Reusable Building Blocks for Agent-Based Simulations: Towards a Method for Composing and Building ABM/LUCC

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***Abstract*—The *5-Steps Simplified Modelling Process* (*5-SSIMP*) is a method designed to develop modular and reusable *Agent-Based Models of Land Use and Cover Change* (*ABM/LUCC*) in an interdisciplinary context. It is based on the definition of three types of *Reusable Building Blocks* (*RBBs*): *Conceptual-RBB* (*conRBB*), *Computer-RBB* (*comRBB*), and *Executable-RBB* (*exeRBB*). We present a practical modelling example based on the *5-SSIMP* method for creating an *ABM/LUCC* applied to the socio-economic tourism system of Corsica.**

Keywords-Modelling method; ABM/LUCC; RBB.

I. Introduction

The computer simulation of "*Agent-Based Models of Land Use and Cover Change*" (*ABM/LUCC*) represents an inherently interdisciplinary research field, integrating computer science, software engineering, economics, geography, social sciences. Within this context, the intrinsic complexity of the spatial socio-economic systems under study necessitates a rigorous method to ensure the coherence, reliability, and validity of the simulation models. This is particularly pertinent to the specialisation of *Agent-Based Models* (*ABM*). The *5-Steps Simplified Modelling Process* (*5-SSIMP*) presented in this paper, is a stringent modelling and simulation method dedicated to the development of modular and reusable *ABM/LUCC* and their simulation experiments. Additionally, *5-SSIMP* enhances collaboration among the various disciplines involved. The process begins with a *conceptual model* that specifies the key elements of the system and progresses to the *computer modules* of the *executable model* in the digital world. During the *5-SSIMP* modelling process, modellers isolate and characterise these key elements in intermediate abstract and concrete models, grouping both generic and context-specific characteristics. The generic characteristics correspond to *Reusable Building Blocks* (*RBB*) and they group similar functionalities. The *5-SSIMP* process necessitates the definition of three types of *RBB*: *conceptual-RBB* (*conRBB*), *computer-RBB* (*comRBB*), and *executable-RBB* (*exeRBB*). In this paper, we explain how to characterise these elements in *ABM/LUCC* through the *5-SSIMP* process, which we review in Section 2. In section 3, we introduce the concept of *RBB*, key elements of this process, ensuring the modularity and reusability of the concepts, components, and codes involved. In section 4, an implementation example focused on the creation of an *ABM/LUCC* of the Corsican socio-economic tourism system is presented. In Section 5, we conclude and present the future perspectives of this research in computer simulation.

II. 5-SSIMP Method

The *5-SSIMP* modelling process is divided into five essential steps: (1) *Conceptualisation*, (2) *Integration*, (3) *Implementation*, (4) *Simulation*, and (5) *Data Analysis*. The production of *RBB* pertains to steps (1) to (3) of the process, which we refer to as the "*modelling phase*". The (4) to (5) steps of the process, refer to as the "*simulation phase*".

A. Modelling phase

In the *(1)-Conceptualisation* step, modellers simplify the real system by formulating a conceptual model, identifying key components and their relationships. During the *(2)-Integration* step, modellers translate the conceptual model into a computer model by defining appropriate objects, modules, and links. In the *(3)-Implementation* step, modellers convert the computer model into an executable model. They use computer programming languages and techniques for this, including *Object-Oriented Programming* (*OOP*) and *Design Patterns* (*DP*) [1]. As illustrated in Figure 1, the executable model is continuously improved through the iterative cycle of continuous adjustments (iterations).

B. Simulation phase

During the *(4)-Simulation* step, modellers validate and verify the model with rigorous tests to ensure the accuracy and reliability of the *simulated data*, comparing it with *real data* when possible. In the *(5)-Data Analysis* step, modellers finalise the *executable model* for routine practical use, ensuring it is reliable, robust, and efficient.

III. Reusable Building Block Concept

We have seen that the *5-SSIMP* modelling process is divided into five distinct stages, providing a clear and methodical structure for constructing an *ABM/LUCC* in an interdisciplinary context. During the first three stages, modellers identify and isolate key elements characterising the complex system, defining intermediate *abstract* and *concrete models*. These elements possess characteristics that are both generic and specific to the study context. Elements with generic characteristics are grouped into *RBBs* within the intermediate models, organising reusable structures and functionalities in a modular manner. Each *RBB* encapsulates a generic aspect of the intermediate model, such as generic agent behaviours, generic social interactions, or generic economic dynamics.

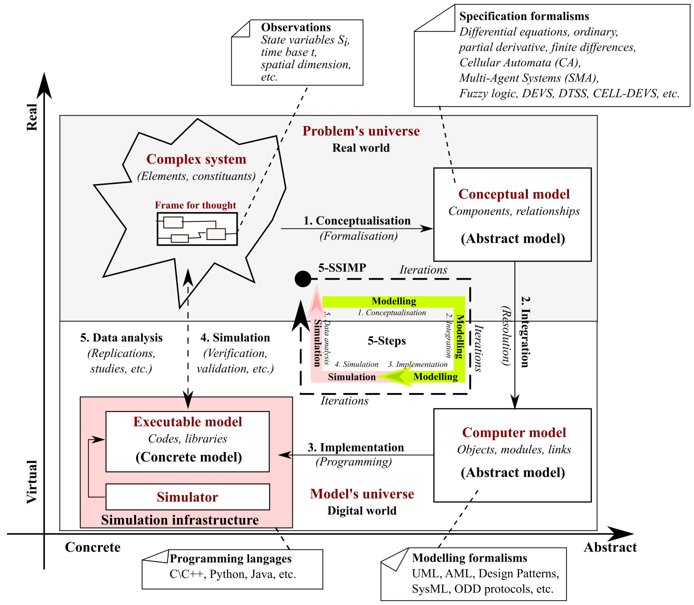

Figure 1. The *5-SSIMP* process is an iterative method for creating modular and reusable *ABM*, facilitating interdisciplinarity.

