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Department  
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Ca' Foscari University of  
Venice

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A Spatial Agent-Based Model to  
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## A Spatial Agent-Based Model to Explore Scenarios of Adaptation to Climate Change in an Alpine Tourism Destination

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First Draft: 1/3/2010

### Abstract

A vast body of literature suggests that the European Alpine region may be one of the most sensitive to climate change impacts. Adaptation to climate change of Alpine socio-ecosystems is increasingly becoming an issue of interest for the scientific community while the people of the Alps are often unaware of or simply ignore the problem. ClimAlpTour is a European research project of the Alpine Space Programme, bringing together institutions and scholars from all countries of the Alpine arch, in view of dealing with the expected decrease in snow and ice cover, which may lead to a rethinking of tourism development beyond the traditional vision of winter sports. The research reported herein analyses the municipality of Auronzo di Cadore (22,000 ha) in the Dolomites under the famous peaks of the "Tre Cime di Lavaredo". The local economy depends on tourism which is currently focused on the summer season, while the winter season is weak. As a whole, the destination receives approximately 65,000 guests per year with a resident population of 3,600 inhabitants. Since recently the Community Council is considering options on how to stimulate a further development of the winter tourism. This paper refers to a prototype agent-based model, called AuronzoWinSim, for the assessment of alternative scenarios of future local development strategies, taking into account complex spatial and social dynamics and interactions. Different typologies of winter tourists compose the set of human agents. Climate change scenarios are used to produce temperature and snow cover projections. The model is mainly informed by secondary sources, including demographic and economic time series, and biophysical data which feed-in its spatial dimension. Primary data from field surveys are used to calibrate the main parameters. AuronzoWinSim is planned for use in a participatory context with groups of local stakeholders.

### Keywords

Alpine Winter Tourism, Spatial Agent-Based Model, Climate Change Adaptation

### JEL Codes

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*This Working Paper is published under the auspices of the Department of Economics of the Ca' Foscari University of Venice. Opinions expressed herein are those of the authors and not those of the Department. The Working Paper series is designed to divulge preliminary or incomplete work, circulated to favour discussion and comments. Citation of this paper should consider its provisional character.*

## 1. INTRODUCTION

The Alpine region in Europe is among the areas that are most rapidly affected by climate change. In general, the mean temperature of this region has increased up to +2°C for some high altitude sites over the 1900-1990 period against +0.78°C in the last 100 years at a global level (IPCC 2007, ESFR ClimChAlp 2008). With a certain degree of local variability, glaciers have lost 50% of their volume since 1850 and snow cover is decreasing especially at the lowest altitudes and in fall and spring. A clear signal of climate change about precipitations is not detectable yet, but increasing risks of extreme events have been projected including floods, debris flows, avalanches, glacial hazards, and mountain mass movements (Castellari 2008). The main expected impacts on the Alps concern the hydrological conditions and water management, forests and biodiversity, agriculture, energy management, and eventually tourism, which is the focus of this paper. While summer tourism is most probably going to be favored by climate change (Bourdeau 2009), the World Tourism Organization started warning about the possible negative implications for winter tourism and sports since 2003 (UNWTO 2003). Nowadays already 57 of the main 666 ski resorts of the European Alps are considered to not be snow-reliable<sup>1</sup> (OECD 2007). However, climate change is also an opportunity for those resorts that are snow-reliable, as they will face less competition in the future (Simpson et al. 2008, p. 62).

The Alpine people are often unaware of or simply ignore the problem, which is a common problem of climate change

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<sup>1</sup> In general, a ski resort is considered to be snow-reliable if, in 7 out of 10 winters, a sufficient snow covering of at least 30 to 50 cm is available for ski sport on at least 100 days between December 1 and April 15 (Burki et al. 2007).

adaptation. Perhaps, at a very local level, climate patterns are not evident enough to question the development model based on the “white dream” which has prevailed since the seventies. Indeed, a model of development based on snow, no matter if natural or artificial, is still somehow surviving notwithstanding the maturity of the traditional ski product and the stagnation of the market demand (Macchiavelli 2009). At this point very careful assessments should be carried on before any further snow-based development plan (WWF 2007).

