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An iterative process to construct an interdisciplinary ABM using MR POTATOHEAD: an application to Housing Market Models in touristic areas

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Abstract

This work demonstrates an interdisciplinary modeling process between economists and computer scientists to formulate an Agent-Based Model of Land Use and Cover Change (ABM/LUCC). The MR POTATOHEAD (Model Representing Potential Objects That Appear in The Ontology of Human - Environmental Actions & Decisions) generic modeling methodology for ABM/LUCC process building is used to construct the interdisciplinary ABM. In our paper, this methodology is applied to an ABM/LUCC describing a collection of tourist areas that have faced an intense development leading to huge pressure on land prices as well as to land-use conflicts (local residential market, tourist rental investments, agricultural production). The process moves from the conceptual template description, to conceptual model, to its computer model counterpart. The NetLogo Design Pattern is used to efficiently integrate the spatial aspects of the ABM. The paper highlights benefits offered by this software technique of engineering to design modular, extensible and scalable ABM/LUCC computer models. We present preliminary work aiming to better model the dynamical complex system of ABM/LUCC. Preliminary results show that the MR POTATOHEAD modeling process facilitates both interdisciplinary dialogs and computer model formulation. This conceptual template approach facilitates interdisciplinary communication and interaction between economists and computer scientists.

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Keywords: Complex systems; ABM/LUCC; MR POTATOHEAD; Conceptual Modeling; NetLogo pattern.

1. Introduction

In the last few years, Agent-Based Models (ABM) have sought to address questions of economics in the field of Land Use and Cover Change (Parker, 2014). For land market models in particular, Agent-Based Models of Land Use and Cover Change (ABM/LUCC) provide modeling paradigms and formalisms that are more and more acknowledged for their effectiveness to produce modular and scalable computer models for virtual experimentation. They supply engineering concepts, methods and IT techniques that provide a new way to overcome the inherent difficulty of spatial land-use planning models that describe economic development and land competition. ABM/LUCC computer models facilitate the behavior of highly heterogeneous economic agents in very diverse areas and biotopes. While corresponding classic economic models are generally analytically intractable, the ABM/LUCC make it possible to simulate heterogeneous behaviors integrating many interacting components. Conceptual formalisms based on Agent-Based Models (ABM) are a prerequisite to effectively carry out the interdisciplinary labor that is needed to development computer code. However, the path from the verbal and mathematical model descriptions traditionally employed by economists to the detailed specifications required to create a computer model is not transparent. The methods and formalisms coming from Modeling & Simulation computer science (M&S) can dictate a formal modeling process that can assist in this process.

In this paper, we present a method to build an ABM/LUCC of land and housing market using Design Patterns. We highlight benefits offered by this software engineering technique to design reusable, extensible and scalable code for economic models. Design patterns couple recurrent problems and their solutions to overcome the difficulties raised when designing software components. They are usually employed by modelers experienced in Object Oriented Programming (O.O.P.). The use of Design Patterns in M&S is fairly new and seems to be promising – especially in ABM design (Cruz Torres et al., 2011; Alexander, 1977). Design patterns provide solutions for modelers to design and write computer models that are accessible to all researchers community members.

Hence, design patterns improve the modeling process in multidisciplinary contexts, such as our case study. We show how design patterns can be used in the modeling process: from the conceptualization and description of the real-world problem, to design of the computer model, to implementation of the programming model. Our contribution also aims to increase uptake of design patterns used at all stages of the modeling process by a larger audience of researchers in M&S. To this end, we use textual specification and graphics formalisms, the MR POTATOHEAD: Property Market Edition to develop a conceptual model representing the different points of view and behaviour of system actors, for our real world case study. The exercise provides an example of an interdisciplinary process modeling involving economists and computer scientists to formulate an ABM/LUCC computer model, which describes the organization of computer code. By means of the ABM/LUCC formalisms, we built our ABM/LUCC for a tourist area that faces an intense residential development leading to a huge pressure on land prices as well as to land-use conflicts.

The rest of the paper is organized as follows. In section 2, we present the use of design pattern in computer simulation and describe the MR POTATOHEAD conceptual design pattern specifically used for describing ABM/LUCC. A short review of ABM/LUCC literature regarding the main papers used to formulate the structure, the behavior algorithms as well as the simulation rules governing the ABM/LUCC agents follows. In section 3, we present how we apply the methodology based on MR POTATOHEAD Property Market Edition standardization (Parker et al., 2019) in the context of our case study and the construction of the computer modeling process (Parker et al., 2008a,b; Parker, 2014). We conclude and draw research perspectives in Section 4.

2. From the real world to the model

2.1. The modeling process

Computer simulation is a developing science that works to understand natural or artificial phenomena of our environment. For that purpose, simulation modelers have developed software tools based on conceptual computer models aiming at producing simulation data. Computer simulation has profited from recent progress in computer science in terms of concepts (paradigms, formalisms,

52 norms, standards, algorithms, etc.), technologies (programming languages, structures, objects, com-
53 ponents, etc.), and hardware (CPU, memory, GPGPU, networks, etc.). The modeling process has
54 also been the subject of much recent literature discussion (Chwif et al., 2013; Balci, 2011; Mitroff
55 et al., 1974). In the area of economic research, computer simulation science has the potential to
56 improve our understanding capacity to investigate real economic complex systems (Arthur, 2014;
57 Tesfatsion, 2017). These systems are composed of a large number of heterogeneous entities and
58 consequently, behavioral descriptions result from multiples entities' interactions. The process of
59 modeling such systems principally includes formulations of conceptual and computer models that
60 are carried out by modelers in charge of a simulation project.

