Agent-based modelling and geographic information system for evaluation of eco-district's scenarios

AGENT-BASED MODELLING AND GEOGRAPHIC INFORMATION SYSTEM

FOR EVALUATION OF ECO-DISTRICT'S SCENARIOS

CATERINA CAPRIOLI
MARTA CARLA BOTTERO

Interuniversity Department of Regional and Urban Studies and Planning (DIST)
Politecnico di Torino
e-mail: caterina.caprioli@polito.it,
marta.bottero@polito.it

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ABSTRACT

Nowadays, urban regeneration processes increasingly face energy issues. The European Union has recently adopted some directives for promoting energy redevelopment and diffusion of almost zero energy buildings at a large-scale with a view to post-carbon cities. However, to achieve a sustainable growth, the reduction of the greenhouse gas and energy consumption is not sufficient. A wide range of problem dimensions must be investigated and considered, such as social, economic and environmental aspects.
In this multidimensional context, to investigate the stakeholders' role and to understand their objectives and desires is essential not only to achieve consensus among parties but also to increase planners' capabilities in solving decision problems. In this context, the agent-based model (ABM) is of interest to urban planners and municipalities, thanks to its bottom-up approach. The possibility to observe the agent's (individual actors) actions come from the interactions among them in a specific environment is particularly important to address the sustainable and long-term vision of a city. To those aspects is added the necessity to link this simulation model with spatial and temporal analysis, to create a real world of investigation. The use of GIS and its linkage with ABM seems particularly effective to achieve the final goal. The case study investigates potentials and limits coming from the integration of the two methods in the evaluation of different scenarios with the aim to realize an eco-district in the heart of Turin (Italy). The objective of the research is to use the San Salvario neighbourhood as a test-bed for an upgrading of the overall city sustainability.

KEYWORDS
Urban Planning; Agent-based Model; Geographic Information System; Energy

1 INTRODUCTION

Nowadays, there is an intensive debate about the reduction of Green House Gas (GHG) emission, the decrease in energy consumption and the transition to renewable energy. Many are the directives adopted by the European Union for promoting energy redevelopment with a large-scale view of post-carbon cities. As a direct consequence, cities have started to define future strategies and plans to achieve these goals. In that context, the retrofitting of buildings is strictly important for their highest amount of energy usage in our cities. However, the retrofitting strategies are not sufficient unless they are considered in a larger view of development, in which all the pillars of sustainability should be considered. In fact, the energy transition must be a part of a vision concerning the experimentation of urban policies able to face new challenges in the social and environmental transformations governance of a city or a part of it. It is thus clear that apart from the investigation of all multidimensional aspects, it is necessary to pass from the analysis of a single building to an analysis at the district/neighbourhood level, following those models of sustainable energy transition generally called "eco-districts" or "sustainable neighbourhoods". Although these terms refer to a very broad array of concepts, the literature review has underlined some principles to be taken into account for a sustainable urban development, such as satisfaction of human needs, considering neighbourhood impact on the wider environment, providing compact development and integrated sustainable mobility and developing harmonized coupled human-environment system (Luederitz et al., 2013).

The picture that emerges is of an area of investigation extremely complex, in which policymakers must take decisions often not so clear as a first approximation. For that reason, over the years, different evaluation approaches and techniques, from the most consolidated (such as SWOT, Costs Benefits or Multicriteria analysis) to the innovative ones (such as Choice Experiments or Fuzzy analysis), have been developed to face the complexity of decision-making problems in urban areas. An interesting research path concerns the so-called Mixed Methods, that combine qualitative approaches typical of social sciences with quantitative ones based on mathematical models and statistical analysis.

An innovative and powerful analytic and computational method recently emerged is the Agent-Based Model (ABM). This approach offers a flexible architecture able to realize a detailed representation of complex agent systems, including the behaviour of agents, their social interactions and the environments that surround them (Khansari et al., 2017).

In a certain way, also these methods do not consider a fundamental element related to the urban complex problems, namely the real spatial nature of urban and territorial problems. Therefore, the objective of our research is combined this innovative approach (ABM) through Geographic Information Systems (GIS) capable to synthetize geographic information and data.

The case study investigates potentials and limits coming from the integration of the two methods in the evaluation of different scenarios of sustainable development with the aim to realize an eco-district in the heart of Turin (Italy). The objective of the present paper is to frame a methodological proposal for the application of the integrated ABM-GIS model. The real case study of the San Salvario neighbourhood in Turin will be considered for the experimentation.

2 AGENT-BASED MODEL (ABM)

In the present section, a brief description of the ABM methodology is proposed, coupled with an analysis of the relevant articles in the domain of urban planning.