ClimAlpTour is a European project of the Alpine Space Programme, bringing together institutions and scholars from all countries of the Alpine arch, in view of dealing with the expected decrease in snow and ice cover, which may lead to a rethinking of tourism development beyond the traditional vision of winter sports<sup>2</sup>. The project analyses 22 pilot areas with diverse environmental, social and economic conditions in order to provide a global perspective on the Alpine tourism. Raising the awareness of the stakeholders including tourists, population and businesses on the impact of climate change on tourist economy of the Alps and on possible adaptation strategies is one of the goals of the whole project.

This paper explores the conceptualization phase of an agent-based model (ABM) capable of gathering the available heterogeneous information and assess different scenarios of future local development, and eventually tourist supply, taking into account complex spatial and social dynamics and interactions. This methodology has already proven to be successful for other tourism related issues (i.e. Perez et al. 2009). However, to our knowledge, this is one of the first attempts to explore the

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<sup>2</sup> The project website is [www.climalptour.eu](http://www.climalptour.eu)

interactions between climate change and winter mountain tourism by means of an agent-oriented approach<sup>3</sup>. Our work is still in progress and is meant to complement a decision support system (DSS)<sup>4</sup>, which will be implemented during a series of participatory workshops.

## **2. CASE STUDY**

The research reported herein analyses the municipality of Auronzo di Cadore located in the province of Belluno, in the Veneto region, in the north-east of Italy. It covers a vast area (22.000 ha) which includes Misurina with its lake and the most famous mountain of the Dolomites, namely the “Tre Cime di Lavaredo”, part of the UNESCO world heritage since 2009.

The village of Auronzo (866m on the sea level) hosts almost the entire population of the municipality of approximately 3,600 inhabitants. It is located in the middle of the valley of the Ansiei river, which forms the artificial Santa Caterina Lake, due to the presence of an old dam. The lake basin is 3 km long and is endowed with beach facilities that periodically host motor nautical and canoe competitions. Misurina is a small settlement at 25 km from the main village, placed at an altitude of 1754 meters, just under the Tre Cime di Lavaredo peak, which is accessible both by means of several mountain paths and by a toll regulated carriageway.

The local economy depends on tourism which is currently focused on the summer season, while the winter season is weak, with only 25% of arrivals (Regione Veneto 2009). Indeed, hiking (200 km

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<sup>3</sup> See also Sax et al. 2007.

<sup>4</sup> See Giupponi and Sgobbi 2008.

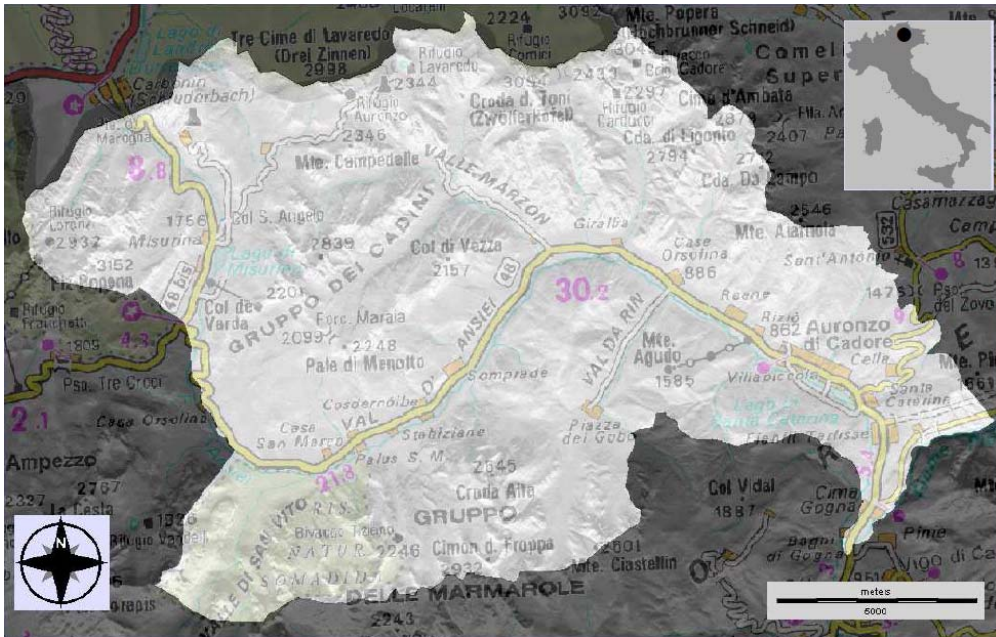
of signed mountain paths and 10 alpine refuges) and relax are the main elements of attraction. The total hosting capacity is of approximately 7.300 beds of which around 1700 in the hotel sector and the remainder in the extra-hotel sector (B&Bs, lodgings, etc.). The 75% of the hotels' beds concern structures with 1 or 2 stars. In 2008 63.700 arrivals and 305.400 tourist nights were registered, showing a slight decrease from the previous year. The last 10 years have witnessed the increase of arrivals and the contraction of average stay.