61 The concept of model is first and foremost, the representation of the complex system under study in
62 the form of an abstraction (reality simplification). The abstraction should clearly articulate parts of
63 the complex system in a set of components. These components must be formulated using carefully
64 chosen criteria and according to a relevant point of view for the study. In the literature, numerous
65 authors have pointed out to that a model must remain sufficiently “simple” regarding component’s
66 formulations (Tsfatsion, 2017). Indeed, refined descriptions of components may considerably slow
67 down the modeling process, generate unnecessary complexity, and provides both wrong simulation
68 and questionable results. In computer simulation science, it is now understood that every rigorous
69 modeling process needs prior to describe a first abstraction of the complex system: the conceptual
70 model. The conceptual model is the first representation of the complex system. This first represen-
71 tation is developed according to a layered descriptive process. Historically, mathematics initiated
72 the abstraction process, giving the first abstractions methods for complex systems. In computer
73 simulation, the modeling process corresponds to the use of methods describing sets of sequential
74 transformation (generic if possible) working to move the initial math abstraction from its continuous
75 universe (problem’s universe) to the discrete universe of the computer science (model’s universe).
76 Thus, the conceptual model constitutes a prerequisite for writing computer models describing the
77 computer code organization that finally runs on the computers (Chwif et al., 2013).

78 Economics has had a long tradition of conceptual model description via formal closed-form math-
79 ematics, accompanied by sparse verbal descriptions. Such a conceptual model suffices for non-

complex systems – those for which analytical mathematics can be applied to describe the system and fully characterize its behavior. However, agent-based models of economic systems need to move beyond such mathematical conceptual representations, because they are simulated, potentially non-equilibrium systems. Thus a further challenge is created – how to create a conceptual design pattern that can move from a traditional economic model description to the full detail needed to implement a computer simulation.

2.2. A brief history of design patterns

The concept of a design pattern comes from Alexander (1977), whose authors worked in the 1970's on architectural design. They defined the notion of pattern, as follows: *"Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice."* This sentence has been the source of Design Pattern concept, i.e. formulation of a recurrent issue, and its solution in a precise context. Later, Design Patterns were introduced into computer science, thanks to O.O.P. with the Model-View-Controller (MVC) pattern¹ (Buck and Yacktmann, 2010). Towards the end of 1980's, the works of Reid Smith also contributed to the use of design patterns in computer science (Smith, 1987). Beck (1987) proposed adapting the pattern language to O.O.P, through five compositions for user interfaces design. In 1995, the use of design patterns accelerated thanks to the *"GoF"* (*"Gang of Four"*): Erich Gamma, Richard Helm, Ralph Johnson and John Vlissides (Gamma, 1995). In this book, the design patterns are described under an accurate terminology for developing reusable software components with O.O.P. languages. These patterns are well-known solutions to classic design problems of software components encountered in a given programming context. For that, when it's possible they must appear in the computer model. They must be used to enhance simulation code explanations and reproducibility.

As it is noted in modeling literature, the production of a computer model is therefore the result of

¹The MVC pattern is used in a software engineering to separate the components in charge of logic (model), data (GIS, database, etc.) and views (screen, print, etc.) into three distinct categories of software components.

105 prior formalization work (conceptual model). Such prior formalization makes it possible to avoid
 106 constraining the modelers' thinking within the constraints of the technical considerations of M&S. In
 107 addition, the computer model aims to produce modular, scalable and interoperable computer code
 108 (the programming model) (cf. Figure 1). In M&S, with the complexity of conceptual models, there
 109 is a need to develop methodologies to correctly and efficiently explain computer model components
 110 and their interconnections. These methodologies must ease production of object simulation code
 111 in a modular, extensible, and scalable form, and they also make best use of the modern computers
 112 multi-task and parallel hardware (Touraille et al., 2011). Hence, they must capitalize knowledge and
 113 know-how within the simulation researchers community, which use O.O.P. as a modeling framework
 114 (Rovere et al., 2016; Innocenti et al., 2009). While design patterns have the potential to solve these
 115 challenges, today, despite their many benefits, they are still rarely used in computer simulation. In
 116 this paper, through illustration of the role of design patterns in our model development, we hope
 117 to make design patterns more accessible to modelers in charge of computer simulations.