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2.1 METHODOLOGICAL BACKGROUND

The Agent-Based Model (ABM) is a powerful method able to build complex systems starting from individual actors (called agents) whose coincident acting leads to emergent effects or outcomes (Hinker et al., 2017). These 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 allows realizing a decision-making process really based on a bottom-up approach, in which the stakeholders act to achieve their own objectives and interests. Another element that characterizes this approach is the presence of a shared environment in which the agents interact. Connecting the environment with the all multidimensional aspects of the decision process can be a useful tool for study the effects on processes that operate at multiple scales and organizational levels (Brown, 2006). In more detail, it is possible to define three components as the key elements that characterize the ABM, namely *the agents*, *the interactions* and *the environment*. About *the agent*, the literature does not provide a univocal definition on his characteristics. However, Macal and North (2010) underline certain essential characteristics that the agents need to have:

- **autonomy** in its environment and in its interactions;
- **self-sufficiency, modularity, uniqueness and individual identifiability**[1];
- **a state** that varies over the time;
- **a social dynamic** that influences its behaviour through the interactions with other agents.

The interactions among agents are particularly important because they generate changing in agent behaviours. Primary issues of the modelling are to figure out whom agents are connected and the types of interactions' mechanisms. Related to the first aspect, not all agents interact with all the others, but with a subset of them: this group represents the neighbour of an agent. For the second aspect, exist many types of agent relations' modelling: with Cellular Automata (CA), in the 2D or 3D Euclidean Space, with Network topology, with Geographic Information System (GIS) and with the aspatial "Soup" model (Macal & North, 2010). *The environment* represents the place in which agents interact. It could have different information and detail levels: it may give only information about the agents' spatial location or a rich set of data, like a GIS.

2.2 LITERATURE REVIEW

The analysis of the literature has underlined different phenomena with respect to the theme of ABM. With the use of the database Scopus, we investigated all articles related to the Agent-Based Model (ABM). In that case, the documents resulted are more than 11 thousand, already written before the seventies, but with a significant increase after 2005. On the contrary, the publications related to the Agent-Based Model (ABM) and its application in urban and energy regeneration are considerably less of about 120 documents. All were written after 2000 and the considerable growth occurs after 2005 (Fig. 1). Considering only the documents that use an integration between ABM and GIS, the relevant articles passed from 118 to 5. In-depth analysis underlines two relevant aspects: first, exist in addition to agent-based model (ABM) the so-called multi-agent systems (MAS), normally used for the separation of logical components of intelligent systems (Hinker et al., 2017); second, the scale of the project is in most cases an urban scale and so, less indicated to analyse district regeneration and transformation. The ABM seems to be very useful to define land use in relation to the

[1] These characteristics allow to clearly define the boundaries of each agent.

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behaviour of the agents considered. An exception is represented by the Hinker et al. (2016) research, that uses the ABM for analysing socio-technical optimality gaps in the energy domain at a district level: both the project scale and type of agents involved are similar and comparable to our case study. The main papers consulted for our research are given in Tab. 1.

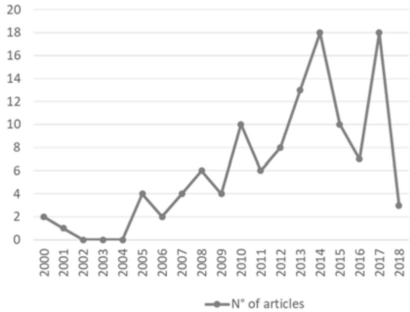

Fig. 1 Number of publications related to the Agent-Based Model (ABM) and urban-energy regeneration written over the years

AUTHORS	TITLE	DESCRIPTION	YEAR
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
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
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
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
Macal, C.M. & North M.J.	Tutorial on agent-based modelling and simulation	ABM	2010
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

Tab. 1 Main articles from literature review in the context of urban planning

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3 CASE STUDY

3.1 DESCRIPTION OF THE SAN SALVARIO NEIGHBORHOOD

Fig. 2 Location of the San Salvario neighbourhood in Turin

Fig. 3 The San Salvario neighbourhood

The case study is located in Turin and, in particular, in the San Salvario neighbourhood. This area is placed in a strategical location in the south-east of the city (Fig. 2) close to the city centre, the railway station of Porta Nuova and the Valentino park (Fig. 3). The neighbourhood has a population of about 36 thousand and an extension of about 2.2 sq.km. Although the local population has started to decline since 1995, the number of people who live in that area remains rather stable, thanks to the increasing number of young people, mainly students, and foreigners. However, most of the population is old (Fig. 4), as well as in many other parts of the city.