Notwithstanding the presence of two small downhill ski areas and two cross-country ski centers some hotels don't even open for the winter season. The four ski-lifts of Mount Agudo, which reach a maximum elevation of 1600m, supply seven ski-trails covering 15 km. In the locality of Palus San Marco, just at halfway between Auronzo and Misurina, there is the Somadida Forest, one of the largest of the province, which becomes a cross-country ski centre (with nine loops of 52.5 km in total) during the winter season. The Marmarole sled-dog centre and an ice-kart circuit are also placed Palus. In addition, Misurina, which has an hosting capacity of approximately 500 beds is endowed with the two ski-lifts of Col de Varda (from 1756m to 2220m) that supply five ski-tracks, and 17km of cross-country ski loops.

Since recently the Community Council is considering options on how to stimulate a further development of the winter tourism. There exist several projects of ski-areas development. The most ambitious is located in Marzon valley, a few km from the main village, which would connect the valley to the ski-area of Misurina (with an average altitude over 2000m). The main problem at stake is how to develop winter tourism in the next 40 years, in a context of climate change and market demand that is

not favorable. In particular, the spatial heterogeneity given by the bipolarity of the case study, suggested the elaboration of a spatially explicit ABM.

**Figure 1. Map of the Municipality of Auronzo di Cadore**



### 3. MODEL DEVELOPMENT

The development of a conceptual model has been carried out to support the design of the ABM by integrating three methods gravitating around different research groups of the heterogeneous ABM scientific community. The ARDI (Actor, Resources, Dynamics, and Interactions) method belongs to the companion modeling tradition, mainly applied to natural resource management. It can be extremely efficient for jumpstarting the process of visual formalization of the domain model (Etienne 2006). The ODD (Overview, Design concepts, Details) protocol belongs to the individual-based modeling branch of ecology, but

is gaining further diffusion in social science. Differently from the other methods, it consists of a narrative description of the various elements of an ABM, contributing to a more rigorous formulation phase (Grimm et al. 2006). Finally, the UML (Unified Modeling Language) belongs to the computer science tradition and is probably the most effective methods, preceding the coding phase, which can guarantee the full replicability of the model (Boch et al. 1999).

These methods have been firstly applied in the order in which are presented, subsequently leading to a more iterative approach. By means of ARDI we identified the tourist facilities as the main resources of the system, the winter tourists as the acting agents and the meta-economic agents as the economic units in charge of accounting the economic flows for each tourism sub-sector. The application of ODD led to the definition of the tourists' heterogenic behavior and of the future scenarios. Finally, through UML, we were able to formalize in diagrams all the details. The clear advantage is that the modeler is endowed with a set of tools mutually checking the model internal consistency with regards to both its static and the dynamic aspects.