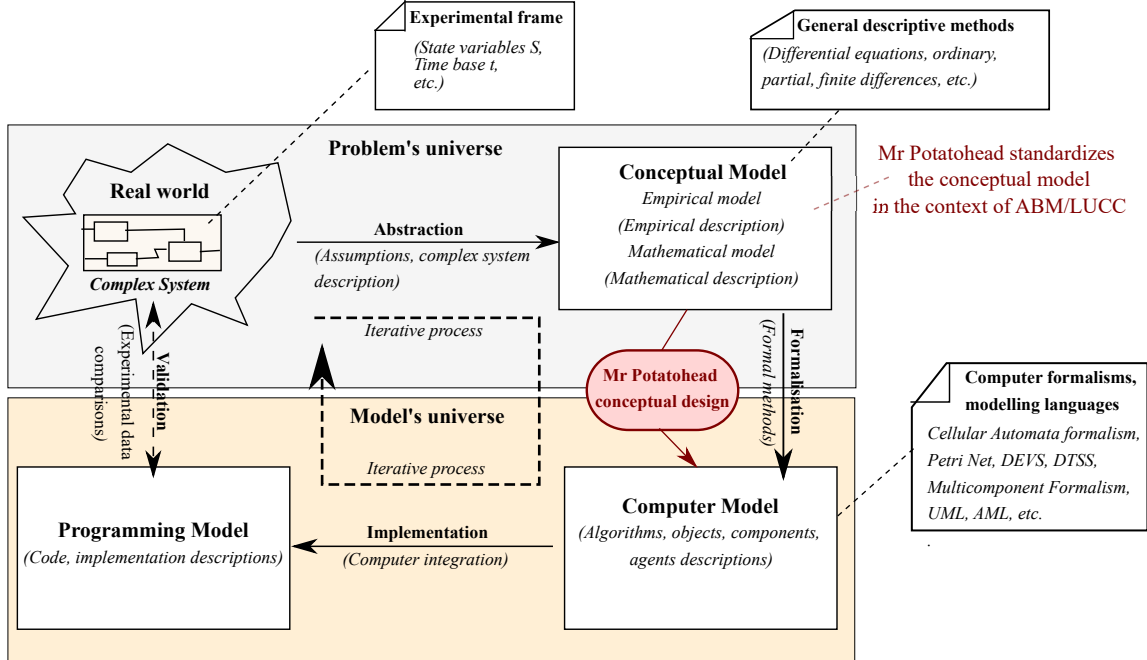


Figure 1: The Iterative Modeling process.

118 2.3. The MR POTATOHEAD conceptual design pattern

119 The path from real-world description to conceptual model to computer/programming code
120 presents an infinity of choices available for simplifying assumptions, corresponding to an infinity
121 of formal abstractions, and following from them, many very different computer models, obtained
122 via different process, but for a same complex system. This fact is well sum-up by Robinson (2015)
123 through the quote "*conceptual modeling is more an art than a science*", p.1826. Agent-based mod-
124 eling of land-use and land-cover change (ABM/LUCC) illustrate this phenomena. While their
125 development has grown exponentially over the last 20 years, modelers developing case-study mod-
126 els in different locations, from different disciplinary perspectives, and with different resources, have
127 developed a small universe of similar, but different ABM/LUCC. This trend is no less evident even
128 in the smaller sub-field of agent-based land market models (ABM/LMM), where even collaborators
129 sharing similar disciplinary backgrounds have developed divergent models of almost identical sys-
130 tems.

131 Concurrently, agent-based modeling of complex systems has acquired increasing rigor and formal
132 methods (Wilensky and Rand, 2015; Railsback and Grimm, 2019), and can be now considered as
133 a science in its own right, providing today a plethora of concepts, formalisms and methods aiming
134 at considerably streamlining the modeler's job. The conceptual design pattern and conceptual mod-
135 eling framework MR POTATOHEAD presented in this paper follow this trend, striving to bring
136 harmonized formalization and standardization to the cacophony of ABM/LUCC and ABM/LMM.
137 The need for systematize the information on ABM for bridging the gap between social scientists
138 and computer scientist has led to attempts to develop a common language, e.g., the Agent-Based
139 Model Canvas presented in Garibay et al. (2019). The need for harmonized formalization and stan-
140 dardization in specific fields like ABM/LUCC and ABM/LMM requires more specific tools. MR
141 POTATOHEAD was developed specifically to counter the problem described in general here: a
142 multiplicity of slightly different conceptual, formal, and programming models developed for exactly
143 the same real-world systems.

144 The MR POTATOHEAD conceptual design pattern (CDP) was developed by Parker et al. (2008a)
145 as a generic standardized template for describing agent-based models of land-use and land-cover
146 change. The CDP takes the form of a hierarchical ontology, which describes key components of
147 and ABM/LUCC and their potential sub-instances, taking an object-oriented design approach. The
148 CDP was designed to address challenges not addressed by standardized model description protocols
149 such as ODD (Grimm et al., 2010) and UML (Ambler, 2005). These forms were found to be too
150 generic, and to lack sufficient detail, to ensure full model transparency and replicability. Further,
151 they could not be used to show how different model implementations were instances of a more
152 general meta-model. Most significantly from the perspective of this paper, there is not a clear and
153 direct linkage between the structure of a protocol such as ODD and the structure of a software
154 design pattern (discuss below), which is one of the issues and challenges of ODD (Grimm et al.,
155 2020). MR POTATOHEAD has been demonstrated to overcome some of these deficits. The CDP
156 has been used to describe five different models (Parker et al., 2008a), to compare ABM/LUCC of
157 frontier regions (Parker et al., 2008b), and to develop an interdisciplinary survey of the behaviour
158 of residential land owners. Its formulation has proven to be an effective documentation protocol
159 for the ABM/LUCC modeling process, facilitating better model communication and comparisons.
160 Here, we demonstrate that it can also be used to facilitate development of a computer model and
161 its incrementation.

