented to DMs and stakeholders. At the same time, this can help to understand the priority actions to be implemented and most frequently selected in the various scenarios.

Future improvements to the study could consider the use of BWM for estimating the values given by citizens to alternative activities and actions. The current version of the mixed model uses the pooling of RP and SP to obtain the most relevant actions for the citizens. This implies that only a set of actions resulting as significant. This means that some ABM actions cannot be chosen by the citizen in ABM. Moreover, using BWM also for citizens elicitation of the preferences allows to follow the same utility function. Therefore, two slightly different calculations of utility functions had to be realized (see Section 8.4.4.3).

Future development would entail the selection of the first stakeholder. Currently, the model randomly chooses one of the stakeholders in the first tick. The consideration of the same stakeholder for many simulations can give information about similarities or differences in the scenarios created according to the first stakeholder involved.

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Chapter 9

Agent-based model and Multi-agent system: A methodological perspective for future research

9.1 Thesis overview and the role of evaluation for urban decision-making problems

This PhD thesis has put into light the hard task of supporting policymaking and scenario planning in urban contexts today. Different stakeholders, a plurality of objectives, and conflicting aspects need to be simultaneously considered as intrinsically relevant in the decision-making process. In particular, when the principles and aims of sustainable development have to be achieved, one of the core elements of the process is the people, also in their agglomeration as stakeholders. In fact, sustainable development achieves its sustainable objectives when technical aspects and factual problems are interrelated with the satisfaction of human needs and put into practice thanks to individual actions.

These premises synthetically recall the main contents expressed in Chapters 2 and 3 of this work. Chapter 2 has presented the aspects often lacking in today's policies and actions, mainly the people. The role of the population and individuals is often a central argument of DMs and PMs, also stated as the main aim that guides their decisions and choices. However, in many decision-making problems, people's voices are not completely considered and understood. Within this context, evaluation methods can support the integration of the opinions, needs, and behaviours of individuals and stakeholders into the decision-making process. An overview of the different abilities of various evaluation methods and tools in the consideration of these multiple perspectives is illustrated in Chapter 3, spanning

qualitative and quantitative approaches and both monetary and no-monetary methods, such as SA, MCDA, RP, and SP.

These contents of Chapter 2 and Chapter 3 essentially answer the first research question of this thesis, i.e., the fundamental role of evaluation methods in studying urban phenomena, policies, and development strategies. Only through them, it is possible to give answers to complex problems, structure them, and support clear and justified solutions.

Chapter 4 adds another piece to this discussion, about the topic of complexity. A complex system is characterized by many elements and by dynamicity, since it changes over time. This implies working with the multi-dimensionality of decision-making problems and, also, their multi-temporality. To do that, dynamic models can add knowledge and support to the analysis of today's problems due to their ability to modify variables over time as a function of their past and current values. Among the available dynamic models (briefly illustrated in Chapter 3 and Chapter 4) and based on the previous arguments, ABM/MAS is considered a powerful tool to take into account these two intrinsic elements of urban decision-making, i.e., multi-dimensionality and multi-temporality. Additionally, Chapter 4 presents a literature review of ABM/MAS applications in urban contexts, which also supports the identification of the case studies. At the same time, as presented in Chapter 5, the ABM/MAS ability to interrelate the multiple dimensions with a bottom-up approach makes possible to simultaneously consider all the relevant aspects of decision-making processes in urban contexts. In fact, as the dissertation has often underlined, these interrelations and conflicts, generated by human practices and sustainable objectives, are intrinsically part of urban and regional sustainable development. The results of this methodological investigation of ABM/MAS, combined with the outcomes obtained from the literature review, were beneficial for the identification of the case studies explored with ABM/MAS.

The potential of ABM/MAS is then applied to three applications in this thesis (Chapters 6, 7, and 8). The aim is to understand the flexibility of this simulation model for analysing urban-decision problems, where agents (i.e., individuals and stakeholders) with their objectives, expectations, and interactions have a central role as catalysts in the diffusion or inhibition of sustainable processes in urban contexts. The thesis tries precisely to include the opinions, behaviours, and preferences of individuals and stakeholders not simply as a part of the evaluation process, but as the crucial and central focus of the entire structure of the model and assessment of dynamics, policies, and actions in urban contexts. Accordingly, the novelty of the research is both related to the various integrations of methods proposed and to the real-world applications performed. ABM/MAS is used in a lot of literature to study theoretical and methodological phenomena and dynamics in urban studies. According to the literature review, there are few applications in which ABM/MAS are used to support real-world policies and transformation actions in urban contexts, as well as research works that involve an in-depth characterization of individuals and their interconnected surroundings. Based on this

limit, the problems investigated in Chapters 6, 7, and 8 represent promising and underexplored areas of investigation for ABM/MAS, as emerged from the literature review and due to the inclusion of real-world spatial data. In particular, the first case study (Chapter 6) investigates a socio-energetic problem in the urban context. It relates to the definition of coherent policies for the diffusion of cleaner technologies based on the specific characteristics and behaviours of the people in the context under analysis. The second case study (Chapter 7) explores a socio-economic problem that can occur in urban areas, i.e., the phenomenon of green gentrification. Considering the individual preferences in the property market, the ABM investigates the impact of realising a new urban park on pushing out minority and low-income residents. Finally, the third case study (Chapter 8) analyses a socio-environmental problem in urban contexts, where de-industrialisation and decentralisation have provoked the abandonment and contamination of huge portions of the city. In this case, ABM/MAS aids the regeneration process by taking into account both the satisfaction of citizens' and stakeholders' preferences, as well as the overall sustainability of the site.

In the following section, the pros and cons of ABM/MAS are highlighted in order to answer the second and third research questions of this thesis.

9.2 ABM/MAS applicability in urban decision-making problems and sensitive aspects

In light of the case studies developed in this thesis, it is possible to state that the use of simulation models, and particularly ABM/MAS, represents a promising field of experimentation. As demonstrated by the three applications, ABM/MAS can be potentially used for analysing very different problems. In general, these simulation models can be applied to studying processes and dynamics that span how diseases spread, how a territory changes over time, how to design a portion of a city, or assess the effect of various policies, among others. It is worth mentioning that the ABM/MAS maximum potential is expressed for problems in which variables change over time and these variations as an impact on how individuals, stakeholders, or the environment in which they act and react. As a result, the data requirements for the implementation of these simulation models will also be very different. Certainly, the collection of individual or stakeholder preferences, as well as data related to the surrounding environment in which they interact, are fundamental elements that must have.

In particular when real-world sustainable scenarios and policies are tested and evaluated, the ability of ABM/MAS to predict the effects, consequences, and performance over the time is essentially possible only through them. They are able to simultaneously consider economic and non-economic components, situational factors, and social interactions, which are often quite hard in simulation, but in general in all assessment processes. Moreover, more traditional and consolidated

methods usually lack the consideration of individual and stakeholder preferences, particularly in their interactive process among them and external aspects. With their bottom-up approach instead, ABM/MAS make possible the simulation of the preferences and behaviours of individuals and stakeholders in a real-world context characterized by the interrelations among them and the surrounding environment, as well as an exchange of data and information. If this environment is populated with data about objects and infrastructures in cities and with the multidimensional aspects of the decision-making process, it is possible to have a virtual laboratory to test and experiment with problems and processes that operate at multiple scales and organisational levels. To do that, the combination of GIS and ABM/MAS makes possible the inclusion and cooperation between spatial datasets and behavioural and interactional rules. The effectiveness and efficiency of policies and actions, particularly in urban contexts, is essentially based on the fact that citizens and stakeholders recognise, reason about, and react to what institutions propose and make, and what is around them.

This social-centre perspective is something really promising in the context of scenario planning and policymaking under the triple-bottom-line approach. In fact, the comprehension of the interrelations between more technical aspects and sustainability objectives to the satisfaction of human needs and actions represents the only way to make the transition from the sustainability concept to a sustainable development one.

At the same time, the predictive capacity of ABM/MAS can help PMs and DMs not make mistakes. ABM/MAS should be the reference model for public operators, whose aim is primarily the satisfaction of people's needs and their well-being. Therefore, the possibility to anticipate the effects and predict potential outcomes of people and stakeholders' interactions can really support policymaking and decision-making processes.

Nevertheless, some cons can be highlighted that emerge from the implementation of the case studies of this PhD thesis.

Firstly, ABM/MAS often requires a lot of data for its accurate implementation, validation, and verification. The use of too many assumptions and hypotheses risks producing incorrect results or reproducing abstract schemas unable to describe real-world events. Therefore, its combination with other evaluation methods seems like one of the most promising and suitable ways to solve this internal con of ABM/MAS. In fact, the mixed method approach offers a powerful choice to systematically integrate quantitative and qualitative data, as well as to combine the pros of various assessment tools.

Secondly, another con when approaching ABM/MAS for the first time is surely related to the implementation of them through existing software. It is worth mentioning that due to the complexity, but also flexibility, of this model, the entire structure of the model and the output produced need to be completely realised according to the written language of the software used. This requires, compared to the other evaluation methods, more time to be confident with the specific language

as well as to verify the consistency between what we want the model to do and how we write it. This can also be a strong obstacle to its adoption by public bodies, private entities, and researchers when time is limited and costly. It is therefore hard to imagine that ABM/MAS could be widely applied by practitioners or local administrations without a simplification of existing software. At the same time, the flexibility of ABM/MAS to approach completely different problems and at various scales makes it difficult to realise fixed and guided tools. The written language, also simple as in Netlogo software compared to the others, allows analysts to be free and flexible in the implementation of whatever they want. Additionally, it is important to underline that the rules that guide the behaviours, interactions, and actions of people and stakeholders are usually simpler than those used in other simulation models, based, for example, on differential equations. The main idea of ABM/MAS is, in fact, to reproduce behaviours and actions that are often simple and recursive, often based on "what…if" reasonings. It is therefore possible to say that the long time spent writing the model is balanced by the fact that there is less effort in the mathematical formulation of the model. This is surely a powerful strength of ABM/MAS that can be exploited by all private and public entities supported by an expert in this field. Additionally, in urban context research, it can be considered the possibility of building simpler tools that support the user in the creation of each component of ABM/MAS (agent, environment, and interactions). The user can simply focus on the definition of a set of rules and interactions, translated into a few equations, and the inclusion of GIS maps.

Thirdly, the hardest part of ABM/MAS is probably related to modelling individuals. The number of situational factors that affect and characterise individual behaviours is so great that often the answer to questions is "it depends". This is particularly true when individuals are modelled and the scale of analysis is broad, like cities or territorial scales. In these cases, the models must work with target population data and not individual data. Alternatively, the simulations become more suitable and efficient for analysing simpler phenomena, related to daily habits and not to complex behaviours. The problem of modelling individuals and their behaviour needs to be underlined many, many times, because it is inherent both in the implementation of the model and also in the results that come out. This also means that the results should be used as guidelines, not as definitive answers. They can give trajectories of processes and phenomena that are fundamental to PMs and DMs, anyway.

ABM/MAS, therefore, can be considered as less competitive in the market compared to other traditional models, but they propose a relevant way to analyse policies and urban phenomena from an inherent social perspective. They are, in fact, able to overcome the limited financial approach or the static view of most traditional models by proposing a predictive analysis of economic and social behaviours that is useful for not making mistakes in urban policies and decision-making processes.

9.3 Conclusions and future research perspectives

The previous considerations allow to trace some conclusions and trajectories for future research with ABM/MAS, starting from the knowledge acquired during the implementation of the three case studies.

From the first case study, it is possible to appreciate the ability of ABM to support the analysis of the diffusion of innovations. This also explains the increasing interest of ABM in this field and for this purpose. This case study is also the simplest in terms of methods integration, since the use of existing behavioural models, like TPB, reduces the need for other methods for its structuring and implementation. However, on one hand, these existing behavioural models can be used only for solving a limited number of problems, essentially based on products available and exchangeable in the market. On the other hand, these models need to be accurately verified with real data or through direct surveys. Nevertheless, the integration of ABM and GIS cannot be excluded in this analysis, particularly when the aim is to support PMs and DMs in the definition of coherent local policies.

In the second case study, the idea was to start from a well-known studied phenomenon in ABM research, trying to take a step forward. Gentrification has been widely explored in simulation and modelling, but most of the applications refer to two supply-side theories, i.e., the filtering theory and Smith's rent gap theory, or one demand-side theory, i.e., the household life cycles. Few attempts try to combine both these two sides of gentrification, and none with a detailed spatial representation of individuals, houses, and infrastructures, as the case of Brisbane does. Compared to the first case study, this experimentation showed the importance of integrating MCDA into ABM/MAS research. In fact, when the analysis does not adopt existing behavioural theories, other methodologies and tools can support the structuring of the complex problem. The incorporation of MCDA here allows to consider both endogenous and exogenous factors in the residential mobility choice and structures the individual rules based on each identified criterion. This also implies that the model can be reproduced in different contexts by simply modifying the set of criteria and the relative weights assigned. At the same time, the model validity can be tested by incrementally adding or removing criteria and comparing them with real-case studies where gentrification occurred in the past. It is worth mentioning that this step is not so easy to put into practice because it requires the construction of a new model strictly based on the data of another case study. Additionally, each case study is often unique, so what happens in one circumstance cannot be true for another.

Therefore, the first and second case studies have shown how predictive models such as ABM/MAS, of course, cannot be used as revealed truth. They can be valuable tools for guiding and giving trajectories for policy-making and decision-making processes. However, it is important to know that even a small variation in the real system conditions can provoke changes in what really happens in reality. For example, no one could have predicted that a pandemic would happen, changing

the fate of the world for at least a couple of years.