### **3.1 Representing Heterogeneous Market Behavior**

Even though winter sports, and especially downhill skiing, are still the essence of winter mountain tourism the market has reached its maturity and is challenged by (a) loss of shares in the tourist market in the Alpine countries throughout Europe, (b) competition from other tourist destinations, (c) the growing economic and territorial divide between large and small resorts, (d) the need for huge new investments against the background of a



reduction of public funding, (e) new recreational practices (freestyle and freeride), (f) the ageing of the tourist population, (g) demand for environmental quality, (h) the changed notion of resort<sup>5</sup>, (i) the inclination toward shortened and repeated holidays, (j) behavioral unpredictability, due to wheatear forecasts, and finally (k) the search for new markets (Minghetti, 2002, Daidola, 2006, Bourdeau 2009, Macchiavelli 2009). However, according to Camanni [2002] and Daidola<sup>6</sup> [2007], a new light ski industry, with less investments and more flexibility with regard to climate conditions, is possible and the small resorts may thus be advantaged.

ABMs can be of great value in dealing with such dynamics because they are particularly well suited to incorporate heterogeneity of behavior. Our approach focuses on the simulation of tourists' response (demand-side) to alternative strategies of development of tourism facilities of the destination (supply-side) in order to provide the local stakeholders (residents, entrepreneurs, local tourism organizations, community council), with quantitative indicators of possible futures which depend on their collective decisions.

Drawing on the above cited literature and especially on secondary data from marketing surveys of the tourism statistical observatories of Trentino and Alto Adige<sup>7</sup> (Provincia Autonoma di Trento 2007, Provincia Autonoma di Bolzano 2009), we created a

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<sup>5</sup> "The idea of the resort as a unity of place, time and action, can be circumvented or deviated by a new interpretation of the mountain playground. One example is the striking contrast that can be observed by the expansion and interconnection of large ski areas, and the micro-scale of space in which the new sports are practiced by young snow surfers such as the snowparks" (Bourdeau 2009).

<sup>6</sup> Daidola's hypothesis is that artificial snow is less satisfying and more dangerous than natural snow. Because of artificial snow, the current ski style has become repetitive, expensive and boring, and at the same time too easy to learn and too fast. On the contrary ski and snowboard magazines mainly propose powdery snow and exciting experiences. Moreover artificial snow is responsible for the vicious circle of huge investments of the last years.

<sup>7</sup> These are the two most important winter tourism regions of the Italian Alps.

set of eight tourist profiles which is rich enough to take into account (1) the actual winter tourists of Auronzo, (2) the actual winter tourist visiting Auronzo's main competitors, and (3) the potential winter tourist of tomorrow (table 1).