162 *2.4. The computer model*

163 The computer model describes in an appropriate modeling language the constituting element
164 assembly of the complex system and their interactions, in a hierarchical manner in the model's
165 universe. The computer model is often referred in literature as a composition, hierarchical or
166 multi-component model. The computer model expresses with a modeling language, components
167 and interactions coming from the descriptive elements of the conceptual model. Subsequently,
168 the programming model describes the implementation of the computer model in a programming
169 language, in accordance with the structural and behavioral entities defined in the computer model.
170 While programming model materializes in a programming language (usually an object oriented

171 programming language), the computer model of the complex system, initially considered in the
172 form of a conceptual model (cf. Figure 1). In computer simulation science, scientific credibility
173 of an interdisciplinary modeling work requires presentation of a clear and precise computer model.
174 The chosen concepts should be rigorously expressed with a modeling language, and materialized
175 at end of the modeling process, using a programming language. Numerous works have striven to
176 define standards for this process (Cervenka and Trencansky, 2007).

177 For our case study, this process was iterative. In fact, the programming model results from successive
178 refinements from the problem universe to the model’s universe. This iterative process allowed us to
179 check both algorithms and data structures of the computer model’s components, while refining the
180 conceptual model, and thereby improving programming model’s quality of implementation (Corum,
181 2014). Furthermore, our iterative modeling process also facilitated modularity, extensibility and
182 reproducibility, as we worked to create a computer model and programming model that could be
183 extended for future work, and for related case studies. Figure 1 illustrates the iterative modeling
184 process used in this work. Our operational schema is in part inspired by the seminal work of
185 Siegfried (2014); Chwif et al. (2013); Robinson (2013).

186 *2.5. Agent-Based Land Market modeling*

187 An ABM is a data structure for computer simulation relying on a formalism applying the
188 concept of Multi-Agent Systems (MAS) (Klügl and Bazzan, 2012). The ABM consists in an abstract
189 representation of a complex system, in which many entities clearly identified, called agents, interact
190 with each other, and with an environment in accordance with a set of precise rules (Clarke, 2018;
191 Ferber and Weiss, 1999). All of these entities constitute an Agent-Based System (ABS), for example
192 ABMs parallel Individual-based models developed for ecological applications Grimm and Railsback
193 (2006). Using the ABM formalism, the modeling process consists of formalizing the details of the
194 agents, their interactions, and their environment (cf. Figure 2).

195 In the context of economics, ABM complements more the traditional approaches to economic
196 modeling to better link the micro and the macro (Hamill and Gilbert, 2016). In recent years,
197 computer simulations of ABM/LUCC have evolved in terms of theories, concepts and computer

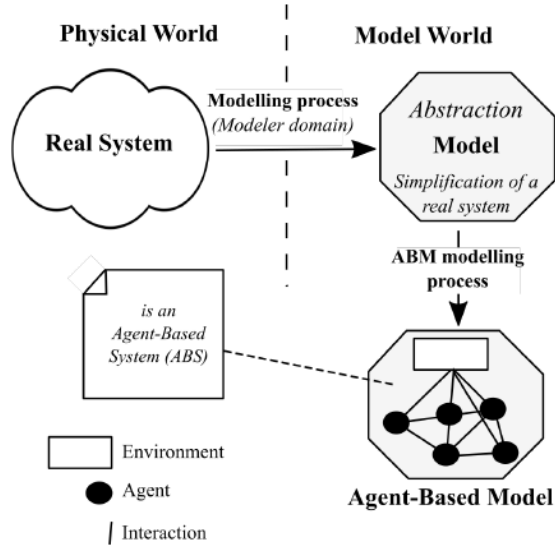


Figure 2: Multi-Agent process modeling

198 hardware developments, encouraging modelers to develop ever more complex conceptual models
 199 (Grignard et al., 2013). Parker and Filatova (2008) argue that such models should also include
 200 representations of land and housing markets, arguing that ABM/LMM can capture the complexity
 201 that traditional economic analytical models can not.

202 3. An illustrative example: Our case study model

203 This section presents the use of the methodology based on MR POTATOHEAD (Property Mar-
 204 ket Edition) for our case study model. After presenting the foundations of our economic conceptual
 205 model and the specificities of MR POTATOHEAD: Property Market Edition, we describe each
 206 step of model abstraction: development of the conceptual design pattern via MR POTATOHEAD,
 207 computer model design, and programming model design.

208 3.1. Case-study model foundations

209 The ABM has various advantages for the development of models more closely to real-world
 210 data. Notably, these models allow consideration of heterogeneous agents, spatial and agent inter-
 211 actions and non-equilibrium dynamics. The model developed by Parker and Filatova in Filatova

et al. (2009a) includes interactions between multiple agent types, the process of bid and ask price formation, and agent decision models combining deductive optimization with inductive models of price expectation formation.

Building from this strand of research, in this paper we propose an economic model based on two markets, one for land and the other for residences. The households' utility maximization program is based on Parker and Filatova (2008), Filatova et al. (2009a) and Filatova et al. (2009b). We also take inspiration from other pieces of work, especially when modeling developers, and when modeling the agricultural landowners' willingness to accept (WTA) functions. This literature generally refers to Magliocca and his co-authors in CHALMS models (Magliocca et al., 2011, 2012, 2015). Finally, two new types of economic agents are introduced in our model in order to better represent the specific context of tourist areas characterized by an intense residential development. On one hand, "non-agricultural landowners" exhibit substantively different behavior than "agricultural landowners". On the other hand, an "Investor" agent is also included. The latter seeks to make money by buying residences and transforming them into tourist rental investments.