Accordingly, in the social sciences, ABM/MAS models have always had limited use and have been widely adopted in the fields of infrastructure and transport or in the spread of diseases and epidemics. These cases simulate simpler habits and behaviours of individuals, while gentrification or housing mobility choices need to take into account considerably more aspects.

Essentially, the core of ABM/MAS models are individuals, but their choices and behaviours are extremely complex to model and simulate in many cases in the long run. Future improvements, in this sense, could involve the adoption of neural networks to automatically estimate complex features, or to scale up behavioural changes among heterogeneous individuals, tracing their macroeconomic and cross-sectoral impacts at a macro scale rather than micro.

This is the reason why a third case study was developed. Coming back to the origin of ABM/MAS and their direct connection with CA, it was proposed an experimentation of alternatives generation, based on a set of multiple criteria of sustainable performance and stakeholders' preferences. This field of research is still little explored both in ABM/MAS applications and, more in general, in decision analysis and operational research. Therefore, it seems particularly innovative and promising. Probably here, ABM/MAS express their maximum potential, integrating the spatial dimension, the interrelations among the environment and the stakeholders, while considering their own specific needs and preferences. Additionally, it is worth mentioning that the multi-methodology and conceptual framework proposed in this case study can be easily applied to other planning and transformation projects, by simply adapting the set of criteria, spatial data, and stakeholders' values to the specific application. However, more innovative experiments can be conducted on the utility functions and the preferences of the stakeholders concerning the strategies proposed.

Another interesting trend close to this third case study could concern the evaluation of targeted improvement actions at the district level, but also at the urban level, for increasing infrastructural connections, the development of primary or additional services for the well-being of citizens, the location of some services, such as hospitals, or even modelling the spatial distribution of current and future ecosystem services. This analysis can also exploit the dynamic ability of ABM/MAS.

In particular, Figure 9.1 synthetically recalls all the methods applied in the three case studies, which are useful for proposing a common methodological framework to be used for future research applications. In the following parts, each step reported in Figure 9.1 is described starting from the experience of the three case studies.

When a multi-dimensional, multi-perspective, and multi-temporal problem needs to be investigated, ABM/MAS are suitable models, since they allow the analyst to understand over time the effects of individual and stakeholder preferences, their relationships and interrelations among them and their environment.

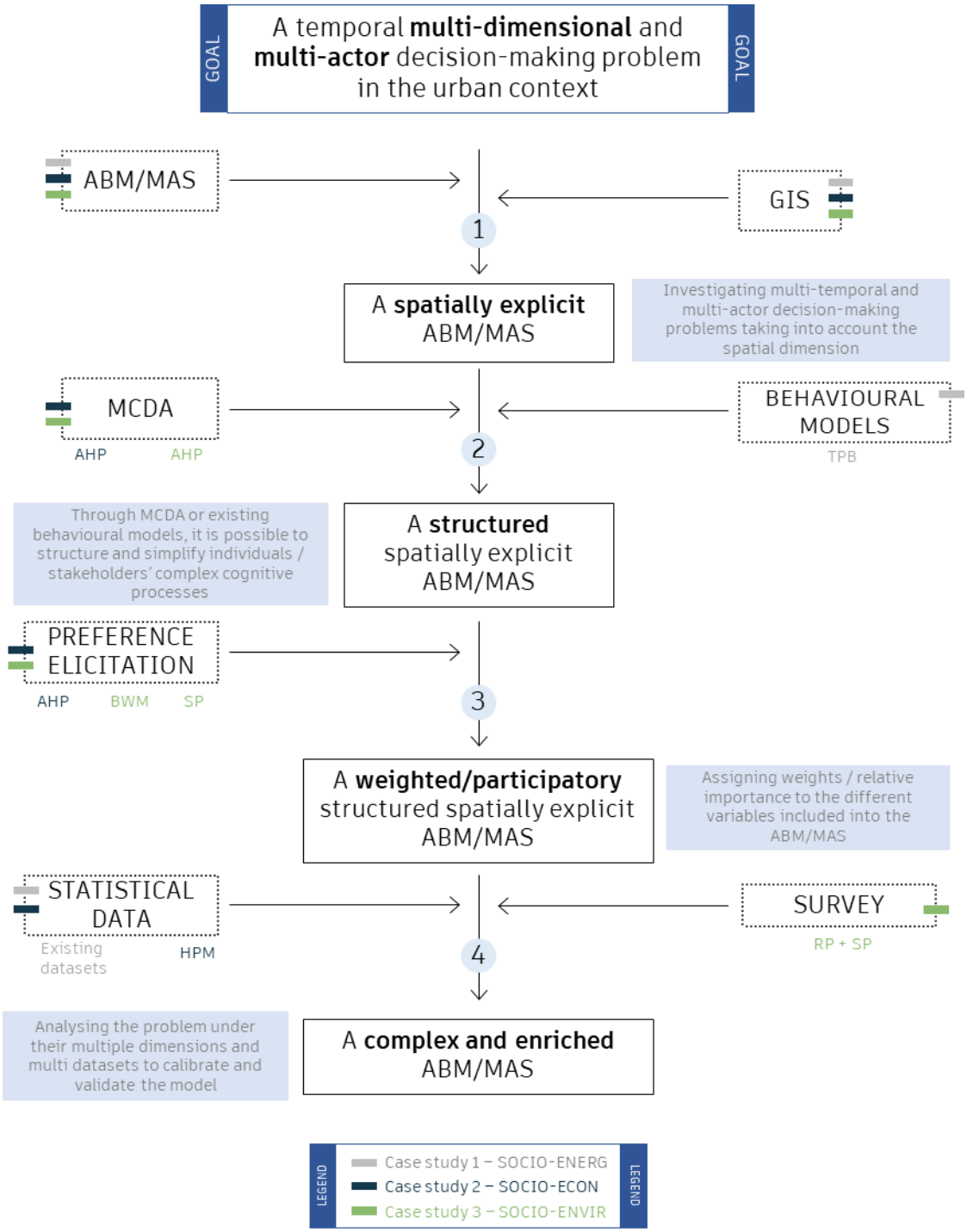


Figure 9.1. A common methodological structure for future research

Additionally, the three applications highlighted the fundamental role of combining ABM/MAS and GIS. This integration is the only way to produce real-world outcomes for PMs and DMs in the definition of coherent policies and valuable strategies for sustainable development. Within this content, one cannot ignore the fundamental role of geographic space and its dynamics. Here, the potential of combining GIS and ABM/MAS makes it possible to conduct scalable and granular analysis and model real geographical systems.

At the same time, when real-world problems are analysed, the decision-making processes of individuals or stakeholders need to be clearly structured. In ABM/MAS research applications, it can be done using behavioural models, such as TPB, explored in the first case study, or MCDA, as in the second and third case studies. Behavioural models are frequently adopted in ABM/MAS, but they work better to simulate the preferences of tradable goods on the market. However, the socio-economic and socio-environmental case studies taught the importance of integrating MCDA into ABM/MAS research, since MCDA provides a more flexible structure to combine a variety of variables and aspects.

A relevant phase that emerged from the case study applications is related to the direct inclusion of the notion of weights and preferences assigned by the stakeholders among the different variables/aspects included. The second and third case studies use different methods for the elicitation of preferences and weights. In the second and third case studies, the classical AHP/BWM weighting approach (i.e., the Saaty fundamental scale) is adopted to model, respectively, the housing mobility preferences of Brisbane citizens and the different stakeholders' preferential actions to be implemented in the area. Additionally, in the third case study, the preferential actions for the citizens are collected by using CE. The applications therefore highlight how the relative importance of the aspects is more significant when stakeholders' preferences need to be modelled (thus, in the third case study). In the second case study, however, the weights assigned do not represent the preferences of each individual, but rather the general preferences in housing mobility choice. It is, of course, an assumption that the model does.

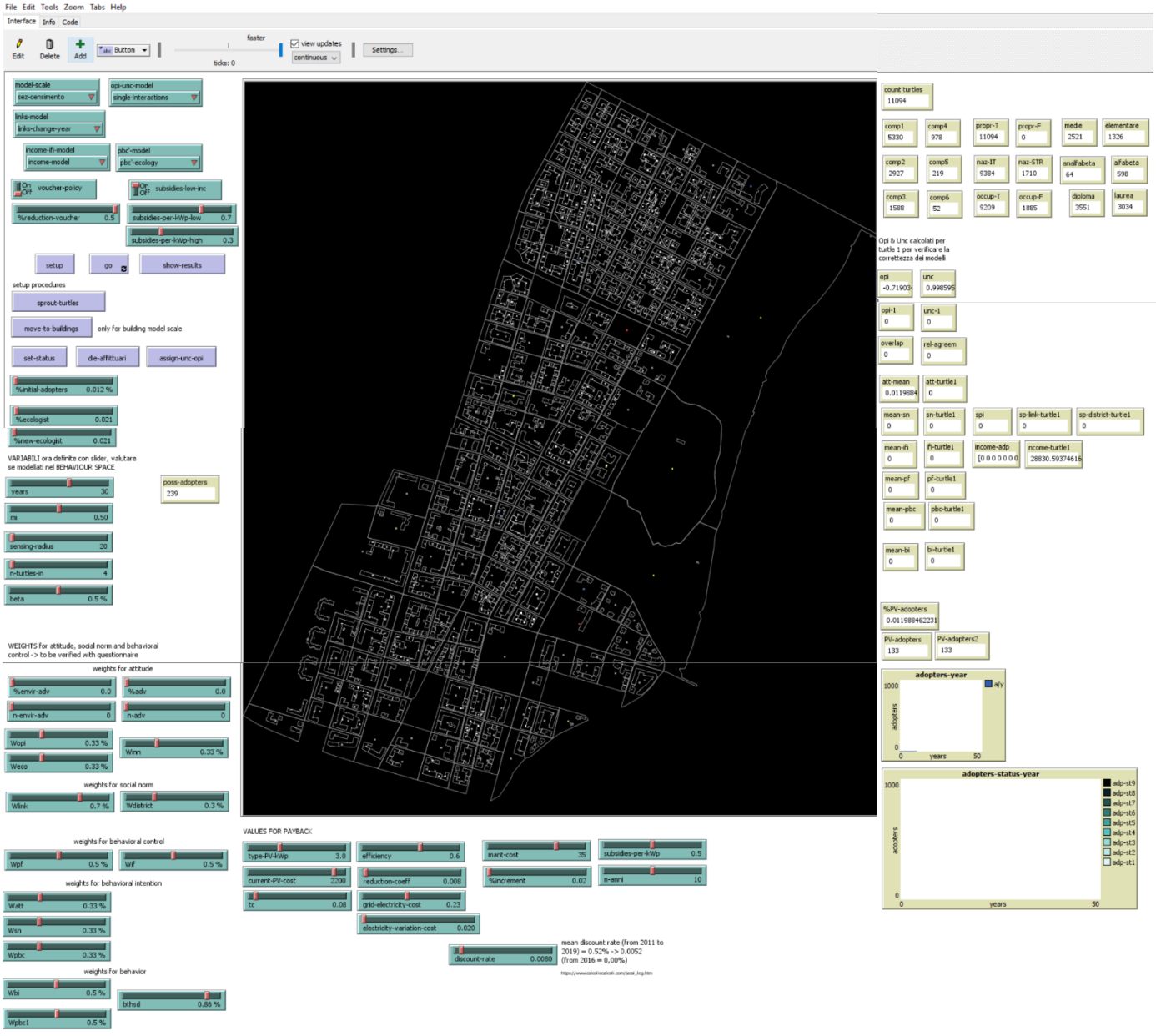
Finally, it is possible to state that the adoption of a mixed method approach and the integration of various datasets makes possible to solve some of the limitations of ABM/MAS and give them additional data to enrich and validate the model, as it was done in the second case study by using HPM and in the first one through statistical data.

This general framework could become a guide for future research applications in this field, as well as a step forward in the way ABM/MAS are adopted for studying various dynamics and processes in urban contexts. The focus on people, their behaviours, and preferences probably represents a suitable and effective way to support a structured achievement of sustainable development that starts with micro individual actions and becomes macro patterns of sustainability in urban areas.