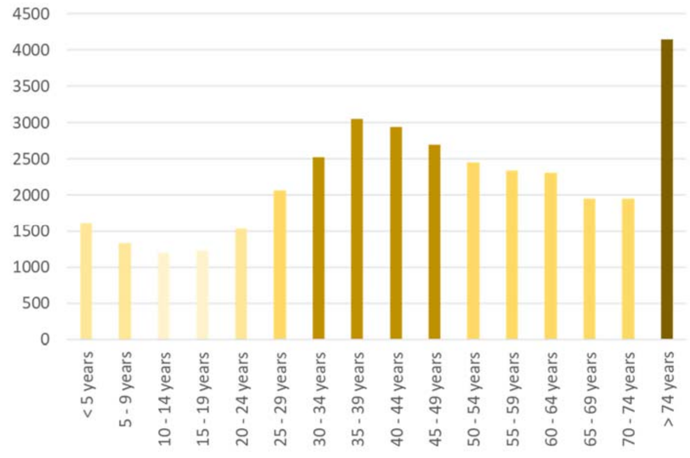

Fig. 4 Population graph of San Salvario (ISTAT data 2011)

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Of interest in our research was the analysis of the building stock of the neighbourhood to think about the retrofitting: as you can see in Fig. 5 the age of the buildings is quite diverse. The nineteenth-century buildings' quality has a considerable architectural value although the absence of ordinary and extraordinary maintenance has caused a significant degradation. Corso Vittorio Emanuele has many buildings with architectural value, while Via Nizza and Via Madama Cristina are characterized by public housing, craft activities, shops and clubs. Via Nizza is characterized by buildings with the C-shape, typical of the nineteenth century. Most of the buildings in Corso Marconi are characterized by the architectural typology known as "umbertina", dating back to the eighties of the nineteenth century. The most recent constructions are along the Valentino park and the area near Piazzetta Primo Levi.

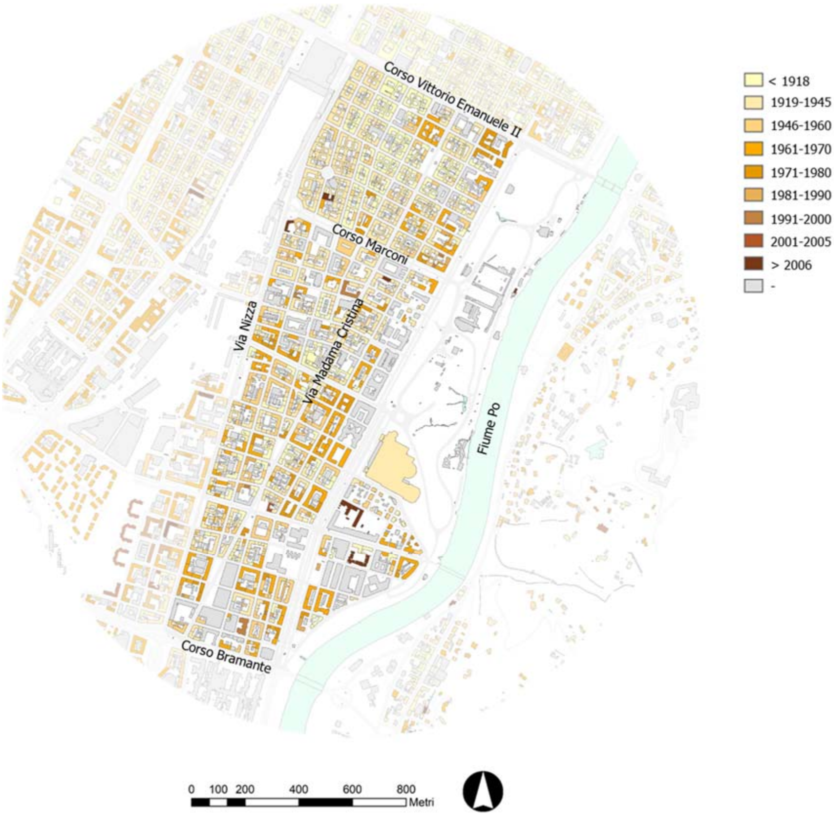

Fig. 5 Age construction of buildings (Geoportale of Turin GIS data 2017)

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3.2 STAKEHOLDERS ANALYSIS

The study of the area and of its peculiarities has underlined some relevant aspects to be considered. In respect to the very different people who live in the area and the many actors interested in this district management project, we have realized a stakeholder analysis. In order to understand what happened or what can happen in a decisional process, the first question that we have to ask is about who has contributed or could contribute to its development and outcome by adopting relevant behaviours (Dente, 2014). The power-interest stakeholders' analysis is one of the most used methods to understand the role of the different actors interested or called to the evaluation process. In particular, it allows to know in advance how we manage each of them: if the stakeholder has a low interest and power must be only monitored during the process; instead, if the interest increased they must be informed; on the contrary, if the interest is low but the power is high they must keep satisfied; finally, if both power and interest are high they must be managed closely. The Fig. 6 shows the stakeholders involved in the transformation process of San Salvario and highlighted their specific role.