**Table 1. Narratives describing the tourist profiles**

<p><b><u>Traditional Ski Intensive (TSI)</u></b>. Mainly motivated by the practice of downhill skiing (3/4) and snowboarding (1/4). Primarily interested about the ski-lifts and trails. Appreciates gastronomy. Not satisfied by the scarce presence of bars and pubs. Has a middle-low profile of expense (110 Euros/day). Has one or more winter holidays every year, often in the same destination. The booking process is often intermediated and the time unit of reference is 7 days. Books his holidays in February and March. Travels in company with one or more friends or with the family.</p> <p><b><u>Ski Part-Time (SPT)</u></b>. Mainly motivated by the natural environment and by the practice of downhill skiing (2/3) and snowboarding (1/3), with a softer approach. The trend towards snowboard is more evident. Interested about ski-lifts and trails, but also about other winter sports. Dedicates to traditional ski activities not more than half of the day. Often novices, mainly with family. Not interested in gastronomy. Not satisfied by the scarce presence of children facilities. Has a low profile of expense (100 Euros/day). Visits the same destination, often for the Christmas holidays. The time unit of reference is 7 days. Tend to book directly to the hospitality structure. Booking is less predictable and more subjected to weather conditions and forecasts.</p> <p><b><u>Sporty Alternative</u></b>. Mainly motivated by the natural environment and the practice of alternative winter sports. Often in group and on a day trip. Often adult or elder. Highly dependent on weather conditions and forecasts. Has the lower profile of expense (under 100 Euros/day). This typology is composed of two profiles: the practitioners of cross-country skiing (<b><u>SAX</u></b>) and the practitioners of backcountry skiing and ski touring (<b><u>SAW</u></b>).</p> <p><b><u>Idle (ID)</u></b>. Mainly motivated by the natural environment. Scarcely interested by any intensive sport activities. Appreciates easy trekking in the snow, children facilities and wellness and spa services. Not satisfied by the scarce presence bars and pubs and other sport facilities. Often females, accompanying skiers. Often with family. Tends to book for the Christmas holidays. Has a middle-high profile of expense (130 Euros/day).</p> <p><b><u>Eclectic (EC)</u></b>. Mainly motivated by the idea of having fun by means of a set diversified activities not related to traditional skiing. Interested in gastronomy, wellness and spa and shopping. Appreciates minor winter activities (i.e. ice skating, hockey, sled-dog...). The natural environment remains important. Has the highest profile of expense (over 150 Euros/day) but the shorter average stay. Not satisfied by the scarce presence of bars and pubs and other sports facilities.</p> <p><b><u>Counter culture</u></b>. Mainly motivated by the desire of having deep and authentic experiences, merging wilderness and playground, nature and adrenaline. Mainly sporty and expert in their discipline. Composed of two profiles: practitioners of freestyle (<b><u>CCP</u></b>) and of freeride (<b><u>CCW</u></b>). Often travelling with friends practicing the same activity. Interested in natural snow, very dependent on wheatear conditions and forecasts. CCP is interested in dedicated facilities as snowparks. CCW appreciates the organization of the natural environment into off-piste trails and the presence of small ski-lifts and security services. Both are sensitive to environmental issues Have a medium-high profile of expense according to the services that are offered.</p>
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### **3.2 Representing Alternative Futures**

Every simulation run requires the users to make three choices: (1) the development strategy to be tested; (2) the societal scenario that sets the conditional context in terms of number of tourists that could be available to choose the destination; and (3) the climate projection, in terms of snow cover and temperature. The combination of these choices defines the future conditions, from 2011 to 2050, under which the tourists' response is simulated. The underlying idea that has inspired the model is to identify the most robust development strategy. In this regard, we have defined four spatially explicit alternative strategies which are able to take into account various orientation towards tourism and the perception of climate change from the local stakeholders' point of view.

The first strategy is the pursue of the traditional ski intensive paradigm. Indeed, one of the most familiar measures in the struggle against snow-deficient winters is the construction of high cost artificial snowmaking facilities (Burki et al. 2007). However, in this strategy Auronzo not only maintains the ski areas of Mount Agudo and Misurina, but also develops two new ski areas with snowpark, on the basis of two projects about Marzon and Da Rin valleys, which have different spatial conditions. The overall hosting capacity remains untouched while a minor increase concerning restaurants and retailers supply is included. The second strategy embraces the vision of Daidola [2006] and Burdeau [2009] of an alternative light ski oriented and post-modern development. It integrates the wilderness and the playground concepts increasing the supply of controlled off-piste tracks (Marzon and Da Rin valleys), cross-country itineraries

(Palus) and snow parks (Mount Agudo). These are assisted by a very limited development of the existing ski lifts and a more sober artificial snowmaking behavior. The third is the non-snow strategy that is the well established, but often not self-sustaining, process of diversification and enlargement of tourist offer by means of higher quality hotels, shopping, gastronomy, pubs and bars, and, most of all, wellness and spa centers. This is mainly implemented in Auronzo, Misurina and Palus villages. The ski areas remain in function without the support of artificial snow. Finally the fatalistic strategy consists of no changes in the supply behavior, which could also be described as “business as usual”.

We are planning to consider 2 societal scenarios, one more conservative and one more optimistic, which will be derived interpolating historic European population dynamics and the alpine tourism fluxes. The climate projections will be developed in order to represent 3 IPCC scenarios of aerosol and GHG forcings (A2, A1B and B1), drawing on the Ensembles European project<sup>8</sup>.