Appendix A

A.1 Netlogo codes – The San Salvario district, Turin (ITA)

a. INTERFACE - t0 state (tick = 0)



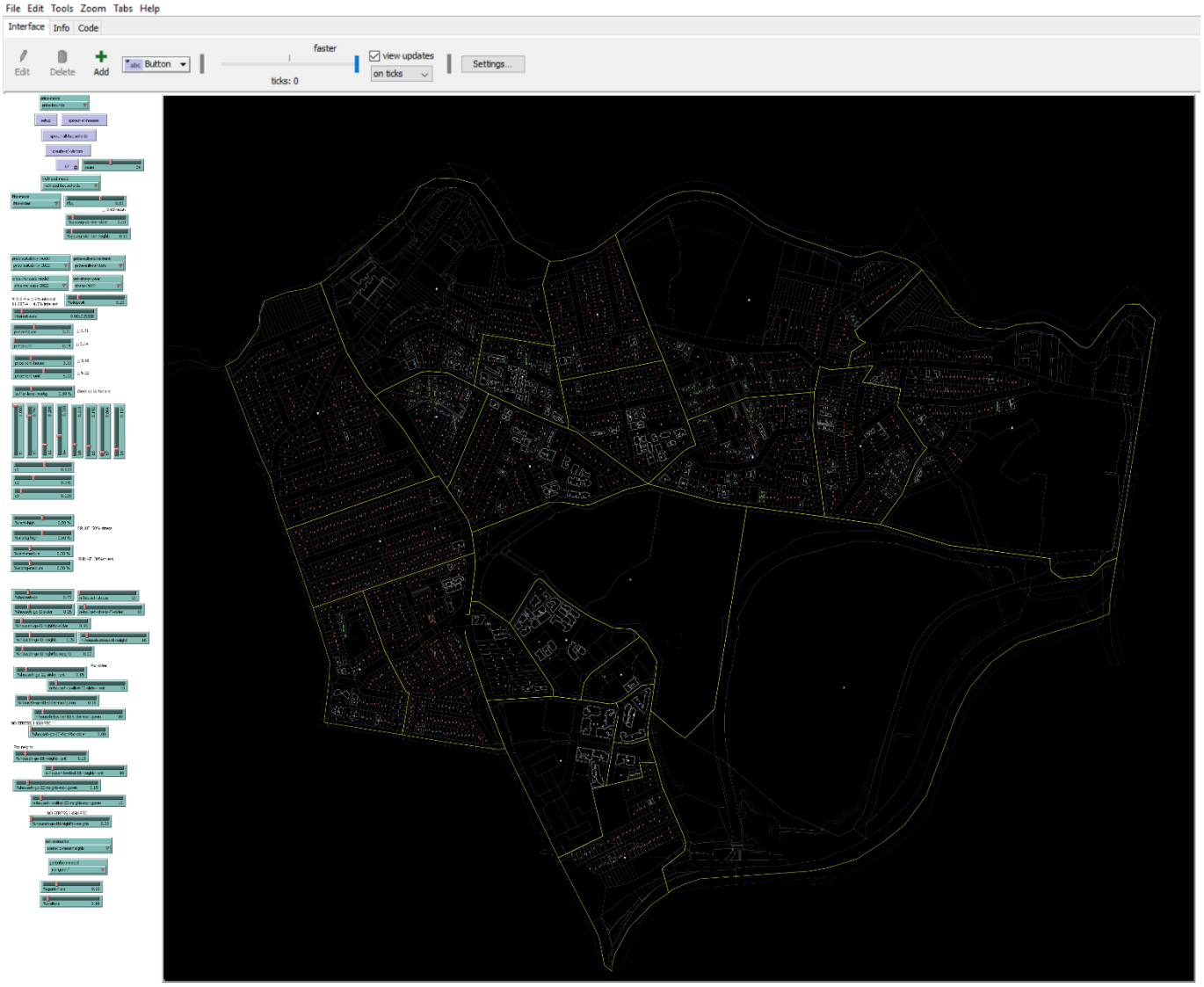
b. CODE: (click on the link below and download the .html file)[41]

[Netlogo-webmodel-SanSalvario]

[41] Once the file is downloaded, it is possible to open it in Netlogo web, by directly clicking on it. An error with the GIS extension will occur: close it and, then, you can navigate in the model. In the bottom part of the web page, you can open the code command.

A.2 Netlogo codes – Kelvin-Grove and Herston districts, Brisbane (AUS)

a. INTERFACE - t0 state (tick = 0)



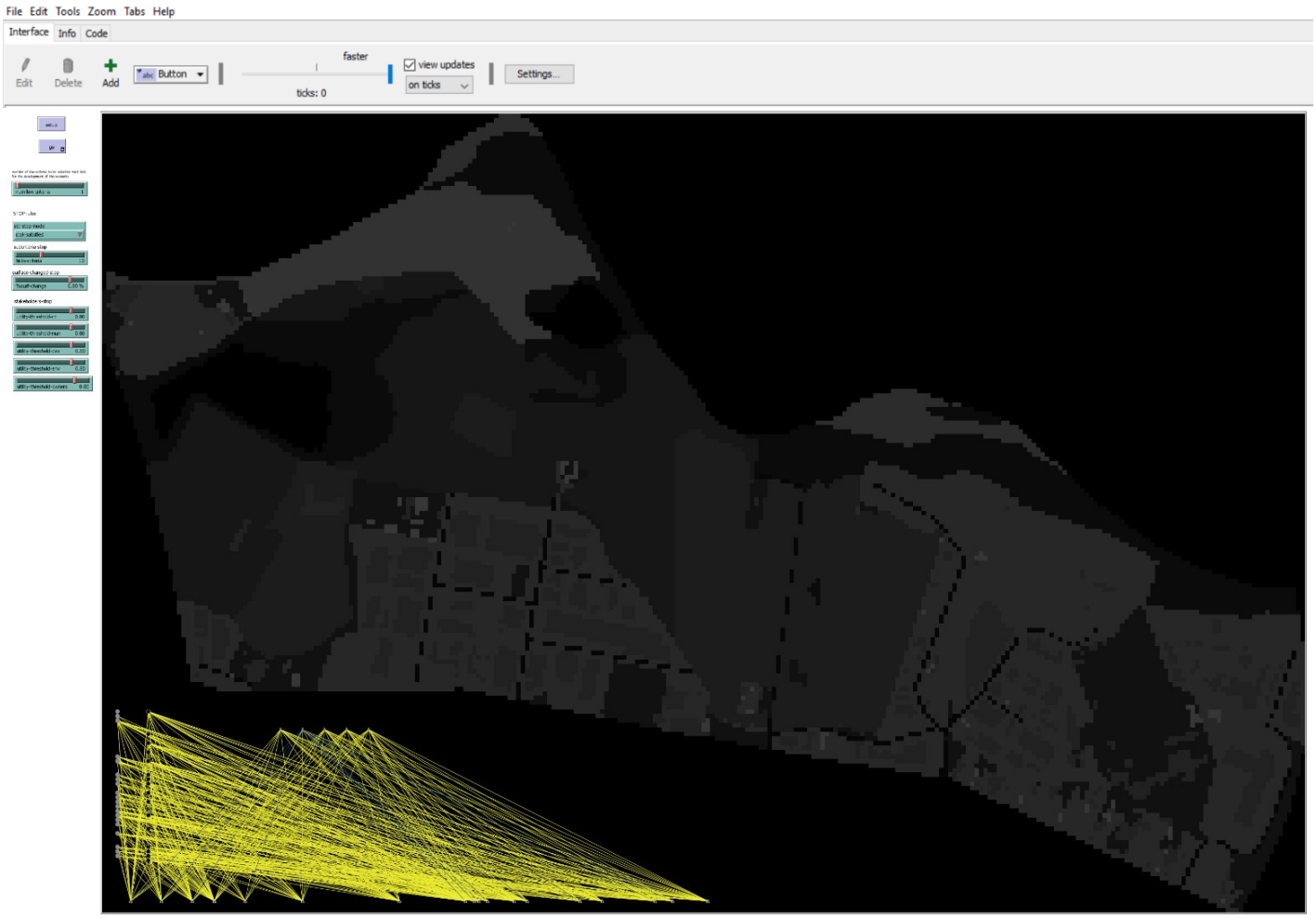
b. CODE: (click on the link below and download the .html file)[42]

[Netlogo-webmodel-KelvinGroveHerston]

[42] Once the file is downloaded, it is possible to open it in Netlogo web, by directly clicking on it. An error with the GIS extension will occur: close it and, then, you can navigate in the model. In the bottom part of the web page, you can open the code command.

A.3 Netlogo codes – The Basse di Stura area, Turin (ITA)

a. INTERFACE - t0 state (tick = 0)



b. CODE: (click on the link below and download the .html file)[43]

[Netlogo-webmodel-BassediStura]

[43] Once the file is downloaded, it is possible to open it in Netlogo web, by directly clicking on it. An error with the GIS extension will occur: close it and, then, you can navigate in the model. In the bottom part of the web page, you can open the code command.

Appendix B

B.1 AHP Questionnaire – Kelvin-Grove and Herston districts, Brisbane (AUS)



Victoria Park (Brisbane) research

Dear expert,

With this survey, we kindly ask you for help in the research jointly developed by Politecnico di Torino and QUT for the analysis of the transformation of the Victoria Golf Course (Brisbane).
In the early future, this golf course will be transformed into a new recreational park for the city and, as emerged from our studies (and also thanks to your collaboration) by developing a spatial hedonic price model, we have understood that this transformation can produce an increase in property values in the surrounding areas (of about 3% uplift around 750 meters from the park).

Now, we aim to understand if this uplift can provoke gentrification phenomena in the two closer districts (Kelvin-Grove and Herston) with changes in the socio-economic and socio-cultural characteristics of people living there. Therefore, the research tries to answer the following questions: Do gentrification dynamics occur? What conditions lead to the creation of gentrification phenomena? Can some policies prevent the spread of these dynamics?
In order to answer to these questions, through a Spatial agent-based model, we will try to simulate people housing mobility based on economic, intrinsic and extrinsic characteristics of their properties, both analyzing the supply and demand side. More specifically,
- ECONOMIC characteristics refers to the affordability of a property compared to the income,
- INTRINSIC characteristics regards the type and size of a property;
- EXTRINSIC characteristics are related to the district quality.
However, these ECONOMIC, INTRINSIC AND EXTRINSIC characteristics of properties have different importance. To this purpose, the Spatial agent-based model should be integrated with Multicriteria Analysis (MCA), in order to assign different importance to the considered elements.

In this survey, we ask you, as experts, to support us in two different stages:

1. To confirm if the characteristics identified are suitable to describe housing mobility choices of Brisbane citizens, or to suggest other aspects.
You can see, in Figure 1, the complete lists of attributes considered and clustered by ECONOMIC, INTRINSIC and EXTRINSIC criteria, as requested by the MCA adopted in this research (i.e. Analytic Hierarchic Process - AHP). AHP requires to structure the decision-problem hierarchically, with, at the higher level, the GOAL, followed by the CRITERIA needed to achieve the goal, and, then, the SUBCRITERIA related to each criterion. Then, after the Figure, you can find the description of all sub-criteria.

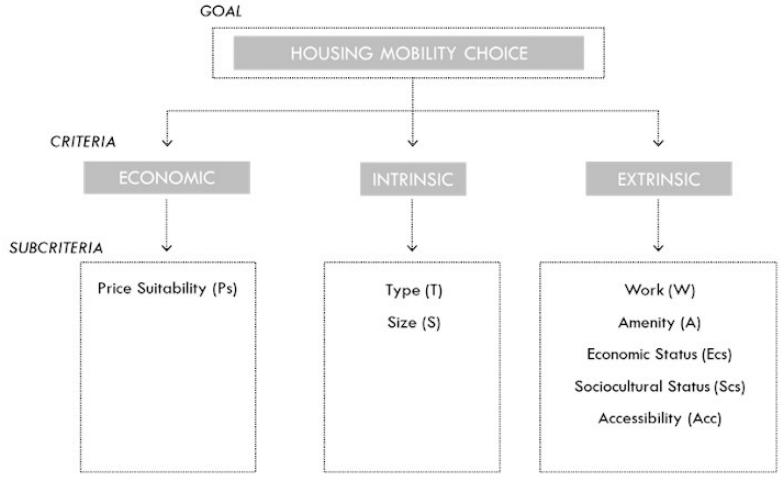
2. To assign the relative importance of all these characteristics using the MCA (i.e. AHP).

In the following parts, you will find a set of specific questions for which we kindly ask you to express your preferences.
Your contribution is really important to us and we thank you in advance for your precious collaboration.

caterina.caprioli@gmail.com (non condiviso) Cambia account

*Campo obbligatorio

Figure 1



Sub-criteria description

PRICE SUITABILITY (Ps): Price suitability (Ps) is used to measure the financial possibility of the households living in his/her house.

TYPE (T): it describes the preference of the household about the house typology where he/she lives. The typology are classified in: SINGLE-FAMILY HOUSES (type = 1), SEMI-DETACHED HOUSES (type = 2) and APARTMENTS (type = 3).

SIZE (S): it describes the preference of the household about the size of the house where he/she lives. The size is classified based on the number of bedrooms.

WORK accessibility (W): it describes the preference of the household about the distance of his/her house to his/her work.

AMENITY proximity (A): refers to the preference of the household about the proximity of his/her house to amenity spaces (e.g. urban grees, sport facilities)

ECONOMIC STATUS (Ecs): it is used to measure the possible level of "segregation" of the household and, therefore, the increasing probability to leave his/her house. EcS is based on the difference between the household income and the mean income of the households in his/her SA1 area

SOCIOCULTURAL STATUS (Scs): it is used as a sociological combined total measure of household status. The combined measure is based on the following own attributes of the households: education, religion, parents' origin and language. This variable considers the possible level of "segregation" of the household and, therefore, the increasing probability to leave his/her house.