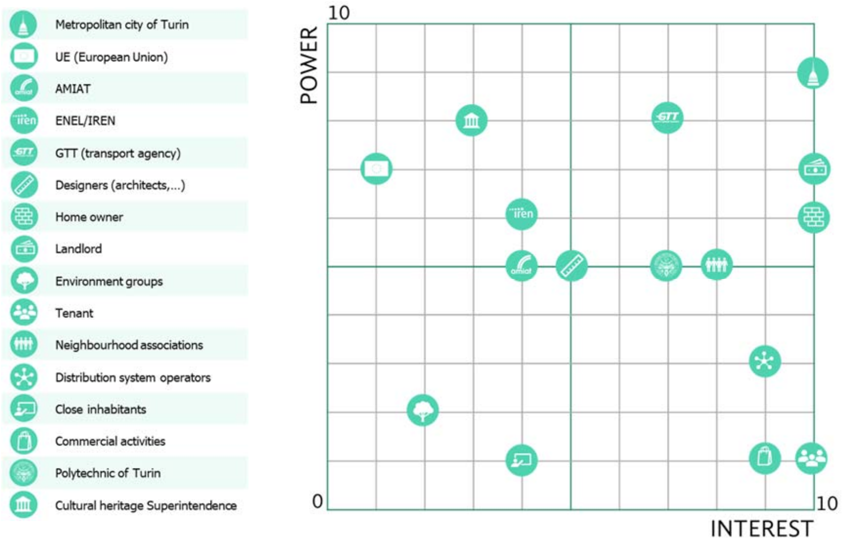

Fig. 6 Power-interest stakeholders analysis for the San Salvario district

4 PROPOSED EVALUATION PROCESS

According to the analysis of the literature developed in section 2, in order to face the difficulties for the application of ABM approach to complex environments, the problem of San Salvario district has been divided into different levels that were considered separately. Every single one represents the all aspects characterizing the eco-district model applied to San Salvario: (1) the retrofit of the building stock and the changing in the energy demand, (2) the improvement of mobility and (3) of recyclable waste collection, considering the social integration of the actual urban structures.

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4.1 OVERVIEW OF THE ABM FRAMEWORK

As described in the methodological background, the three main elements that characterized an agent-based model are the actors, the environment and the interactions. Following the scheme proposed by Hinker et al. (2017) for the application of the ABM approach, it is fundamental to define other aspects (described below) that represent the common framework for the creation of our model.

(1) Objective: represents the specific objective of each level of our ABM model, that, joined with the others, generates the overall aim of the research.

(2) Actor class: a general group of actors with similar intentions.

(3) Layer: represents the actor's field of action. In the first phase, the layers depend on the actor, ultimately, they are harmonised and unified.

(4) (Primary) intentions: in the real world each person has different and specific intentions, but, to reduce the complexity of the model, we have considered the most urgent ones, defined them as the primary intentions of the actor.

(5) Compulsions: with this term, we refer to the all external forces that can ban some actions of other actors. An example of a compulsion could be the presence of a law that inhibited an action.

4.2 EXAMPLES OF INTERACTING SYSTEMS

Starting from the keywords previously described and taking into account all the pillars of sustainability, we have built the structure of our ABM model. For each one of the considered levels for the transformation of the San Salvario district, specific objectives and related actors, layers, primary intentions and compulsions were defined to have a broader picture of the problem for the application of the ABM approach.

<u>Retrofit Of The Building Stock And The Changing In The Energy Demand</u>

A first relevant interaction among agents comes from the realisation of the first objective, i.e. the retrofit of the building stock and the changing in the energy demand. From one side, it creates effects on owner, landlords and tenants caused by the cost of intervention, the profit and the lowering of energy costs. From the other side, the project could generate gentrification phenomena and a change of the inhabitants' social target, that must be considered by the local authorities to avoid possible reactions by the neighbourhood's associations.