3.2. MR POTATOHEAD: Property Market Edition

As described in greater detail in Parker et al. (2019), MR POTATOHEAD has recently been updated and modified to specifically describe land market models. The authors, along with many other collaborators, are working to develop a simple common programming code base for agent-based land market models, which will nest all of our models, implemented in different languages with slightly different assumptions, into a common code base. This code base will allow us to directly compare the implications of different models assumptions, as well as to easily create new hybrid model instances combining model assumptions. As a first step towards this goal, we held two international workshops, during which land-market-specific versions of the MR POTATOHEAD agent decision model, land exchange, and landscape classes were created. These descriptions were successively refined by the authors, to translate the verbal and mathematical economic conceptual model (See Figure 1, upper right) into a detailed and complete description that would support

239 development of the computer and programming models.

240 We found MR POTATOHEAD to be an effective tool to facilitate dialog and communication be-
 241 tween the economists and the computer scientist, especially as it highlighted details that were
 242 required for the model, but not standard in economic descriptions. Through the iterative process
 243 of discussion and model formulation, we further refined MR POTATOHEAD to streamline and
 244 better move towards the structure of a potential computer model implementation. Note that, in
 245 contrast to the description above, agent decision model description templates are implemented for
 246 each agent type in each different role (buyer or seller). Many additional details required for code
 247 development are also included in the templates.

248 Our case study is characterized by an intense residential development, consisting of two markets: a
 249 land market and a real estate market. On the former market, two types of landowners (agricultural
 250 landowners and non-agricultural landowners) and one type of buyers (developers) are considered.
 251 On the latter market, after building a given type of house on a given parcel of land the developer
 252 transforms themselves from buyer to seller. The house is then supplied on the market populated
 253 by only two different types of buyers: households and the investor. The overall structure of our
 254 economic model is described in Figure 3 and the behavior of the various economic agents and their
 255 interactions are described using traditional economic formalism². We use templates to detail all
 256 elements of our economic conceptual model. Eight templates are realized³: one for each market and
 257 one by agent based on their role (buyer or seller). The templates corresponding to our economic
 258 conceptual model are illustrated in Figure 4. Two examples of the templates are provided here-
 259 after⁴: one agent decision template (for the developer buyer on the land market) and one exchange
 260 class template (for the house market).

²The mathematical model is provided by the authors as Supplementary Material (Appendix A) and will be posted online.

³The full templates are provided by the authors as Supplementary Material (Appendix B) and will be posted online.

⁴Templates based on the MR POTATOHEAD are designed to be sufficiently modular to deal exhaustively with the different ABM/LUCC. Below, in the two examples, we only provide the relevant parts of the corresponding templates for our economic conceptual model. Others parts are present in the Online Supplementary Material (Appendix B).

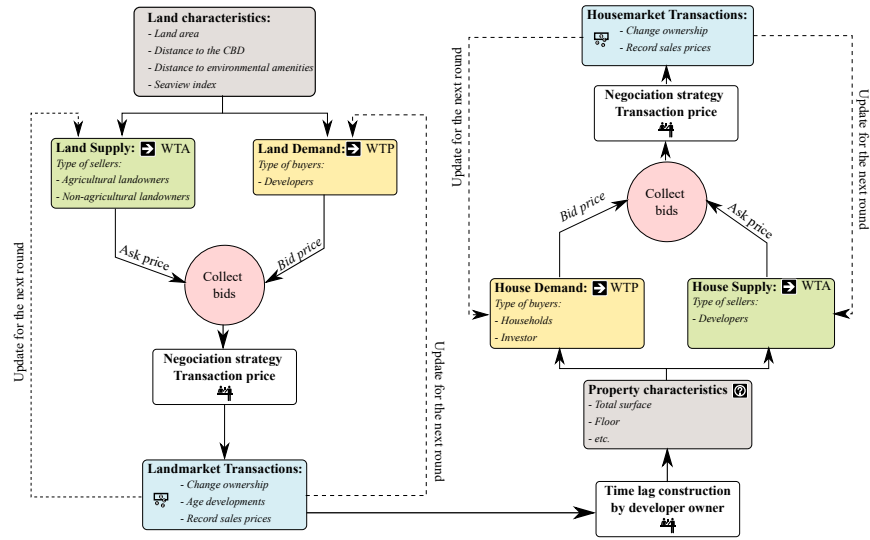


Figure 3: Economic Conceptual Model, after Filatova et al. (2009a).

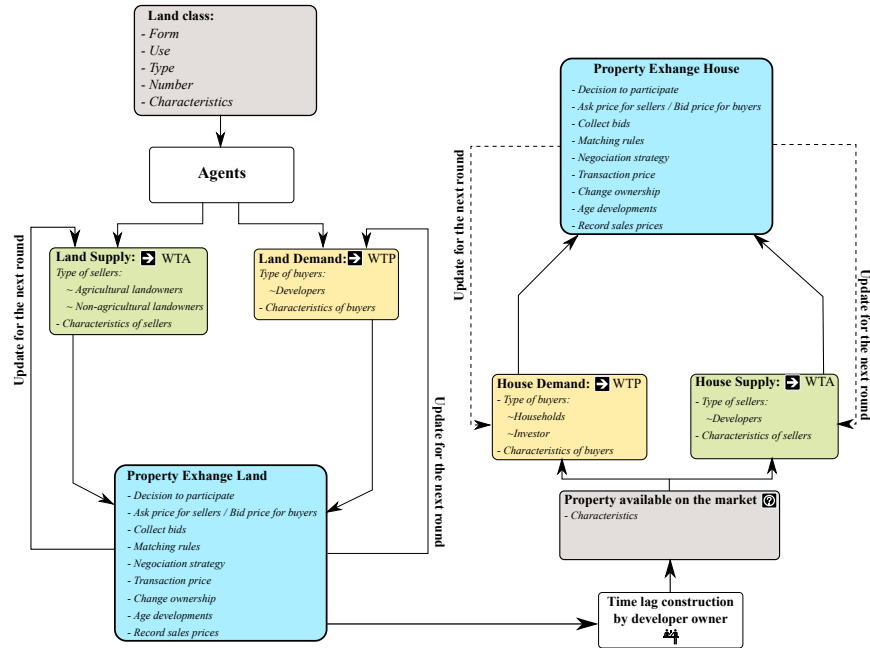


Figure 4: Economic Conceptual Model Templates.