ACCESSIBILITY (Acc): it refers to the proximity and density of various services (shops, schools, main road, bycicle paths, bus stops) from the households' house

Please, write your Name and Surname (e.g. Caterina Caprioli) *

La tua risposta

Considering the list of attributes shown before (i.e. Ps, T, S, W, A, Ecs, Scs, Acc), do you think that some relevant attributes are missing in the housing mobility choice of people in Brisbane? *

- ◯ Yes
- ◯ No

Avanti Pagina 1 di 5 Cancella modulo

New criteria

Since in the previous answer, you said that some relevant attributes missing, now, we ask you to list these missing attributes. We ask you also to try to give a brief description or reference of how to measure each of them. For example: a) Green building preference (Gbp): in Brisbane, young people and those with high education level choose their properties also based on the green label (you can find this information at the following link: xxx.com)

List below the attributes missing with a brief description *

La tua risposta

Indietro Avanti Pagina 2 di 5 Cancella modulo

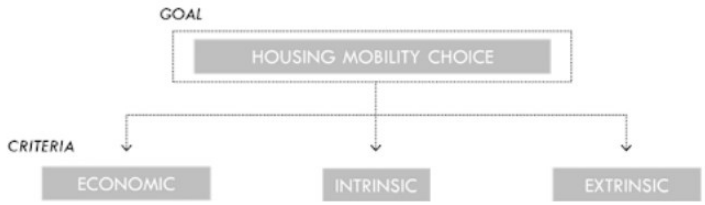
Weighting phase

This section is devoted to the assignment of the PRIORITIES of all the elements considered in the analysis. In the multicriteria method adopted in this research (Analytic Hierarchic Process), the assignment of the priorities is based on the PAIRWISE COMPARISON of each couple of elements with respect to each element placed at the higher level of the hierarchy. For the pairwise comparison, a numerical scale, called Saaty fundamental scale, uses 9 numerical values (see Figure 1 below) to assign how much criterion X contributes more or less effectively than criterion Y to the achievement of a specific objective.
Now, we ask you to assign these numerical values at the CRITERIA LEVEL (Figure 2), by considering how much one criterion is more or less relevant than the other in the housing mobility choice of Brisbane citizens.

Figure 1

Numerical scale	Verbal scale
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Figure 2



With reference to the housing mobility choice of residents, which of these two criteria do you think is more important, the ECONOMIC criterion or the important, choose randomly one of the two) *

- ◯ Economic criterion (affordability of a property)
- ◯ Intrinsic criterion (type and size of a property)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

With reference to the housing mobility choice of residents, which of these two criteria do you think is more important, the ECONOMIC criterion or the EXTRINSIC criterion? Select the most important one (if they are equally important, choose randomly one of the two) *

- ○ Economic criterion (affordability of a property)
- ○ Extrinsic criterion (district quality)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

With reference to the housing mobility choice of residents, which of these two criteria do you think is more important, the INTRINSIC criterion or the EXTRINSIC criterion? Select the most important one (if they are equally important, choose randomly one of the two) *

- ○ Intrinsic criterion (type and size of a property)
- ○ Extrinsic criterion (district quality)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1 2 3 4 5 6 7 8 9

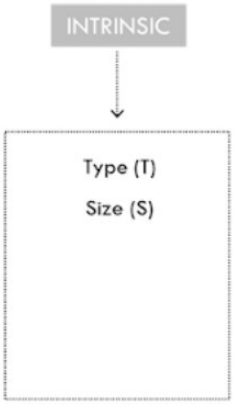
○ ○ ○ ○ ○ ○ ○ ○ ○

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Indietro Avanti Cancella modulo

Weighting phase: Intrinsic criterion

Now, we ask you to assign the Saaty numerical values at the SUB-CRITERIA LEVEL, i.e. by considering how much one sub-criterion is more or less relevant than the other with respect to the achievement of its criterion objective (here, for the INTRINSIC characteristics of properties (Figure below)).



Concerning the Intrinsic criterion (i.e. Type and Size of the properties), which of the two sub-criteria do you think is more important? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Type (single-family house, semi-detached or apartment)
- ◯ Size (number of bedrooms)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

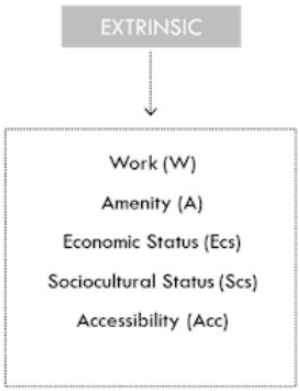
1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Pagina 4 di 5

Indietro Avanti Cancella modulo

Weighting phase: Extrinsic criterion

Now, we ask you to assign the Saaty numerical values at the SUB-CRITERIA LEVEL, i.e. by considering how much one sub-criterion is more or less relevant than the other with respect to the achievement of its criterion objective (here, for the EXTRINSIC characteristics of properties (Figure below)).



Concerning the Extrinsic criterion, do you think that the Work accessibility is more important than the Amenity proximity or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Work accessibility
- ◯ Amenity proximity

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Work accessibility is more important than the Economic Status or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Work accessibility
- ◯ Economic Status (compared to the one of the other households in the same SA1)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Work accessibility is more important than the Sociocultural Status or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Work accessibility
- ◯ Sociocultural Status (compared to the one of the other households in the same SA1)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Work accessibility is more important than the Accessibility of services or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Work accessibility
- ◯ Accessibility of services (e.g. shops, schools, main roads, bus stops)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Amenity proximity is more important than the Economic Status or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Amenity proximity
- ◯ Economic Status (compared to the one of the other households in the same SA1)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Amenity proximity is more important than the Sociocultural Status or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Amenity proximity
- ◯ Sociocultural Status (compared to the one of the other households in the same SA1)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Amenity proximity is more important than the Accessibility of services or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Amenity proximity
- ◯ Accessibility of services (e.g. shops, schools, main roads, bus stops)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Economic Status is more important than the Sociocultural Status or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Economic Status (compared to the one of the other households in the same SA1)
- ◯ Sociocultural Status (compared to the one of the other households in the same SA1)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Economic Status is more important than the Accessibility of services or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Economic Status (compared to the one of the other households in the same SA1)
- ◯ Accessibility of services (e.g. shops, schools, main roads, bus stops)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Concerning the Extrinsic criterion, do you think that the Sociocultural Status is more important than the Accessibility of services or vice-versa? Select the most important one (if they are equally important, choose randomly one of the two) *

- ◯ Sociocultural Status (compared to the one of the other households in the same SA1)
- ◯ Accessibility of services (e.g. shops, schools, main roads, bus stops)

And to what extent? (please, select a score on the Saaty scale, where 1 means equally important, while 9 means that one criterion is extremely more important than the other) *

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

Pagina 5 di 5

Indietro Invia Cancella modulo

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B.2 BWS Questionnaire – The Basse di Stura area, Turin (ITA)



Basse di Stura Park (Turin)

Dear expert,

With this survey, we kindly ask you for help in the research that Politecnico di Torino (Prof. Bottero and Dr. Caprioli) is carrying out on the transformation of the Basse di Stura Park in Turin (Italy).

Basse di Stura, with its 150 ha, represents one of the wider free areas of the city, but, until now, underused due to the high level of contamination of the soil. In the last years, the Municipality of Turin has expressed its interest for this area for the natural potentialities of this site and its strategical location. The area is part of three relevant undergoing projects connected to the regeneration of blue-green infrastructures in the City of Turin and the surrounding Municipalities.
The river Stura, the rural past and the position at the edge of the city constitute fundamental elements in the definition of the natural potential of the area. For that reason, the local administration established, for a long time now, to transform the area in an urban and fluvial park.
The main problem affecting the area, however, is the worrying soil contamination caused by the presence in the past of heavy factories and the illegal disposal of industrial waste.
Other aspects characterize the area of Basse di Stura and its surrounding: a set of farmhouses dating back to the 17th and 18th century, legal and illegal urban allotments located in the residual spaces among infrastructures, the variety of flora and fauna along the river, two quarry lakes and the Roma camps.

Now, we aim to support the construction and evaluation of alternative scenarios for the urban park development, considering at the same time the sustainability of the overall project and the stakeholders' preferences about its implementation.

In this survey, we ask you, as experts, to support us in the following stages:

1. Indicate the most important (BEST) and the least important (WORST) ACTIVITY for the development a sustainable transformation of the Basse di Stura Park

2. Assign the preference ratio of the BEST / WORST ACTIVITY over the other ACTIVITIES

3. Indicate the most important (BEST) and the least important (WORST) ACTION for the implementation of each ACTIVITY

4. Assign the preference ratio of the BEST / WORST ACTION over other ACTIONS

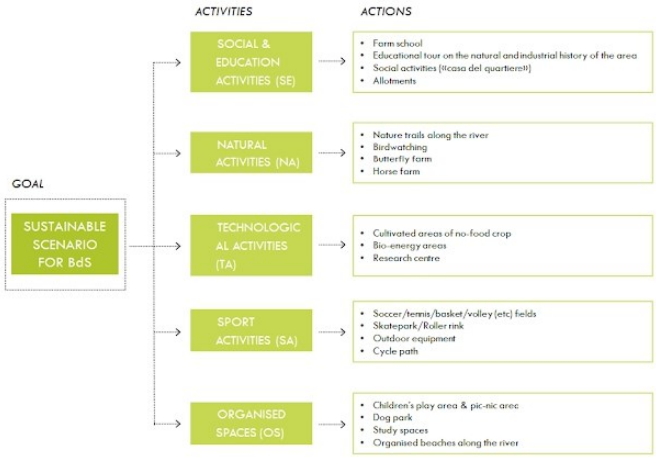
You can see, in the Figure 1 below, the complete list of ACTIVITIES and related ACTIONS. WE RECOMMEND YOU TO EXAMINE ACTIVITIES AND RELATED ACTIONS CAREFULLY BEFORE STARTING THE QUESTIONNAIRE.

Your contribution is really important to us and we thank you in advance for your precious collaboration.

caterina.caprioli@gmail.com (non condiviso) Cambia account

*Campo obbligatorio

Figure 1. Activities and related actions to realize a sustainable scenario for Basse di Stura



Stakeholder Name (ex: Developer) *

STAKEHOLDERS: Developer, Environmentalist, Municipality, Owner

La tua risposta

Avanti

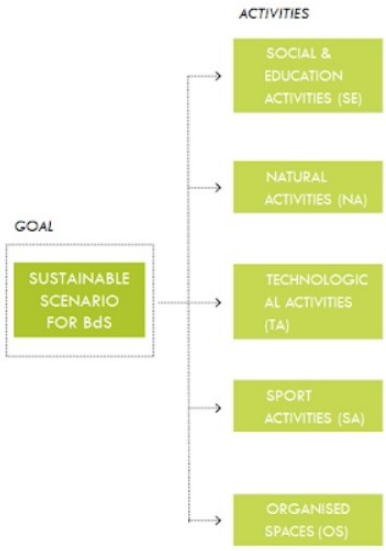
Pagina 1 di 7

Cancella modulo

Best-worst multi-criteria decision-making method

BEST and WORST ACTIVITIES

Indicate the most important (BEST) and the least important (WORST) ACTIVITY for the development a sustainable transformation of the Basse di Stura Park



Select the BEST ACTIVITY *

Scegli

Select the WORST ACTIVITY *

Scegli

PREFERENCE RATIO AMONG ACTIVITIES

Assign the preference ratio of the BEST ACTIVITY over the other ACTIVITIES and all the activities over the WORST ACTIVITY. For this value, adopt the fundamental Saaty scale (see Figure below)

Saaty fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to

BEST vs Socio-educational activities

(if BEST is Socio-educational activities, then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Natural activities

(if BEST is Natural activities, then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Technological activities

(if BEST is Technological activities, then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Sport activities

(if BEST is Sport activities, then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Organised spaces

(if BEST is Organised spaces, then select 1)

1 2 3 4 5 6 7 8 9

Socio-educational activities vs WORST

(if WORST is Socio-educational activities, then select 1)

1 2 3 4 5 6 7 8 9

Natural activities vs WORST

(if WORST is Natural activities, then select 1)

1 2 3 4 5 6 7 8 9

Technological activities vs WORST

(if WORST is Technological activities, then select 1)

1 2 3 4 5 6 7 8 9

Sport activities vs WORST

(if WORST is Sport activities, then select 1)

1 2 3 4 5 6 7 8 9

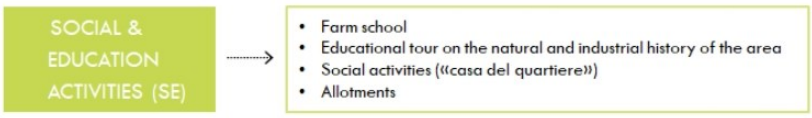
Organised spaces vs WORST

(if WORST is Organised spaces, then select 1)

1 2 3 4 5 6 7 8 9

Indietro Avanti Pagina 2 di 7 Cancella modulo

SUB-CRITERIA - Socio-educational activities



BEST and WORST ACTIONS

Indicate the most important (BEST) and the least important (WORST) ACTIONS for the implementation of SOCIO-EDUCATIONAL ACTIVITIES

Select the BEST ACTION *

Scegli

Select the WORST ACTION *

Scegli

PREFERENCE RATIO AMONG ACTIVITIES

Assign the preference ratio of the BEST ACTION over the other ACTIONS and all the ACTIONS over the WORST ACTION. For this value, adopt the fundamental Saaty scale (see Figure below)

Saaty fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to

BEST vs Farm school on no-food crop and for phytoremediation

(if BEST is "Farm school on no-food crop and for phytoremediation", then select 1)

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

BEST vs Educational tour on the natural and industrial history of the area

(if BEST is "Educational tour on the natural and industrial history of the area", then select 1)

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

BEST vs Social activities («casa del quartiere»)

(if BEST is "Social activities («casa del quartiere»)", then select 1)

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

BEST vs Allotments

(if BEST is "Allotments", then select 1)

1 2 3 4 5 6 7 8 9

Farm school on no-food crop and for phytoremediation vs WORST

(if WORST is "Farm school on no-food crop and for phytoremediation", then select 1)