#### **4. MODEL DESCRIPTION**

This concise model description loosely follows the ODD protocol (Grimm et al. 2006). We also provide the UML class, sequence and activities diagrams (the first two as appendices and the rest in the project website: <http://www.dse.unive.it/clim/climalptour.htm>).

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<sup>8</sup> See <http://ensembles-eu.metoffice.com/>

## 4.1 Model Overview

The model *purpose* is to analyze alternative winter development strategies for the case study simulating the tourists' response under different climate scenarios.

*Entities* and *state variables* are visually presented in the UML class diagram (Appendix A). The main entities are the tourists, the tourism facilities and the meta-economic agents. The tourists are divided in eight profiles: traditional ski-intensive (TSI), ski part-time (SPT), sporty alternative cross-country (SAX), sporty alternative wilderness (SAW), idle (ID), eclectic (EC), counter-culture wilderness (CCW) and counter-culture playground (CCP). According to the profile they belong to (variable "type"), agents have different preferences and behavior with regards to the tourism facilities. The tourism facilities, which in turn compose the destination supply structure, are divided in eight types: four are snow related (facilities dedicated to downhill skiing, snowparks, cross-country skiing and off-piste skiing) and four are non-snow related (accommodations, restaurants, retailers, and other facilities including those for kids, wellness and spa, and other sports). The meta-economic agents are the accountants of the tourism facilities. One meta-economic agent is in charge of managing one type of tourism facility. They keep track of the investment required to put in place their facilities, defined by the development strategy to be analyzed, and of their money flow. The development strategies, which represent possible orientations of the local stakeholders, are set exogenously by the model.

Concerning the *scales*, both the snow and the non-snow related facilities are located in a spatial grid of approximately 10.000 cells which represent the destination. Each cell represents a 150 x

150 meters square and contains the actual geographical information of the area. Nine spatially distributed reference points have been identified in order to represent the different snow conditions under alternative climate scenarios. A simulation is composed of 40 cycles, which are the winter seasons from 2011 to 2050. Each cycle consists of 126 days (time steps) that represent the 18 weeks from the 1<sup>st</sup> of December to the 6<sup>th</sup> of April. Summing up, every simulation takes into account 720 weeks and 5040 time steps.

*Process overview and scheduling* are captured in the UML sequence diagram (Appendix B), which shows the sequence of operations performed by each class. Every operation is then further described as activity diagram. Initially, the spatial units (patches) update their attributes and configure the tourism facilities presence as per selected development strategy. Each of the meta-economic agent is assigned with the investment needed to meet that configuration. The reference points read snow cover and temperature from the climate data which describe the selected climate projection. They also perform three kinds of forecasts concerning snow cover, at short and medium term, and snow security, at short term. Then, the snow facilities check those forecasts and store the information that they will subsequently pass to the tourists. Downhill and snowparks can decide to produce artificial snow. After that, the tourists, whose total amount is taken by the societal scenario, can check the destination in order to become visitors, if their requirements are met. According to their behavior, they can check the forecasts and go to the planning phase, in which they decide their day of arrival. If they are in the destination they enter into a loop of

operations which describe the use of the tourism facilities. Then, every facility can check its own users and pass the information to the patches that can visually describe the tourists density on the grid. The meta-economic agent calculates the return associated to the facilities use and update their balance sheet. Finally, the tourists in their last day of vacation calculate their overall satisfaction. If this is negative they exit from the simulation, if it is positive they remain among the potential visitors and can plan a further vacation. Those that eliminated are substituted by other tourist agents, but they are also accounted for in the statistics about dissatisfaction.

*Input* data is provided in various forms. The spatial units are georeferentiated, based on GIS (geographical information system) layers concerning elevation, slope and radiation. The reference points are provided with climate data in form of time series of snow cover and temperature, according to the selected climate projection. Finally, the societal data provides the total number of tourist agents available for each of the 40 cycles during every simulation.