(1) CHANGING IN ENERGY DEMAND (economic aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Homeowner	Building stock and power grid	Ensuring climate comfort	Limited financial possibility: public administration must support with economic programs the refurbishment
Landlord		Increasing profit	Having a return on the investment
Tenant		Reducing energy expenses	Low economic status

(2) MAINTAIN/REDEVELOPMENT URBAN STRUCTURES (social aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Municipality	Entire district	To incentive building retrofitting, considering the social status of the inhabitants	Limited financial resources Gentrification phenomena

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(3) OPERATIONS ON THE ENERGY INFRASTRUCTURES (technical aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Distributor system operators (including ENEL/IREN)	Power grid and energetic systems	Diffusion of their specific energy strategy and knowledge	Achieving a post carbon district

(4) CHANGING IN THE QUALITY OF LIFE (environmental aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Inhabitants (neighbourhood associations and close inhabitants)	Entire city	Reduction of CO_2 emissions	The realization of the redevelopment project

<u>Improvement of district mobility</u>

The creation of a district characterized by the presence of different alternative means of transport, it is a great opportunity for the inhabitants and in particular for the neighbourhood residents. However, the success of this intervention depends on the intents and the possibilities of both the municipality and the Turin transport agency (GTT).

(1) CHANGING IN THE MOBILITY DEMAND (economic aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Neighbourhood residents (Homeowners and tenants)	Entire city	Reduction mobility expenses	A limited number of public means of transport

(2) INCREASE OF ALTERNATIVE MOBILITY (social aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Municipality	Entire city	Radical change in trade of actual mobility use in favour of the diffusion of alternative means of transport	Limited financial resources

(3) DIFFUSION OF ALTERNATIVE MEANS OF TRANSPORT (technical aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
GTT (transport agency)	Entire city	Increasing the number of people that use its service	Limited financial resources

(4) CHANGING IN THE QUALITY OF LIFE (environmental aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Inhabitants	Entire city	Reduction of CO_2 emissions	The realization of the redevelopment project

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Recyclable waste collection

One of the pillars of the Turin municipality's last policies is the diffusion at a larger scale of the recyclable waste collection. An improvement of the actual way could be texted in this area and, then, spread to the overall city. In that context, the municipality and the waste agency have the responsibility to inform the inhabitants and to acquire the knowledge necessary for the success of the entire project.

(1) CHANGING IN THE RECYCLING WASTE COLLECTION (economic aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Neighbourhood residents	Entire city	Reduction in waste expenses	The comprehension of the roles of recycling waste collection

(2) REDUCTION OF THE QUANTITY OF WASTE (social and environmental aspects)

ACTORS OR CLASS	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
Municipality/Inhabitants	Entire city	Reduction of the quantity of waste, increasing the recyclable one	Limited public financial resources

(3) IMPROVEMENT OF THE RECYCLABLE WASTE COLLECTION (technical aspects)

	LAYERS	PRIMARY INTENTIONS	COMPULSIONS
AMIAT (waste agency)	Entire district	Efficiency in the collection of recyclable waste	Limited financial resources and knowledge of the Turin waste agency

5 DISCUSSION OF THE PRELIMINARY RESULTS AND FUTURE STEPS

In this paper, a methodological framework was conducted to better apply the integration between the ABM and GIS to the specific case study of San Salvario. To facilitate the structure of our model, we have used the so-called ODD (Overview, Design concepts, and Details) protocol, developed by Grimm in 2006 and implemented in 2010. Based on the ODD, we started to draft the so-called "overview", that represents the first macro-step of the protocol. However, the complexity of our case study and the multi-dimensions to be considered has caused the necessity to form a more extensive conceptual model.

For the future steps of the analysis, we will develop the other phases of the ODD, i.e. design concepts and the detailed analysis. In fact, once the model has been conceptualised, it must be formalised into a specification which can be developed into a computer programme. In this sense, a more in-depth analysis is also necessary to decide into the variety of existing software the most appropriate one for the development of our model. In addition, we would like to join to the ABM toolkit the functionality offered by the GIS software libraries to add greater data management and spatial analytical capabilities for the geospatial modelling.

To this end, it is possible to affirm that the proposed approach seems to be particularly useful for structuring the complexity of the decision problem under investigation, as it offers a bottom-up interactive solution to the more traditional aggregated modelling approaches (Chen, 2012).

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AUTHOR'S PROFILE

Caterina Caprioli, research fellow at Interuniversity Department of Regional and Urban Studies and Planning of Politecnico di Torino, Italy. Scientific interests on Regional and Urban Economics, Planning Evaluation, Scenario building and Mathematical Models in Urban Sciences.

Marta Carla Bottero is an associate Professor at Interuniversity Department of Regional and Urban Studies and Planning of Politecnico di Torino, Italy. Scientific interests on Sustainability Assessment, Planning Evaluation, Project Appraisal, Regional and Urban Economics.

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