261 *3.2.1. MR POTATOHEAD Real Estate Market Framework – Agent decision template - Develop-*
262 *ers/Land Buyers*

263 Demographic classes (These are agent types. Each agent type could buy, sell, or rent,
264 out.)

265 1. Buyers

266 (a) Developers – Land buyers

267 Decision making class (filled out for each land-market agent type, 1-4 from above in current
268 models)

269 Four types correspond to NetLogo concepts: class (breed) C; attributes, (-own variable) A;
270 links/relationships (directed-link breeds (parent), undirected-link breeds (friend, neighbour, can
271 have own-variables for links in Netlogo, non-binary) L; processes (go, set-up) P; Documentation D
272 *Authors are encouraged to fill out the agent-decision specific questions in the ODD+D protocol*
273 *additionally*

274 1. A / P – Attributes (methods/function and parameters) that affect decision real estate decision
275 *(These may be called in multiple places—for instance budget could affect decision to move*
276 *and then bid price. Carefully specify any sources of uncertainty/bounded rationality for each*
277 *element.)*

278 (a) Price expectations: $P_{H,i,t-1}(z_i, h_m)$ is the past average price for a house with charac-
279 teristics of land z_i and characteristics of house h_m . It will be given by the results of an
280 econometric model.

281 (b) Margin rate of the developer π_m

282 (c) Cost functions (Developers): $C_{m,t}(h_m)$ is the construction cost to build a house of type
283 m .

284 (d) What will be built (developer land buyer): There are M developers, each of them buy a
285 parcel and build a house of type m , with $m = 1, \dots, M$.

286 (e) Willingness to Pay: They determine these WTP by requiring that the selling price allow
287 them to generate a margin π_m on the total cost of the house built on the parcel of land i

288 (sum of the price paid for buying the parcel of land i and the construction cost to build
 289 a house) They build only one house by parcel. The WTP for a developer m for a given
 290 parcel with the vector characteristics z_i , is given by the following expression:

$$291 \quad WTP_{m,t}(z_i) = \frac{P_{H,i,t-1}(z_i, h_m)}{1+\pi_m} - C_{m,t}(h_m)$$

292 (f) Bid price: It is equal to the WTP.

293 (g) Information sources (i.e. Realtor, listings, neighbours): They have information about
 294 the past prices of parcel and houses built on a parcel sold as a common knowledge.

295 (h) Constraints: Developers have a building capacity constraint which means that they
 296 can only build n houses during a period t . Thus, one developer m will only bid on
 297 $n_m = n - \sigma_m$ parcels of land, where σ_m is the number of construction sites in progress
 298 for this developer.

299 2. P – Decision to participate in the market (become active as a buyer, seller, investor, or renter)

300 (a) Decision to participate in the market as a buyer: They are active in market if they are
 301 below their building capacity constraint.

302 3. P – Participate in the market as a buyer

303 (a) Which properties are evaluated (searching strategy) : All properties are evaluated.

304 (b) WTP – call from above

305 (c) Bid price – call from above

306 (d) Which property(s) to bid on?

307 i. Multiple per buyer: By respect of their building capacity constraints.

308 (e) Negotiation strategy:

309 The negotiation power for the parcel of land i holded by landowner of type q ($q = \{1, 2\}$)
 310 depends on the number of potential demands ND_i for i , i.e. for which: $WTP_{m'}(z_i) \geq$
 311 $WTA_{i,t}^q(\cdot)$; $ND_i \leq \chi$

312 Where χ is the number of developers, for which $n_{m'} \geq 0$, with $m' = \{1, \dots, \chi\}$.

313 (f) Rules if you don't succeed to purchase

314 i. Stay in the market.

315 *3.2.2. MR POTATOHEAD Real Estate Market Framework - Property exchange class template*

- 316 1. Which market is being modeled?
- 317 (a) Residences
- 318 2. Who are the market participants?
- 319 (a) Buyers
- 320 i. Investors
- 321 ii. Households
- 322 (b) Sellers
- 323 i. Developers
- 324 3. What unique products are being bought and sold?
- 325 (a) Generic grid, uniform tessellation (Netlogo default)
- 326 (b) Number of container types: one per parcel.
- 327 i. Characteristics of the spatial entity
- 328 A. Spatial location(s)
- 329 B. Entire lot area
- 330 C. Building footprint area
- 331 D. Number of Stories
- 332 E. Transportation accessibility
- 333 F. Neighbourhood amenities (example, sea view index)
- 334 G. Neighbourhood disamenities (example, flood risk)
- 335 ii. Number of different unit categories in the container: one by container
- 336 iii. Unit category descriptions:
- 337 A. Number of units of this type
- 338 B. Unit area
- 339 C. Number of room/bedrooms
- 340 D. Number of baths
- 341 E. Yard/lot size
- 342 F. Garage