1 2 3 4 5 6 7 8 9

Educational tour on the natural and industrial history of the area vs WORST

(if WORST is "Educational tour on the natural and industrial history of the area", then select 1)

1 2 3 4 5 6 7 8 9

Social activities («casa del quartiere») vs WORST

(if WORST is "Social activities («casa del quartiere»)", then select 1)

1 2 3 4 5 6 7 8 9

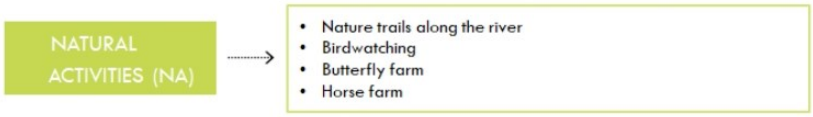
Allotments vs WORST

(if WORST is "Allotments", then select 1)

1 2 3 4 5 6 7 8 9

Indietro Avanti Pagina 3 di 7 Cancella modulo

SUB-CRITERIA (Natural activities)



BEST and WORST ACTIONS

Indicate the most important (BEST) and the least important (WORST) ACTIONS for the implementation of NATURAL ACTIVITIES

Select the BEST ACTION *

Scegli

Select the WORST ACTION *

Scegli

PREFERENCE RATIO AMONG ACTIVITIES

Assign the preference ratio of the BEST ACTION over the other ACTIONS and all the ACTIONS over the WORST ACTION. For this value, adopt the fundamental Saaty scale (see Figure below)

Saaty fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to

BEST vs Nature trails along the river

(if BEST is "Nature trails along the river", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Birdwatching

(if BEST is "Birdwatching", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Butterfly farm

(if BEST is "Butterfly farm", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Horse farm

(if BEST is "Horse farm", then select 1)

1 2 3 4 5 6 7 8 9

Nature trails along the river vs WORST

(if WORST is "Nature trails along the river", then select 1)

1 2 3 4 5 6 7 8 9

Nature trails along the river vs WORST

(if WORST is "Nature trails along the river", then select 1)

1 2 3 4 5 6 7 8 9

Butterfly farm vs WORST

(if WORST is "Butterfly farm", then select 1)

1 2 3 4 5 6 7 8 9

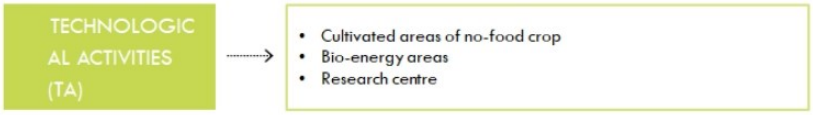
Horse farm vs WORST

(if WORST is "Horse farm", then select 1)

1 2 3 4 5 6 7 8 9

Indietro Avanti Pagina 4 di 7 Cancella modulo

SUB-CRITERIA (Technological activities)



BEST and WORST ACTIONS

Indicate the most important (BEST) and the least important (WORST) ACTIONS for the implementation of TECHNOLOGICAL ACTIVITIES

Select the BEST ACTION *

Scegli

Select the WORST ACTION *

Scegli

PREFERENCE RATIO AMONG ACTIVITIES

Assign the preference ratio of the BEST ACTION over the other ACTIONS and all the ACTIONS over the WORST ACTION. For this value, adopt the fundamental Saaty scale (see Figure below)

Saaty fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to

BEST vs Cultivated areas of no-food crop

(if BEST is "Cultivated areas of no-food crop", then select 1)

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

BEST vs Bio-energy areas

(if BEST is "Bio-energy areas", then select 1)

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

BEST vs Research centre

(if BEST is "Research centre", then select 1)

1 2 3 4 5 6 7 8 9

○ ○ ○ ○ ○ ○ ○ ○ ○

Cultivated areas of no-food crop vs WORST

(if WORST is "Cultivated areas of no-food crop", then select 1)

1 2 3 4 5 6 7 8 9

Bio-energy areas vs WORST

(if WORST is "Bio-energy areas", then select 1)

1 2 3 4 5 6 7 8 9

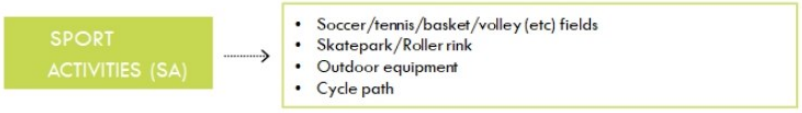
Research centre vs WORST

(if WORST is "Research centre", then select 1)

1 2 3 4 5 6 7 8 9

Indietro Avanti Pagina 5 di 7 Cancella modulo

SUB-CRITERIA (Sport activities)



BEST and WORST ACTIONS

Indicate the most important (BEST) and the least important (WORST) ACTIONS for the implementation of SPORT ACTIVITIES

Select the BEST ACTION *

Scegli

Select the WORST ACTION *

Scegli

PREFERENCE RATIO AMONG ACTIVITIES

Assign the preference ratio of the BEST ACTION over the other ACTIONS and all the ACTIONS over the WORST ACTION. For this value, adopt the fundamental Saaty scale (see Figure below)

Saaty fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to

BEST vs Soccer/tennis/basket/volley (etc) fields

(if BEST is "Soccer/tennis/basket/volley (etc) fields", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Skatepark/Roller rink

(if BEST is "Skatepark/Roller rink", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Outdoor equipment

(if BEST is "Outdoor equipment", then select 1)

1 2 3 4 5 6 7 8 9

SUB-CRITERIA (Organised spaces)



BEST and WORST ACTIONS

Indicate the most important (BEST) and the least important (WORST) ACTIONS for the implementation of ORGANISED SPACES

Select the BEST ACTION *

Scegli

Select the WORST ACTION *

Scegli

PREFERENCE RATIO AMONG ACTIVITIES

Assign the preference ratio of the BEST ACTION over the other ACTIONS and all the ACTIONS over the WORST ACTION. For this value, adopt the fundamental Saaty scale (see Figure below)

Saaty fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to

BEST vs Children's play area & pic-nic area

(if BEST is "Children's play area & pic-nic area", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Dog park

(if BEST is "Dog park", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Study spaces

(if BEST is "Study spaces", then select 1)

1 2 3 4 5 6 7 8 9

BEST vs Organised beaches along the river

(if BEST is "Organised beaches along the river", then select 1)

1 2 3 4 5 6 7 8 9

Children's play area & pic-nic area vs WORST

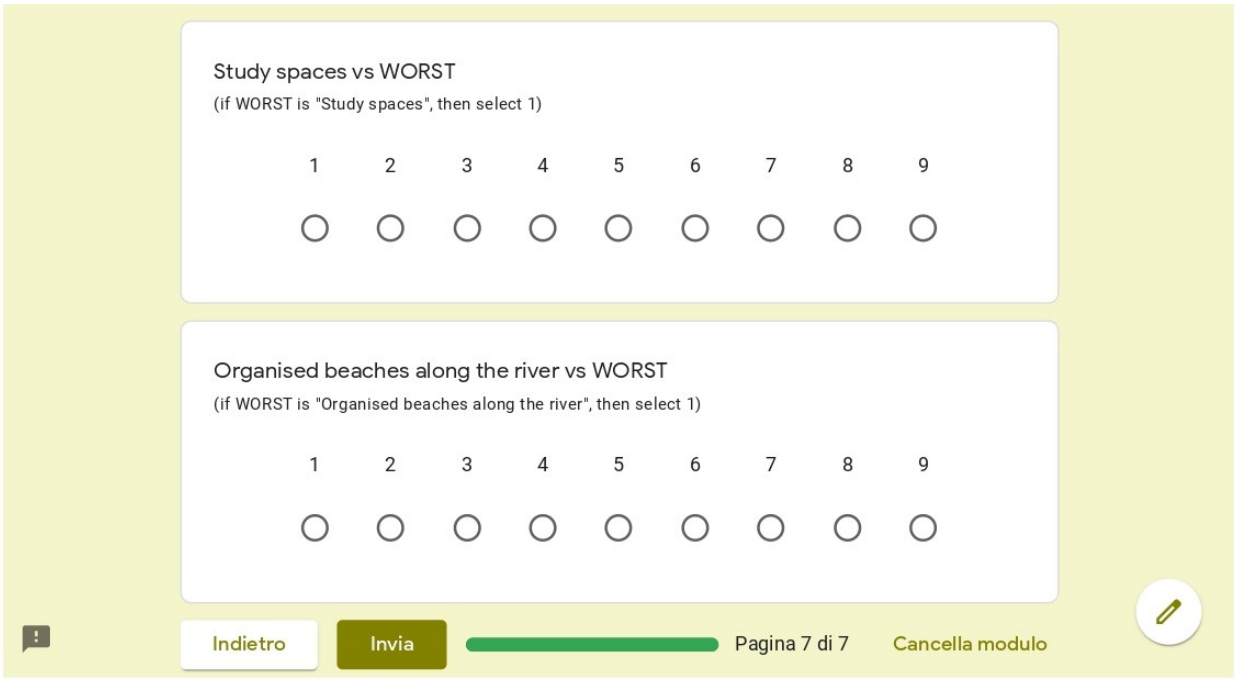
(if WORST is "Children's play area & pic-nic area", then select 1)

1 2 3 4 5 6 7 8 9

Dog park vs WORST

(if WORST is "Dog park", then select 1)

1 2 3 4 5 6 7 8 9


Study spaces vs WORST
(if WORST is "Study spaces", then select 1)
1 2 3 4 5 6 7 8 9
Organised beaches along the river vs WORST
(if WORST is "Organised beaches along the river", then select 1)
1 2 3 4 5 6 7 8 9
Indietro
Invia
Pagina 7 di 7
Cancella modulo

B.3 RP+SP Questionnaire – The Basse di Stura area, Turin (ITA)

A new park for Turin: the Basse di Stura area

Dear citizen,

We invite you to participate in the investigation concerning the possible transformation scenarios for the Basse di Stura area. According to the current Town Plan of the Municipality of Turin, this area will be used as a park. The area, in the northern portion of the Municipality of Turin (see the map at the bottom of the page) covers approximately 150 hectares. It currently still has an industrial function but, in the past, it was an agricultural area of some importance, as can be seen from the historical farmhouses still existing. About the hypotheses of the transformation of the Town Plan, the potential of this place is different: the large spaces allow the creation of diversified functions and activities, while the proximity to the Stura stream and the naturalness of the area allow a development of biodiversity that is difficult to find in a large city like Turin.

The purpose of this survey is, therefore, to identify, based on your choices, the functions to be installed in this new park, to make it attractive not only for those who live in the immediate vicinity but also for all residents of the city of Turin. The questionnaire is aimed at all those who have resided/worked in Turin for at least one year. The survey takes approximately 15 minutes. We remind you that there are no right or wrong answers, so please answer all questions. The information collected will be used for research purposes only and responses will be treated as confidential. The data obtained will be disclosed only in aggregate form. The questionnaire is anonymous.

Your contribution is really important to us and we thank you in advance for your precious collaboration.

SECTION 0

1) Do you voluntarily accept to participate in the questionnaire?
   Do you claim to be 18?
   You declare that you live (as a resident or domiciled) or have worked for longer
   then a year in Turin?
   ☐ Yes
   ☐ No

SECTION 1: use of green spaces.

GREEN SPACES: by green spaces, we mean parks (urban, historical, hilly, river, agricultural),
greenery in the neighborhood, neighborhood play area, dog area, other green spaces (e.g. green space in the place of study/work)

2) Have you ever visited green space in the city of Turin in the last 12 months?*
   ☐ Yes
   ☐ No

   * Just crossing or working in a park is not considered frequent

   If No, go to question number 3. Is Yes, go to question number 4.

3) For what reason? *

Choose **one** or **more** of the following options:

☐ I never go to green spaces

☐ Green spaces are far from my home and/or workplace

☐ I don't like the activities that I can do in the green spaces near my home and / or workplace

☐ I don't like the activities I can do in the green spaces in Turin

☐ The route and connections to reach the green spaces are not adequate

☐ Access for the disabled is not adequate

☐ Other:

After the investigation stops.

4) Starting from where? *

Choose **one** of the following:

☐ From my home

☐ From my workplace

☐ Both from my home and my workplace

If the answer is 'From my home' or 'Both from my home and my workplace' go to question 5. If the answer is 'From my workplace' or 'Both from my home and my workplace' go to question 6.

5) How many times have you gone to a green space in Turin starting from your home? *

Write your answer here *(fill in only one option)*.

____ times a week

____ times a month

____ times a year

* Indicate the frequency by choosing the time frame you prefer (e.g. 1 time a week or 2 times a month or 7 times a year).

6) How many times have you gone to a green space in Turin starting from your place of study/work? *

7) Write your answer here *(fill in only one option)*.

____ times a week

____ times a month

____ times a year

* Indicate the frequency by choosing the time frame you prefer (e.g. 1 time a week or 2 times a month or 7 times a year).

8) Can you locate your place of residence/domicile on the map?

9) Can you locate your place of study/work on the map?

10) Which green spaces in Turin did you frequent the most in the last year?*

Select a maximum of **three** options:

☐ Dog area

☐ Children's play area

☐ Neighborhood garden

☐ Urban, hilly, river, experimental park (e.g. Parco d'Arte Vivente)
☐ Nature reserve
☐ Equipped area for sports (football fields, bowls, etc.)
☐ Urban farming

11) Can you indicate how long it takes to reach them from your home?*
*Answer only for the items selected in question 10.