Most of the operations make use of *submodels* in form of simple algorithms and logical tests which are presented in detail in the activity diagrams. Most of the parameters used in the activity diagrams are calibrated on the case study, by means of field surveys. The rest are retrieved from the literature.

The model *initialization* represents the destination winter tourism conditions in 2011 concerning the actual amount, type and spatial configuration of the tourism facilities.

## 4.2 ABM Design Concepts

- *Emergence.* Once the boundary conditions of possible futures are set by the 3 choices on the scenarios for any model run, then the performance of the destination is a phenomenon that emerges from the tourists' behavior. This is numerically expressed in terms of tourist attracted and money flow produced by each facility type (see `updateUsers` and `updateBalance` activity diagrams) and visualized on the spatial grid at each time step in terms of tourists' density (see `checkOccupation` activity diagram).
- *Objectives.* The tourists can choose whether to go or not to the destination, according to their preferences about the destination supply and to the weather forecasts (see `checkDestination` and `doForecast` activity diagrams).
- *Prediction.* Tourists' expectations are based on the facilities available and their spatial configuration in the destination and on the snow cover and security forecasts.
- *Sensing.* The tourists are fully aware of the destination's facilities and spatial attributes before the vacation, but they perceive the environmental conditions of the facilities they use only *in loco*.
- *Learning.* Each day of their vacation the tourists calculate their satisfaction which depends on the effective environmental conditions encountered in terms of snow cover and tourists' density, so that their availability to a subsequent vacation depends on the memories of the previous one (see `calcSatisfaction` activity diagram).
- *Adaptation.* The tourists adapt by not visiting Auronzo again once their satisfaction goes negative, in favor of other



competing destinations (see updateSatisfaction activity diagram).

- *Interaction.* The tourists directly receive stimuli, through sensing, from the destination's facilities and spatial attributes, which affect their eligibility to book their vacation. They also indirectly interact among each other with negative effects on their respective satisfaction, over certain density thresholds.
- *Stochasticity* is used to reproduce variability in the various agents' decision processes, primarily by means of normal distributions (see the activity diagrams).
- *Observation.* The model collects data on the economic performance of the eight types of facilities and on the spatially distributed tourist fruition of the destination.

## 5. DISCUSSION AND CONCLUSION

Our work is still in progress but it can already provide some interesting insights on the modeling of climate change and tourism.

First of all, the scale of analysis and the level of detail represent a significant improvement in the climate change research, which is normally performed at a much higher level of spatial and temporal aggregation. This scale perfectly fits the crucial socioeconomic dynamics of local adaptation that have to be investigated.

Second, to our knowledge this is one of the first attempts to formalize the supply structure of a winter tourism destination in classes by means of UML. The result is simple and clear but is able to represent complex interactions, for alternative development strategies, in a spatially explicit way. This is

extremely valuable giving our objective of assessing robustness and flexibility rather than finding optimal solutions. This conceptualization can eventually become a generic ontology, if it will be proved to fit the application to other case studies.

Third, the simulation focuses on the feed-backs of the demand side of tourism, which is often missing in the existing tourism models. However, the tourists are the ultimate judges of a destination adaptation strategy, because they will decide the winners and losers of the future. This is why we regarded as fundamental to focus on their agency in an heterogeneous way, drawing from disciplines such as customer behavior, which could only be done by means of an the agent-based approach.

Fourth, the model development itself is a novelty because we integrated some of the main practices of the ABM community which are never found together but can mutually benefit each other.

The next steps of our work include the implementation of the UML model into a software for computer simulation. AuronzoWinSim will then be tested and refined, before being used in a participatory context with groups of local stakeholders, in two ways. Initially, it will support the collective discussion on possible adaptation and development strategies, and the criteria to assess their robustness. Secondly, it will incorporate the strategic adjustments proposed by the stakeholders.