- 343 4. Initialize buyer and seller locations
- 344 (a) One agent per spatial container undeveloped
- 345 5. Ask and bid price rules for market-based land allocation?
- 346 (a) How ask prices posted? (*A real estate agent might be noted here, or other ways that*
- 347 *information about listings is made available*)
- 348 i. Public information
- 349 (b) Bid submission: How many properties can a buyer bid on? Households bid on one
- 350 property by step in a time step and the investor can bid on all properties.
- 351 (c) Bid acceptance: How many bids are accepted per property? All bids.
- 352 6. Matching algorithm: How are buyers matched to purchased properties?
- 353 (a) How units are matched to the seller: *Call to seller ADM(s)*: single property model (one
- 354 to one).
- 355 (b) How are buyer bids matched to units? *Call to buyer ADM(s)*: Only one
- 356 (c) How are winning bids selected? (*Call to seller ADM*): The buyer who has the highest
- 357 WTP is matched to the seller if $WTP \geq WTA$. (if 2 or more buyers have the same WTP,
- 358 the winning buyer is randomly selected).
- 359 (d) How is the transaction price defined?
- 360 i. The negotiation power for the house μ built on parcel of land i depends on the
- 361 number of demands ND_μ from households for whom this house corresponds to
- 362 the maximal utility and from the investor if her WTP is higher than the WTA
- 363 of the developer, $ND_\mu \leq C + 1$. The individual ν who has the highest WTP buys
- 364 the house. The transaction price is fixed as follow: $P_{H,i,\mu,\nu} = WTA_{i,\mu,t}(z_i, h_\mu) +$
- 365 $\frac{ND_\mu}{C+1} [WTP_{\nu,i,\mu,t}(\cdot) - WTA_{i,\mu,t}(z_i, h_\mu)]$
- 366 7. What market housekeeping occurs in your model?
- 367 (a) Check for new home supply
- 368 (b) Change ownership
- 369 (c) Record sales prices for next round

370 (d) Rules for buyers who did not find a home (call to ADM functions): Buyers who did not
371 find properties stay in the market and continue to bid on next time step.

372 (e) Identify active buyers and sellers for next round

373 8. What are your stopping rules for market activity?

374 (a) Process stops when: (1) all houses are sold; (2) all households have a house, (3) there is
375 no more transaction, (4) End time periods.

376 3.3. Computer modeling process

377 We detail in this part the construction of the MR POTATOHEAD computer model designed
378 for our case study and its programming model counterpart.

379 3.3.1. MR POTATOHEAD computer model

380 For the prototype programming model now in development, we are writing our model on the
381 NetLogo platform proposed by Uri Wilensky (Wilensky, 1999). Thus, our computer model relies
382 on the *NetLogo Design Pattern* (cf. Figure 5). Although NetLogo has some technical limitations,
383 it is more likely to be used by others, and contributed to, as a meta design pattern, than a code
384 base in another language. We perceive it as having relatively low barriers to entry, compared
385 to other languages, providing an easy entry point for new modelers, especially those lacking prior
386 computer science training. As discussed by Railsback and Grimm (2019), NetLogo can also be used
387 for large-scale scientific applications.

388 As it relies on the standard NetLogo pattern, the MR POTATOHEAD computer model should
389 also be accessible to a majority of modelers in building ABM/LUCC computer simulations, and
390 facilitate conceptual model cross-model comparisons for the modelers community working or not
391 with NetLogo.

392 3.3.2. NetLogo Design pattern

393 The MR POTATOHEAD computer model is built upon the NetLogo pattern. This pattern
394 allows efficient description of the ABM in the light of four groups of generic agents: Observer,
395 Patch, Turtle and Link.

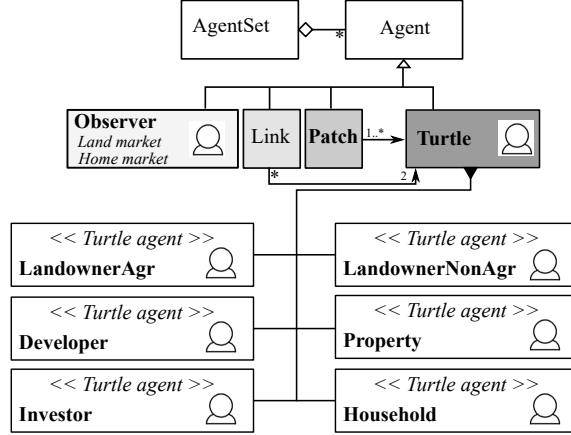


Figure 5: The MR POTATOHEAD computer model.

396 The Observer is a unique agent which observes the environment and may give order to other agents.
 397 Patches are agents that model fixed locations of plan. For example, they can represent cell's
 398 abstractions encountered in Cellular Automata Models (CAM) (Innocenti et al., 2016). Turtles are
 399 mobile agents where locations match with patches agents on which they are placed, i.e. a location
 400 of the cellular space. Turtles can move, and there may be several turtle agents on a same patch
 401 agent. Links are very special agents that allow to link two turtles agents with each other. As
 402 seen in Figure 5, turtle agents will be specialized in the context of the study using the inheritance
 403 mechanism of O.O.P. – instantiated as “Breeds” in Netlogo.
 404 Using the *MR POTATOHEAD conceptual model*, we describe the computer model, integrating the
 405 economic agents described in the previous part. Note that while the *MR POTATOHEAD conceptual*
 406 *model* specifies different conceptual descriptions for agent types in buyers and seller roles, as Figure 5
 407 shows, buyers and sellers are unified in single land-market-actor type turtle breeds in the computer
 408 model. Because Netlogo cannot implement sub-types, we use Boolean switches to activate (or
 409 suppress) buyer and seller roles for turtle breeds.