	Less than 5 minutes	5-10 minutes	10-20 minutes	20-30 minutes	More than 30 minutes
Dog area	☐	☐	☐	☐	☐
Children's play area	☐	☐	☐	☐	☐
Neighborhood garden	☐	☐	☐	☐	☐
Urban, hilly, river, experimental park	☐	☐	☐	☐	☐
Nature reserve	☐	☐	☐	☐	☐
Equipped area for sports	☐	☐	☐	☐	☐
Urban farming	☐	☐	☐	☐	☐

12) Can you indicate how long it takes to reach you from your workplace?*
*Answer only for the items selected in question 10.

	Less than 5 minutes	5-10 minutes	10-20 minutes	20-30 minutes	More than 30 minutes
Dog area	☐	☐	☐	☐	☐
Children's play area	☐	☐	☐	☐	☐
Neighborhood garden	☐	☐	☐	☐	☐
Urban, hilly, river, experimental park	☐	☐	☐	☐	☐
Nature reserve	☐	☐	☐	☐	☐
Equipped area for sports	☐	☐	☐	☐	☐
Urban farming	☐	☐	☐	☐	☐

13) Can you indicate the means of transport you use most frequently to reach them starting from your home?
*Answer only for the items selected in question 10.

	On foot	Bicycle/bike sharing/skate/scooter/roller	Public transport (metro, bus, ...)	Own car/car sharing
Dog area	☐	☐	☐	☐

Children's play area	☐	☐	☐	☐
Neighborhood garden	☐	☐	☐	☐
Urban, hilly, river, experimental park	☐	☐	☐	☐
Nature reserve	☐	☐	☐	☐
Equipped area for sports	☐	☐	☐	☐
Urban farming	☐	☐	☐	☐

14) Can you indicate the means of transport you use most frequently to reach them starting from your workplace?
*Answer only for the items selected in question 10.

	On foot	Bicycle/bike sharing/skate/scooter/roller	Public transport (metro, bus, ...)	Own car/car sharing
Dog area	☐	☐	☐	☐
Children's play area	☐	☐	☐	☐
Neighborhood garden	☐	☐	☐	☐
Urban, hilly, river, experimental park	☐	☐	☐	☐
Nature reserve	☐	☐	☐	☐
Equipped area for sports	☐	☐	☐	☐
Urban farming	☐	☐	☐	☐

15) Could you indicate the reasons for visiting these green areas?*
*Answer only for the items selected in question 10.

	Playing sport	Walking, running, and/or cycling	Relaxing	Taking the dog for a walk	Walking with children	Eating	Studying in the open air	Gardening	Attending events
Dog area	☐	☐	☐	☐	☐	☐	☐	☐	☐
Children's play area	☐	☐	☐	☐	☐	☐	☐	☐	☐
Neighborhood garden	☐	☐	☐	☐	☐	☐	☐	☐	☐

Urban, hilly, river, experimental park	☐	☐	☐	☐	☐	☐	☐	☐	☐
Nature reserve	☐	☐	☐	☐	☐	☐	☐	☐	☐
Equipped area for sports	☐	☐	☐	☐	☐	☐	☐	☐	☐
Urban farming	☐	☐	☐	☐	☐	☐	☐	☐	☐

SECTION 1: mapping green space.
In this section, you should locate the green areas that you previously indicated on the map.
[Each interviewee must indicate on the map the areas indicated in question 10 (maximum 3). Below are 3 example questions as if the interviewee had selected 10 "Dog area", “Children's play area”, “Neighborhood garden” in question 10]

16) Can you locate the DOG AREA you frequented in Turin on the map?*
17) Can you locate the CHILDREN'S PLAY AREA you frequented in Turin on the map?*
18) Can you locate the NEIGHBORHOOD GARDEN you frequented in Turin on the map?*

SECTION 2: In this section, the questions will refer only and exclusively to your attitudes towards a specific green space: that is the PARK (urban public green area of considerable size, preserved from urbanization and equipped for recreational use).

19) Which of these urban parks in Turin have you visited most frequently in the last 12 months?
    Choose **only one** of the following:
    [A list of urban parks in the city of Turin is provided to the interviewee. The "None" option is present in the list. If "None" is selected, go to question 20. Otherwise, go to question 21]

20) Why didn't you visit any urban park in Turin?
    Choose **one** or **more** of the following options:
    ☐ I never go to urban parks
    ☐ Urban parks are far from my home and/or workplace
    ☐ I don't like the activities that I can do in urban parks near my home and/or workplace
    ☐ I don't like the activities I can do in the urban parks in Turin
    ☐ The journey and connections to reach the urban park are not adequate
    ☐ Access for the disabled not adequate
    ☐ Other: *(please specify)*
    Then go to question 44.

21) How often did you frequent these urban parks in Turin?*
Write your answer here (fill in only one option).
____ times a week
____ times a month
____ times a year
* Indicate the frequency by choosing the time frame you prefer (e.g. 1 time a week or 2 times a month or 7 times a year).

22) How much did each of the reasons listed below affect your use of this urban park in Turin?

	Not at all	Slightly	Moderately	Very	Extremely
Playing sports	☐	☐	☐	☐	☐
Walking or running	☐	☐	☐	☐	☐
Taking the dog for a walk	☐	☐	☐	☐	☐
Relaxing	☐	☐	☐	☐	☐
Observing plants and animals	☐	☐	☐	☐	☐
Eating	☐	☐	☐	☐	☐
Studying outdoors	☐	☐	☐	☐	☐
Gardening	☐	☐	☐	☐	☐
Attending events	☐	☐	☐	☐	☐

23) With whom do you frequent this urban park in Turin?

	Always	Very often	Sometimes	Rarely	Never
Alone	☐	☐	☐	☐	☐
Family members	☐	☐	☐	☐	☐
Friends	☐	☐	☐	☐	☐
Animals	☐	☐	☐	☐	☐

24) How often do you use the following means of transport to reach this urban park in Turin?

	Always	Very often	Sometimes	Rarely	Never
On foot	☐	☐	☐	☐	☐
Bicycle/bike sharing/skate/scooter/roller	☐	☐	☐	☐	☐
Public transport (metro, bus, ...)	☐	☐	☐	☐	☐
Own car/car sharing	☐	☐	☐	☐	☐

25) How long does it take on average to reach this urban park in Turin?
☐ < 5 minutes
☐ 5-10 minutes
☐ 10-20 minutes
☐ 20-30 minutes
☐ > 30 minutes

26) At what time do you usually visit this urban park in Turin?

	Always	Very often	Sometimes	Rarely	Never
Early morning (between 6 am and 9 am)	☐	☐	☐	☐	☐
Morning (between 9 am and 12 pm)	☐	☐	☐	☐	☐
Lunchtime (between 12 pm and 3 pm)	☐	☐	☐	☐	☐
Afternoon (between 3 pm and 7 pm)	☐	☐	☐	☐	☐
Evening (after 7 pm)	☐	☐	☐	☐	☐

27) Which days of the week do you usually use this urban park in Turin?

	Always	Very often	Sometimes	Rarely	Never
Weekday	☐	☐	☐	☐	☐
Holiday	☐	☐	☐	☐	☐

28) How long will you stay in this urban park in Turin?

	Always	Very often	Sometimes	Rarely	Never
< 15 minutes	☐	☐	☐	☐	☐
15-30 minutes	☐	☐	☐	☐	☐
30 minutes -1 hour	☐	☐	☐	☐	☐
1 – 2 hours	☐	☐	☐	☐	☐
2 – 4 hours	☐	☐	☐	☐	☐
> 4 hours	☐	☐	☐	☐	☐

29) What season of the year do you use this urban park in Turin?

☐ All the year
☐ Summer
☐ Spring
☐ Autumn
☐ Winter

30) What activities are present in this urban park in Turin?

Choose **one** or **more** of the following options:

☐ Educational farm
☐ Historical-cultural itinerary
☐ "Casa del quartiere" (social activities hub)
☐ Urban farming (allotments)
☐ Camping site
☐ Birdwatching area and/or botanical path

☐ Butterfly farm (butterfly house)
☐ Stables for horses
☐ Land for "no-food" crops (for non-food purposes)
☐ Experimentation area of land phytodepuration
☐ Area for the production of bio-energy (e.g. solar panels)
☐ Research Center
☐ Sports fields (football, tennis, bowls, etc.)
☐ Skatepark/roller skating spaces
☐ Equipment for outdoor sports
☐ Bicycle lane
☐ Children's play area
☐ Area bounded for dogs
☐ Study/relax area
☐ Beaches along the river

SECTION 3: Evaluation of the environmental good under investigation (Basse di Stura)
The Turin Town Plan provides for the construction of an urban park in the Basse di Stura area: the reasons are many (presence of the Stura, hydro-geological constraints that prevent new buildings, ..), as well as the criticalities (land pollution, presence of abandoned industrial areas, ...). However, starting from the potential of the area (the proximity to the Stura, the presence of two artificial lakes, the large spaces available, the presence of historic farmhouses) it is possible to think of a project that integrates different functions: from the primary ones of the park urban (areas equipped for sport, leisure, and relaxation) to unique activities (such as socio-educational activities, areas for research and scientific experimentation).

31) Did you know the Basse di Stura area before this survey?
☐ Yes
☐ No

32) Were you aware of the function envisaged by the Town Plan of the Municipality of Turin for the Basse di Stura area, namely to create an urban park?
☐ Yes
☐ No

33) If in the last year the park of Basse di Stura had already been there, would you have gone there? (Considering the park of Basse di Stura with similar characteristics of the park that you usually visit)
☐ Very probably
☐ Probably
☐ Probably not
☐ Definitely not
If the answer is "Very probably" and "Probably", go to question 34. If the answer is "Probably not" and "Definitely not", go to question 35.

34) For what reason?

☐ Proximity to home and / or workplace.
☐ I like to change parks often.
☐ I am not satisfied with the park I attend.
☐ I am interested in the activities that the new park could offer.
☐ Other: (*please specify*)
Go to question 36

35) For what reason?

☐ Distance from home and/or workplace.
☐ I am satisfied with the park I attend.
☐ I am not interested in the activities that the Basse di Stura park could offer.
☐ I don't go to urban parks.
☐ Other: (*please specify*)

36) If the park of Basse di Stura existed, how many times would you go there?

____ times a week
____ times a month
____ times a year
* Indicate the frequency by choosing the time frame you prefer (eg: 1 time a week or 2 times a month or 7 times a year).

37) With whom would you frequent the urban park of Basse di Stura?

	Always	Very often	Sometimes	Rarely	Never
Alone	☐	☐	☐	☐	☐
Family members	☐	☐	☐	☐	☐
Friends	☐	☐	☐	☐	☐
Animals	☐	☐	☐	☐	☐

38) What means of transport would you use most frequently to reach the Basse di Stura urban park?

	Always	Very often	Sometimes	Rarely	Never
On foot	☐	☐	☐	☐	☐
Bicycle/bike sharing/skate/scooter/roller	☐	☐	☐	☐	☐
Public transport (metro, bus, ...)	☐	☐	☐	☐	☐
Own car/car sharing	☐	☐	☐	☐	☐

SECTION 4: Choice experiment

In this section, a series of possible scenarios for the Basse di Stura area will be compared with its usual park. Please choose which solution you prefer from time to time: whether to continue visiting the park that you usually frequent or to choose the design alternatives proposed for Basse di Stura.

39) Which option do you prefer?

Choose **only one** of the following:

☐ Park usually frequent ☐ Basse di Stura scenario 1

	Historical-cultural itinerary Camping site Bird watching and / or botanical path Stables for horses Land for "no-food" crops (for non-food purposes) Experimentation area of land phytoremediation Sports fields (football, tennis, bowls etc) Skatepark / roller skating spaces Bicycle lane Beaches along the river
Directly completed based on the options selected in question 30	
40) Which option do you prefer? Choose **only one** of the following:	
☐ Park usually frequent	☐ Basse di Stura scenario 2
	Historical-cultural itinerary Urban farming (allotments) Camping site Butterfly farm (butterfly house) Stables for horses Land for "no-food" crops (for non-food purposes) Area for the production of bio-energy (e.g. solar panels) Research Center Sports fields (football, tennis, bowls etc) Skatepark / roller skating spaces Children's play area Area bounded for dogs Beaches along the river
Directly completed based on the options selected in question 30	
41) Which option do you prefer? Choose **only one** of the following:	
☐ Park usually frequent	☐ Basse di Stura scenario 2
	"Casa del quartiere" (neighborhod center) Butterfly farm (butterfly house) Experimentation area of land phytoremediation Research Center
Directly completed based on the options selected in question 30	

	Sports fields (football, tennis, bowls etc) Skatepark / roller skating spaces Children's play area Area bounded for dogs Study / relax area Beaches along the river
42) Which option do you prefer? Choose **only one** of the following: ☐ Park usually frequent	☐ Basse di Stura scenario 3
Directly completed based on the options selected in question 30	Educational farm Butterfly farm (butterfly house) Stables for horses Land for "no-food" crops (for non-food purposes) Area for the production of bio-energy (e.g. solar panels) Sports fields (football, tennis, bowls etc) Bicycle lane Children's play area Study / relax area

SECTION 5: Personal information

43) Sex?

☐ Female

☐ Male

44) How old are you?

_____ years

45) Please indicate your nationality.

_____

46) Please indicate the number of members of your household (including you).