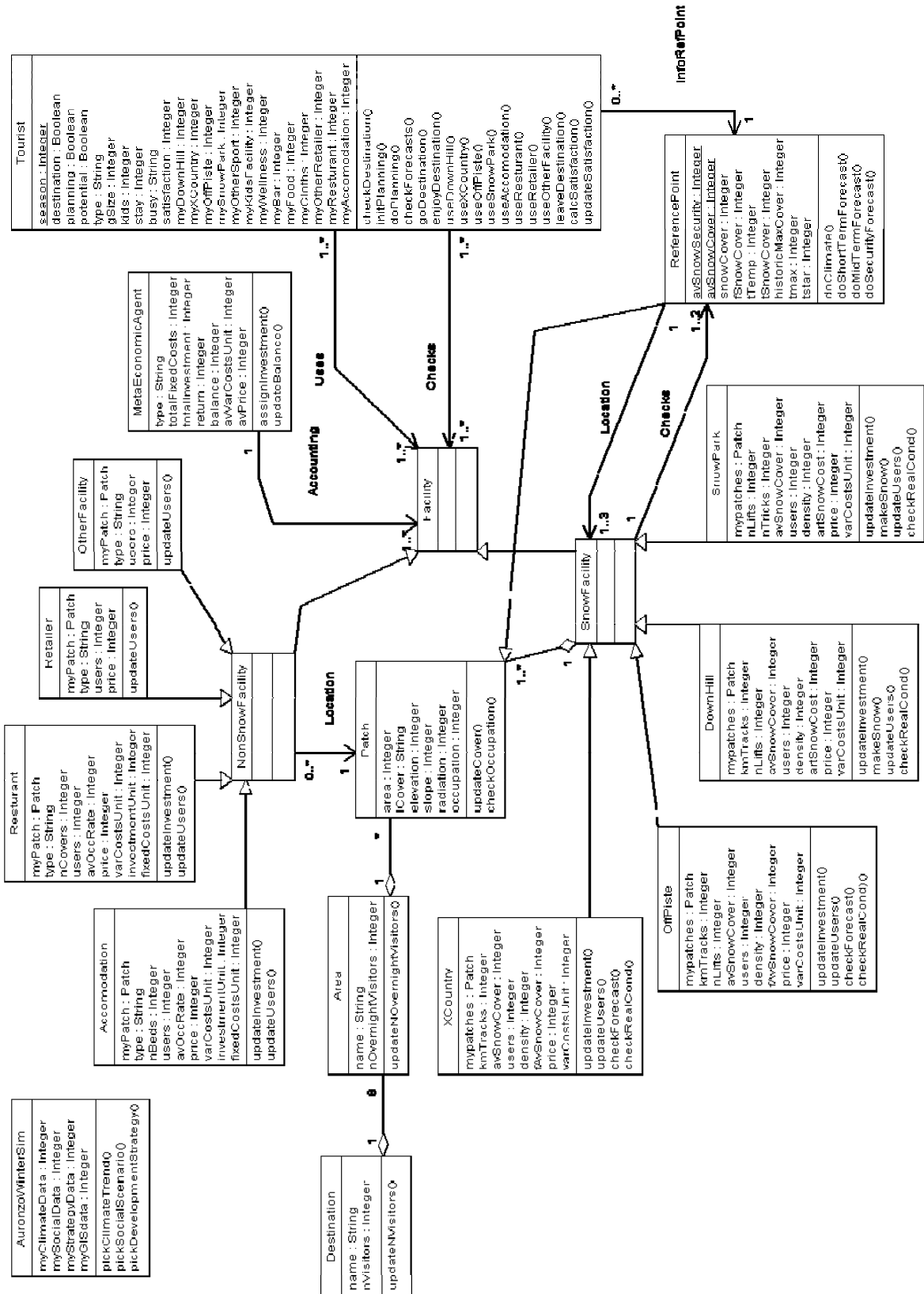
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# APPENDIX A. AuronzoWinSim CLASS DIAGRAM



## APPENDIX B. AuronzoWinSim SEQUENCE DIAGRAM