- 410 • For the land market:
 - 411 – LandownerAgr (Sellers).
 - 412 – LandownerNonAgr (Sellers).

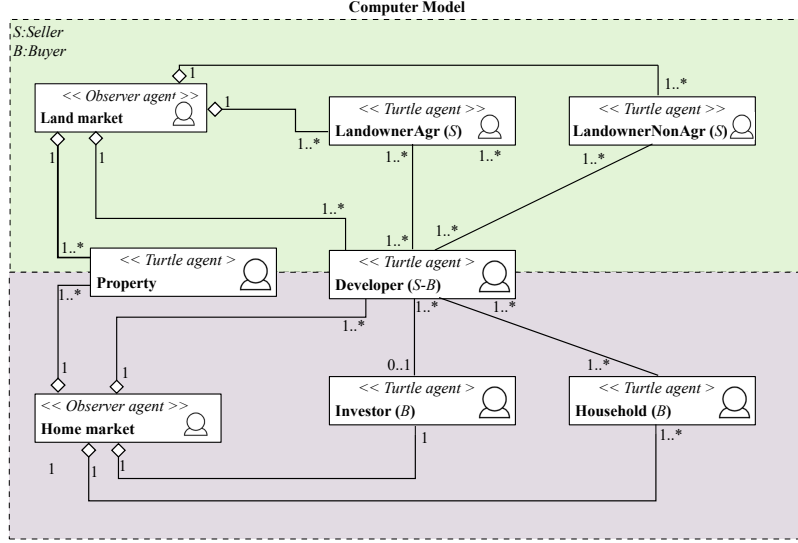


Figure 6: Agent's interactions of our MR POTATOHEAD computer model.

- For the house market:
 - Investor (unique - Buyer).
 - Household (Buyers).
- Land and House market:
 - Developer (Buyers on the land market and sellers on the house market).
 - Property (Land parcel history).

The interactions of the agents are summarized Figure 6.

The *Property* agent's role is crucial in our model. These agents are placed on each land parcel of the world (Patches). They are used to implement land parcel evolution over time from a basic state to the building state which correspond to the last state of the house market. They are made up of several real estates properties. In short, use of the *Property* agents in Netlogo efficiently facilitates one-to-many patch to property relationships (such as an apartment building on a single land parcel), and many-to-one relationships between properties and land actor agents (such as an investor or developer who owns multiple properties). This type of agent remains fixed and has no

behavioral rules, although they inherit characteristics of land-actor *Turtles* agents. Their task is limited information storage for the market process. At $t = 0$, several agents are placed on the world constituting the initial conditions of the simulation. Property agents are placed on the land parcels of the world.

4. Conclusions

In this paper, we have detailed a new generic multidisciplinary method to build ABM/LUCC of land and housing market aiming at simulate and evaluate territorial planning policies.

Our method is based on both conceptual modeling and Design Patterns software engineering techniques. Design Patterns inspire all stages of the modeling process proposed and help to formulate efficient and lasting software solutions in multidisciplinary contexts. As example, we detail the construction of an ABM/LUCC from its conceptual model to its computer model counterpart.

We use the MR POTATOHEAD Property Market Edition as a Conceptual Design Pattern for building a conceptual ABM/LUCC. The MR POTATOHEAD ontology provides a structured way to “decompose that system into the relevant parts, their properties, and the relationships between them” and to separate model design from model construction, as recommended by Smaldino (2020), line 303, as best practices for translation of verbal models to computer code. Moreover, the method help us to bridge the gap between economic descriptions and computer model/programming model. The NetLogo software is used to implement the resulting programming model throw the generic NetLogo Design Pattern. Our method permits us to efficiently integrate the spatial aspect of ABM/LUCC.

The preliminary results show the method facilitates the ABM/LUCC formulation and one-to-many and many-to-one relationships between physical land parcels and properties descriptions.

The Netlogo design pattern helps in our particular case study that we had one team member who had a deep understanding of both economic and agent-based models, as well as rudimentary understanding of computer science and programming concepts. This method allowed us to build a prototype of the economic conceptual model on NetLogo providing a generic virtual laboratory. We also think that this method could be of interest to the readers of this journal who are expanding

models on biocomplexity in the environment to individual based modelling, as they would normally have a similar formal mathematical presentation of their models to the economics norm. This model will now be applied to Corsica (France), which represents an ideal framework for analysis because of its specificities: islands with a high expansion of population and tourists and high demand for accommodation. Policymakers could benefit from the empirical evidence provided by our study through the greater understanding of agents' behaviour and interactions. In a future work, we will employ real data in order to parametrize and calibrate the ABM/LUCC. The data (PERVAL) will come from an original dataset – filled by notaries – containing all real estate transactions in Corsica in last 15 years. By means of standard and spatial econometric procedures, in order to take into account space-time effects, we will be able to identify all the main parameters of the ABM/LUCC and perform simulation analysis.

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