____ Children

____ Adults earning income

____ Adults who do not receive income

____ Seniors

47) Education level

☐ Primary school

☐ Secondary school

☐ High school graduate

☐ Bachelor degree
☐ Master degree
☐ Postgraduate degree
☐ No title

48) Job:
☐ Student
☐ Entrepreneur
☐ Self-employed worker (craftsman, trader, direct farmer)
☐ Freelance
☐ Executive, supervisory manager
☐ Office worker/employee/teacher
☐ Worker/foreman
☐ Retired
☐ Housewife
☐ Unemployed
☐ Other condition *(please specify)*

49) In which branch of economic activity do you operate?
☐ Agriculture, hunting, and fishing
☐ Extraction, energy
☐ Industry and manufacturing activity
☐ Construction
☐ Wholesale and retail trade
☐ Hotels and restaurants
☐ Transport, storage and communications Monetary and financial intermediation
☐ Real estate, rental, IT, research, and other professional or business activities
☐ Public administration and defense
☐ Education
☐ Health and other social services
☐ Other

50) How much is your family's total monthly net income? (including income from work, annuities, pensions, social policies, insurance ...)
☐ I do not know
☐ _____ €/month

51) If you don't know exactly, please indicate what the net monthly income of your household is closest to? (including income from work, annuities, pensions, social policies, insurance...)
☐ More than 10,000 €/month
☐ 9,000 €/month
☐ 7,000 €/month
☐ 6,000 €/month
☐ 5,000 €/month
☐ 4,000 €/month

☐ 3,000 €/month
☐ 2,500 €/month
☐ 2,000 €/month
☐ 1,800 €/month
☐ 1,600 €/month
☐ 1,400 €/month
☐ 1,200 €/month
☐ 1,000 €/month
☐ 800 €/month
☐ 600 €/month
☐ less than 600 €/month

52) How many hours do you work on average in a week?
☐ Less than 20 hours
☐ Between 20 and 30 hours
☐ Between 30 and 40 hours
☐ More than 40 hour

Appendix C

Courses – Hard and soft skills

H Soft Skills (required >= 40)	162	**H Hard Skills (required >= 100)**	207
Points Soft Skills	205.33	**Points Hard Skills**	275.67
Points outside activities	3.8		
Total Points	**484.80**		

Hard skills

1. (01QTVRS) **Behavioural theories** (h. 15) – 21/2/2020 – score 1.33
2. (01QTZRS) **Geomatics and gis for environmental application and regional planning** (h. 30) – 18/1/2019 – score 1.67
3. (01RGKRS) **Multicriteria analysis and strategic assessment** (h. 10) - 1/9/2020 – score 1.67
4. (01TBVRS) **Multi-methodology and urban renewals: mixing methods for facing urban uncertainty** (h. 15) – 4/2/2019 – score 1.67
5. (01ULSRS) **Psycology of urban life** (h. 10) – 7/1/2020 – score 1.33
6. (01SDGRS) **Socio-technical urbanization** (h. 16.00) – 6/3/2019 – score 1.33
7. (02QUBRS) **Statistical data processing** (h. 20) – 13/3/2019 – score 1.67
8. (01TBWRS) **Sustainable urban forms: a quantitative and qualitative perspective** (h. 15) – 7/1/2020 – score 1.33
9. (external) **ABM2019 Agent-based modeling for Geographical Applications** (h. 20) –16-20/9/2019 – score 1.00

Soft skills

1. (01SINPG) **Antropologia dei contesti scolastici ed educativi** (h. 30) – 26/7/2021 – score 1.33

2. (02LWHRS) **Communication** (h. 5) – 16/11/2019 – score 1.33
3. (01SIOPG) **Didattica, tecnologie e ricerca educativa** (h. 30) – 23/7/2021 – score 1.33
4. (01SHMRS) **Entrepreneurial Finance** (h. 5) – 21/11/2019 – score 1.33
5. (01UNYRS) **Personal branding** (h.1) – 18/12/2020 – score 1.33
6. (08IXTRS) **Project management** (h. 5) – 21/11/2019 – score 1.33
7. (01UHIBG) **Psicologia dell'educazione e dell'apprendimento in contesti scolastici** (h. 30) – 21/7/2021 – score 1.33
8. (01RISRS) **Public speaking** (h. 5) – 29/9/2019 – score 1.33
9. (01SYBRS) **Research integrity** (h. 5) – 16/11/2019 – score 1.33
10. (01SWQRS) **Responsible research and innovation, the impact on social challenges** (h. 5) – 6/1/2019 – score 1.33
11. (02RHORS) **The new Internet Society: entering the black-box of digital innovations** (h. 6) – 20/11/2019 – score 1.33
12. (01SWPRS) **Time management** (h. 2) – 18/11/2019 – score 1.33
13. (01UNXRS) **Thinking out of the box** (h.1) - 16/12/2020 – score 1.33

14. (external) **Horizon Europe and Project Writing** (h. 2) – 25/10/2019 – score 1.00
15. (external) **Pedagogia della relazione educativa e formativa per la scuola secondaria** (h. 30) – 24/9/2021 – score 1.00

List of papers

Publications indicator	
Indicatore R	412.642075
50N	350
"Parametro α"	10

a. Guest editor of special issues

1. **Topic:** Dynamic Modeling to Support the Decision-making Process in the Planning of Sustainable and Resilient Socio-Ecological Systems **Journal:** Ecological Modelling

b. Journal articles

1. Berisha, E., Caprioli, C., Cotella, G. (2022). Unpacking SDG target 11.a: what is it about and how to measure its progress? *City and Environment Interactions*, 100080. https://doi.org/10.1016/j.cacint.2022.100080

2. Assumma, V., Bottero, M., Caprioli, C., Datola, G., & Mondini, G. (2022). Evaluation of Ecosystem Services in Mining Basins: An Application in the Piedmont Region (Italy). *Sustainability*, 14(2), 872. https://doi.org/10.3390/su14020872

3. Assumma, V., Bottero, M., Caprioli, C., & Dell'Ovo, M. (2021). Decision making in complex urban contexts: an application for a critical area in the city of Torino (Italy). *Sustainable City and Society*, 103028. https://doi.org/10.1016/j.scs.2021.103028

4. Caprioli C., & Bottero, M. (2021). Addressing complex challenges in transformations and planning: A fuzzy spatial multicriteria analysis for identifying suitable locations for urban infrastructures. *Land Use Policy*, 102, 105147. https://doi.org/10.1016/j.landusepol.2020.105147

5. Caprioli, C., Bottero, M., De Angelis, E. (2020). Supporting Policy Design for the Diffusion of Cleaner Technologies: A Spatial Empirical Agent-Based Model. *ISPRS Int. J. Geo-Inf.*, 9(10), 581. https://doi.org/10.3390/ijgi9100581

6. Treves, A., Bottero, M., Caprioli, C., & Comino, E. (2020). The reintroduction of Castor fiber in Piedmont (Italy): An integrated SWOT-spatial multicriteria based approach for the analysis of suitability scenarios. *Ecological Indicators*, 118, 106748.

https://doi.org/10.1016/j.ecolind.2020.106748

7. Bottero, M., Caprioli, C. (2019). Spazi ibridi e modelli di cambiamento: l'area di Basse di Stura a Torino. *Atti e Rassegna Tecnica*

8. Bottero, M., Caprioli, C., Cotella, G., & Santangelo, M. (2019). Sustainable cities: A reflection on potentialities and limits based on existing eco-districts in Europe. *Sustainability*, 11(20), 5794. https://doi.org/10.3390/su11205794

9. Bottero, M., Foth, M., Mitchell, P., Rittenbruch, M., Caprioli, C. (2022). Hedonic Price Model of recreational parks for the city of Brisbane (Australia), Urban Forestry and Urban Greening **(under review – II round)**

10. Bravi, M., Bottero, M., Caprioli, C., Dell'Anna, F. (2022) A combination of revealed and stated preferences for the definition of new strategies for the area of Basse di Stura in Turin (Italy) **(under review – I round)**

11. Bottero, M., Torrieri, F., Caprioli, C., Datola, G. (2022) A participatory Multicriteria Analysis for the evaluation of alternative urban transformation scenarios in the area of Rogoredo in Milan (Italy), Valori e valutazioni **(under review – I round)**

12. Abastante, F., Caprioli, C, Gaballo, M., Lami, I. (2022) Economic Evaluation of Projects in learning processes: an integrated framework **(under review – I round)**

13. Bottero, M., Caprioli, C., Dell'Ovo, M., Oppio, A. (2022) Combining ecosystem services assessment and cost-benefit analysis for urban transformation (ongoing)

14. Assumma, V., Caprioli, C., Dell'Ovo, M. (2022). Decision-making and stakeholder role for supporting future perspectives of Matera (Italy) (on-going)

15. Caprioli, C., Bottero, M., De Angelis, E. (2022). A combination of spatial agent-based model and Multicriteria Analysis for assessing variables priorities in people housing choice in Brisbane (Australia) (on-going)

16. Bottero, M., Bravi, M., Caprioli, C., Dell'Anna, F., Dell'Ovo, M. (2022) A Best-to-Worst Scaling experiment for exploring housing

preferences connected to the COVID-19 in two Italian metropolitan cities (Milan vs Turin) (on-going)

c. Book chapters

1. Bottero, M., Caprioli, C., & Oppio, A. (2021) A Literature Review on Construction Costs Estimation: Hot Topics and Emerging Trends. *Appraisal and Valuation*, 117-131. https://doi.org/10.1007/978-3-030-49579-4_9

2. Bottero, M., Caprioli, C., & Berta, M. (2020). Urban problems and patterns of change: The analysis of a downgraded industrial area in Turin. *In Green Energy and Technology*. https://-doi.org/10.1007/978-3-030-23786-8_22

3. Assumma, V., Bottero, M., Caprioli, C., Datola, G., Dell'Anna, F., Mondini, G. (2020). Strategic assessment and urban planning: the revision of the municipal plan of Turin. Green Energy and Technology **(in press)**

d. Conference proceedings

1. Caprioli C., Oppio A., Baldassarre R., Grassi R., & Dell'Ovo M. (2021) A Multidimensional Assessment of Ecosystem Services: From Grey to Green Infrastructure. In: Gervasi O. et al. (eds) Computational Science and Its Applications – ICCSA 2021. ICCSA 2021. Lecture Notes in Computer Science, vol 12955. Springer, Cham. https://doi.org/10.1007/978-3-030-87007-2_41

2. Bottero M., Bravi M., Caprioli C., Dell'Anna F., Dell'Ovo M., & Oppio A. (2021) New Housing Preferences in the COVID-19 Era: A Best-to-Worst Scaling Experiment. In: Gervasi O. et al. (eds) Computational Science and Its Applications – ICCSA 2021. ICCSA 2021. Lecture Notes in Computer Science, vol 12954. Springer, Cham. https://doi.org/10.1007/978-3-030-86979-3_9

3. Caprioli, C., Bottero, M., Zanetta, E., & Mondini, G. (2020). Ecosystem Services in Land-Use Planning: An Application for Assessing Transformation Scenarios at the Local Scale. *In INTERNATIONAL SYMPOSIUM: New Metropolitan Perspectives* (pp. 1332-1341). Springer, Cham. https://doi.org/10.1007/978-3-030-48279-4_124

4. Caprioli, C., Bottero, M., & Mondini, G. (2020). Urban Ecosystem Services: A Review of Definitions and Classifications for the Identification of Future Research Perspectives. *In International Conference on Computational Science and Its Applications* (pp. 332-344). Springer, Cham. https://doi.org/10.1007/978-3-030-58814-4_23

5. Caprioli, C., Bottero, M., & Pellegrini, M. (2019). An Agent-Based Model (ABM) for the Evaluation of Energy Redevelopment Interventions at District Scale: An Application for the San Salvario Neighborhood in Turin (Italy). *In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. https://doi.org/10.1007/978-3-030-24302-9_28

6. Caprioli, C., & Bottero, M. C. (2018). Agent-based modelling and Geographic Information System for the evaluation of eco-district's scenarios. In A. Leone & C. Gargiulo (Eds.), *Environmental and territorial modelling for planning and design* (pp. 35–45). Naples: FedOAPress. https://doi.org/10.6093/978-88-6887-048-5

7. Bottero, M., Caprioli, C., Datola, G., Caruso, N. (2022) Regeneration of Rogoredo railways: a combined approach using multi-criteria and financial analysis. ICCSA 2021. Lecture Notes in Computer Science. Springer, Cham. **(under review – I round)**

8. Bottero, M., Caprioli, C., Dell'Ovo, M., Oppio, A. (2023) A proposal to assess the benefits of Urban Ecosystem Services, New Metropolitan Perspectives (NMP) **(under review – I round)**

Abroad period

1. 16 August – 1 September 2019: Brisbane, Australia, QUT – **Queensland University of Technology** (Urban Informatics, QUT Design Lab) *QUT Supervisor: Professor Marcus Foth*

2. July – October 2020: Brisbane, Australia, QUT – **Queensland University of Technology**
   QUT Supervisor: Assoc. Prof. Tan Yigitcanlar (Urban and Regional Planning) (cancelled for COVID-19)

Teaching activities

Teaching activity - courses

1. 01RUTQA (a.a. 2021/2022) (IT) - Pianificare il territorio e il paesaggio (Atelier) (Prof. Bottero M.): Estimo ambientale (Master's Degree In Pianificazione Territoriale, Urbanistica E Paesaggistico-Ambientale - Torino)
2. 759589 (PoliMi) (a.a. 2021/2022) (EN) - Economic evaluation of project (Prof. Dell'Ovo M.) (Master's Degree in Architettura delle Costruzioni - Milano)
3. 01DLLJZ (ASP) (a.a. 2020/2021) (EN) - Complex decision making and policy design – ASP School - Alta Scuola Politecnica school, 18-22 October, Loano, ITALY
4. 01QLYPQ (a.a. 2020/2021) (EN) - Architecture and urban economics (Design Unit) (Prof. Abastante F.): Real Estate evaluation (Master's Degree In Architecture Construction City - Torino)
5. 01VFAJZ (ASP) (a.a. 2020/2021) (EN) Decision Making for Chancing Cities – ASP School - Alta Scuola Politecnica courses, 16-27 November, online
6. 01QLYPQ (a.a. 2019/2020) (EN) - Architecture and urban economics (Design Unit) (Prof. Lami I. and Abastante F.): Real Estate evaluation (Master's Degree In Architecture Construction City - Torino)
7. 01UFYJZ (ASP) (a.a. 2018/2019) (EN) Decision Making and Policy Design – ASP School - Alta Scuola Politecnica courses, 22-26 July 2019, Sestriere, ITALIA
8. 01RUUQA (a.a. 2018/2019) (IT) - Pianificare la città (Atelier) (Prof. Lami Isabella Maria): Valutazione e fattibilità economica (Master's Degree In Pianificazione Territoriale, Urbanistica E Paesaggistico-Ambientale - Torino)
9. 053186 (PoliMi) (a.a. 2018/2019) (EN) – Project Appraisal (Prof. Bottero, Prof. Torrieri), Master's Degree Architecture - Built Environment Interiors
10. 01SFYPQ (a.a. 2018/2019) (IT) - Workshop "Esercizio professionale" (Prof. Bottero Marta Carla) (Architettura Costruzione Città - Torino; Architettura per il Restauro e Valorizzazione del Patrimonio - Torino; Design Sistemico - Torino; Architettura per il Progetto Sostenibile - Torino) [course organization and management]
11. 01SXVJZ (a.a. 2018/2019) (EN) Decision Making in Changing Urban Contexts – ASP School - Corsi Alta Scuola Politecnica, 23-27 July 2017, Sestriere, Torino, ITALIA
12. 01SFYPQ (a.a. 2017/2018) (IT) - Workshop "Esercizio professionale" (Prof. Bottero M.) (Architettura Costruzione Città - Torino; Architettura per il Restauro e Valorizzazione del Patrimonio - Torino; Design Sistemico - Torino; Architettura per il Progetto Sostenibile - Torino) [course organization and management]

Teaching activity – lessons

1. “Ecosystem services” - Multicriteria-Analysis and Project Appraisal (Politecnico di Milano), 2 November 2022, Piacenza, ITALY
2. “Servizi ecosistemici” - Strumenti per le Valutazioni di Impatto Ambientale (Politecnico di Milano), 5 November 2022, Lecco, ITALY
3. “Multicriteria Spatial Decision Support System (MC-SDSS): Un approccio integrato allo studio dei problemi complessi in ambito urbano e territoriale” - Scuola di Specializzazione in Beni Architettonici e del Paesaggio, 13 May 2021
4. “Decision making nella pianificazione urbana – Multicriteria Spatial Decision Support System (SDSS)” – Master Politecnico di Milano “Estimo e valutazione immobiliare (MReV)”, 18 March 2021
5. “Multicriteria Spatial Decision Support System (MC-SDSS): Un approccio integrato allo studio dei problemi complessi in ambito urbano e territoriale” - 03KZTPM (a.a. 2018/2019) Valutazioni di impatto ambientale, 9 May 2020
6. “Multicriteria Spatial Decision Support System (MC-SDSS): un caso applicativo” - INT1207 (a.a. 2018/2019) Urban Management, 1 April 2020
7. “Analisi Costi-Benefici” - 02JNLPW (a.a. 2018/2019) Fattibilità economica di piani e progetti, 13 December 2019
8. “Integrating spatial analysis with a combination of revealed and stated preferences for the evaluation of a public good” – Scuola di Specializzazione in Beni Architettonici e del Paesaggio, 17 May 2019
9. “Multicriteria Spatial Decision Support System (MC-SDSS): Un approccio integrato allo studio dei problemi complessi in ambito urbano e territoriale” - 03KZTPM (a.a. 2018/2019) Valutazioni di impatto ambientale, 9 May 2019
10. “Team work e competenze relazionali - Lavorare in team: le dinamiche di gruppo” corso professionalizzante GEAM sulle “Capacità operative e relazionali”, 16 April 2019
11. “Multicriteria Spatial Decision Support System (MC-SDSS): un caso applicativo” - INT1207 (a.a. 2018/2019) Urban Management, 1 April 2019
12. “Decision making nella pianificazione urbana – Multicriteria Spatial Decision Support System (SDSS)” – Master Politecnico di Milano “Estimo e valutazione immobiliare (MReV)”, 7 March 2019
13. “Basse di Stura, a downgraded industrial area in Turin” - 01QLXPQ (a.a. 2018/2019) Architettura ed economia urbana B (Estimo) Corso di Laurea Magistrale in Architettura Costruzione Città, 6 March 2019
14. “Analisi Costi-Benefici” - 02JNLPW (a.a. 2019/2020) Fattibilità economica di piani e progetti, 14 December 2018

Project involvement

1. **VALIUM – VALuation Integrated for Urban Management project (I call 2018-2019 and II call 2019-2020)** *(Research group: Professor Bottero, Bravi, Cotella, Giaimo, Mondini, Santangelo, Rossi; junior researchers: Caterina Caprioli, Federico Dell'Anna; external collaboration: Energy Center Lab, Universitat Politècnica de Catalunya, CPSV - Centre de Política de Sòl i Valoracions)*
   The research project VALIUM (VALution for Integrated Urban Management) aims to reflect on complex urban problems and regeneration operations, focusing in particular on the role of evaluation tools for supporting decision-making. During the project, I collaborate in the development of: 1. A combination of Stated Preferences model and Revealed Preferences model (Travel Cost Method + Choice Experiment) with GIS for the assessment of new scenarios for the area of Basse di Stura; 2. An agent-based model (ABM) integrated with GIS for the evaluation of energy redevelopment scenarios in the San Salvario district.

2. **New Municipal Plan for Torino** *(Research group: Professors Mondini, Bottero; PhD students Vanessa Assumma, Caterina Caprioli, Giulia Datola, Federico Dell'Anna).*
   Collaboration for supporting the definition and analysis of new strategies for the revision of the municipal plan of Torino.

3. **ZOOM BioPark - Torino** *(Researchg group: Professors Mondini, Bottero, Arch. Elisa Zanetta; PhD students Vanessa Assumma, Caterina Caprioli, Giulia Datola, Federico Dell'Anna).*
   Collaboration for the elaboration of the PEC for the biopark and SEA for the ZOOM park.

4. **Ivrea – SWOT analysis for transformation scenarios** *(Research group: Professors Corgnati, Bottero, Becchio; PhD students Vanessa Assumma, Caterina Caprioli, Giulia Datola, Federico Dell'Anna, Giulia Vergerio).*
   Collaboration with the Energy Center for the evaluation of alternative scenarios for the AEG Coop of Ivrea and for the requalification of the Olivetti buildings in Ivrea.

5. **Gattico-Veruno Municipal Plan** *(Research group: Professors Mondini, Bottero; PhD students Vanessa Assumma, Caterina Caprioli, Giulia Datola, Federico Dell'Anna).*
   Participation in the agreement between Politecnico di Torino and comune di Gattico-Veruno (Novara).

6. **QUICHE (Quali misurazioni per quali politiche: verso il Sustainable Development Goal 11) -** *(Research group: Professors and research group: Lami, Abastante, Aru, Bravi, Berisha, Buzzacchi, Caprioli, Caruso, Chiodelli, Cotella, Dell'Anna, Janin Rivolin, Mecca, Mondini, Salone, Rebaudengo, Prizzon, Zotteri. No-PoliTO Professors: Moroni, Oppio, Micelli, D'Alpaos)*

7. **ASP Project GreenTA - (Green roof Technology Assessment). The role of green roof in the provision of ecosystem services: the case of the Lingotto in Turin -** *(Research group: Professors and research group: Bottero (coordinator), Bravi, Corgnati, Becchio, Berta, Longo, Rebecchi, Caprioli, Crespi, Dell'Anna, Dell'Ovo)*

Conferences/workshop participation

Conferences (as speaker)

1. EWG-MCDA 2022 | 93rd online meeting of the EURO Working Group in MultiCriteria Decision Aiding | April 7-9, 2022, Belgrade, SERBIA (online)
   "Sustainable urban projects: an application of the Best Worst Method in the city of Turin (Italy)"
2. ICSSA 2021 | The 21st International Conference on Computational Science and its Applications | 13 September 2021, Cagliari, ITALY
   1. "A choice modelling for exploring new housing needs in post-COVID 19 era"
   2. "A Multidimensional Assessment of Ecosystem Services: From Grey to Green Infrastructure"
3. A.I.S.Re Conference | XLII Conferenza scientifica annuale | 8-10 September 2021(online)
   "Scenari di mobilità sostenibile e sviluppo urbano: un'esplorazione delle potenzialità del modello eco-neighborhood"
4. SIMAI 2020-2021 | 2020 edition of the bi-annual congress of the Italian Society of Applied and Industrial Mathematics | 30 August – 2 September 2021, Università di Parma, ITALY (online)
   "Supporting policy design for the diffusion of cleaner technologies: a spatial empirical Agent-Based Model"
5. EURO 2021 | 31st European Conference on Operational Research (EURO) | 10-14 July 2021, Athens, GREECE (online)
   1. "Multicriteria evaluation and agent-based model for simulating housing mobility propensity of residents"
   2. "A choice modelling for exploring new housing needs in post-COVID 19 era"
6. EWG-MCDA 2021 | 91st online meeting of the EURO Working Group in MultiCriteria Decision Aiding | April 29-30, 2021, online
   "Assessing Ecosystem Services through Multi-Criteria Decision Analysis: a case study in Turin"
7. Urbanpromo 2020 | Progetti per il paese | 20 November 2020, Milan, ITALY (online)
   "Spazio fisico VS spazio digitale: esplorare le nuove esigenze abitative attraverso l'impiego di un modello di scelta"
8. Urbanpromo Green 2020 | IV edizione | 18 September 2020, Venezia, ITALY (online)
   1. "A multidimensional assessment of Ecosystem Services: from grey to green infrastructure"
   2. "Analisi multicriteri e analisi finanziaria: un approccio integrato per la rigenerazione degli scali ferroviari di Rogoredo"
9. ICSSA 2020 | The 20th International Conference on Computational Science and its Applications | 3 July 2020, Cagliari, ITALY (online)
   "Urban ecosystem services: a review of definitions and classifications for the identification of future research perspectives"
10. NMP2020 | New Metropolitan Perspective | 27 May 2020, Reggio

Calabria, ITALY (online)
"Ecosystem services in land-use planning: an application for assessing transformation scenarios at the local scale"

11. SIEV 2019 | Società Italiana di Estimo e Valutazioni | 15 November 2019, Torino, ITALY
    "The SROI (Social Return On Investment) methodology for assessing urban transformation scenarios: a case study in the city of Grenoble" (poster)
12. Building Sustainable and Resilient Cities | Castello del Valentino, 18 July 2019, Torino, ITALY
    "Decision making in urban/territorial transformations"

Conferences (as session chair)

1. ICSSA 2021 | The 21st International Conference on Computational Science and its Applications
   Session: Building multi-dimensional models for assessing complex environmental systems (MES) | 13 September 2021, Cagliari, ITALY
2. EURO 2021 | 31st European Conference on Operational Research (EURO)
   Session: Trade-off between Economics and Environment: the response of cities in the shadow of COVID-19 | 10-14 July 2021, Athens, GREECE (online)
3. ICSSA 2020 | The 20th International Conference on Computational Science and its Applications
   Session: Building multi-dimensional models for assessing complex environmental systems (MES) | 3 July 2020, Cagliari, ITALY (online)
4. Building Sustainable and Resilient Cities | Invited chair: Spiro Pollalis, Graduate School of Design, Harvard University - "Sustainability repositions Architecture" | 18 July 2019, Castello del Valentino (Politecnico di Torino), Torino, ITALY
5. VALuation for Integrated Urban Management (VALIUM) | Final seminar
   28 Febbraio 2019, Sala Regia – Castello del Valentino, Torino, ITALY

Conferences (participation)

1. SIEV (Società Italiana di Estimo e Valutazioni), title "Modelli avanzati per la valutazione dei co-benefit associati a interventi di riqualificazione e conservazione dell'ambiente naturale e costruito", 19 September 2019, Venezia, ITALIA
2. "Horizon Europe and Project Writing", 25 October 2019, Stanza "Arturo Graf", Libreria Arturo, Palazzo del Rettorato, Via Po 17 Torino, ITALIA
3. "Green Future and grey implications of a new park in Brisbane: visions for the Victoria Golf Course", 26 Auguste 2019, QUT Garden Points, Brisbane, AUSTRALIA
4. "Brisbane Conversations #4: The future of affordable housing", 22

Auguste 2019, Brisbane, AUSTRALIA
5. “Design-Ied: roles and responsabilities”, 21 Auguste 2019, Brisbane, AUSTRALIA

Workshop

1. "ABM2019 Agent-based modeling for geographical applications" 16-18 September 2019 (Università di Trento) [Coordinator: Prof. Davide Geneletti; Instructor: Prof. Francesco Orsi]