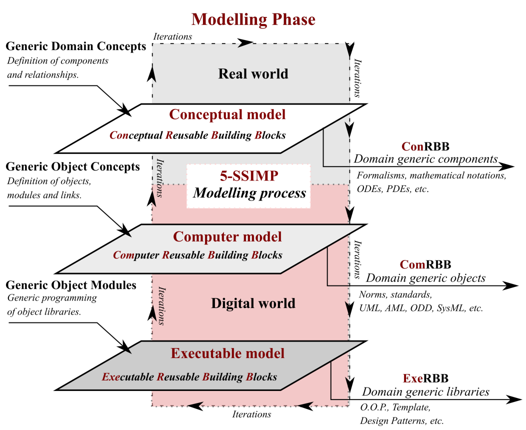

Figure 2. The central concept of *Reusable Building Block* (*RBB*), in accordance with the *5-SSIMP* modelling process.

As illustrated in Figure 2, this organisation of models into blocks promotes: (1) - the updating or replacement of blocks, maintenance, and evolution of the executable model during iterations (*modularity*); (2) - the creation of code libraries, enabling the sharing and reuse of proven code in other simulation projects (*reusability*). (3) - researchers in economics, sociology, and computer science can collaborate more easily by using and adapting these generic modules according to their specific needs.

A. Definition of conRBB

A *Conceptual Reusable Building Block* (*conRBB*) is a type of *RBB* produced in stage (1) of the conceptualisation process in *5-SSIMP*. *conRBBs* are developed using specification formalisms (rules, notations, formal languages, etc.), such as mathematical notations, *Ordinary Differential Equations* (*ODEs*), *specification of Discrete EVent System* (*DEVS* [2]), etc. *conRBBs* characterise in conceptual models the key generic components and their relationships as *Generic Domain Concepts*, in a structured and reusable manner.

TABLE I. LINKS BETWEEN MODELS AND PRODUCTION TOOLS OF *Reusable Building Blocks* IN THE *5-SSIMP* PROCESS.

5-SSIMP Model	RBB	Modelling tools
Conceptual	*conRBB*	Formalisms, mathematical notations, ODEs, PDEs, etc.
Computer	*comRBB*	Norms, standards UML, AML, ODD, SysML, etc.
Executable	*exeRBB*	P.O.O., Templates, Design Patterns, etc.

B. Definition of comRBB

A *Computer Reusable Building Block* (*comRBB*) is another type of *RBB*. It is produced in stage (2) of the integration process in *5-SSIMP*. *comRBBs* ensure coherence, standardisation, and reusability of generic objects across various simulation projects. They consist of sets of generic objects usable in diverse fields of study as *Generic Object Concepts*. To achieve this, *comRBBs* are established according to computer standards and norms such as the *Unified Modelling Language* (*UML*) [3], *Agent Modelling Language* (*AML*) [4], *Overview, Design concepts, and Details* (*ODD*) [5], or the *Systems Modeling Language* (*SysML*) [6], etc. Numerous recent studies demonstrate that *DPs* significantly enhance the modularity and reusability of models in computer simulation [7]–[9].

C. Definition of exeRBB

An *Executable Reusable Building Block* (*exeRBB*) is a type of *RBB* produced in stage (3) of the implementation process in the *5-SSIMP* modelling process. These building blocks correspond to the generic code components of the *executable model* grouped as *Generic Object Modules*. They implement principles from *OOP* and *Generic Programming*, as conceived in the computer model, using *Templates* [10] and *DPs* [1]. *exeRBBs* contribute to the practical execution of computer simulations, providing *reusable blocks of code* and *pseudo-code* adaptable to various simulation projects. These are typically generic software libraries, offering significant advantages in achieving software productivity and reliability.

IV. Practical example

An *Agent-Based Model of Land Use and Cover Change* (*ABM/LUCC*) is an *ABM* that integrates the spatial dynamics of a socio-economic system [11][12]. It is used in this example to simulate the virtual territory of economic agents who evolve according to rules of economic development and land competition. Decision-making processes are based on spatial socio-environmental factors, as well as the heterogeneity and imbalances observed in the real socio-economic system.

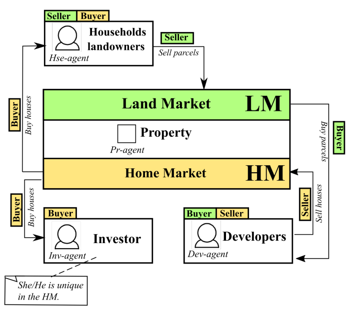

Figure 3. Organisation of agents and markets in the *conceptual model* [13].

The case study presented in this paper focuses on an *ABM/LUCC* that we employed to analyse the tourist areas in Corsica, which have experienced intense residential development in recent years. Its *conceptual model* is detailed in the article [13]. The complex system studied is a spatially defined territory, bordered by the sea and subject to socio-economic dynamics influenced by two main processes: a *Land Market - LM* and a *Home Market - HM*. In the *LM*, interactions occur between "*household seller agents owning land*" (agent-*Hse*) and "*developer buyer agents*" (agent-*Dev*). The *HM*, on the other hand, involves coordination between "*household buyer agents*" (agent-*Hse*) and a single "*investor buyer agent*" (agent-*Inv*). The agents-*Hse* and *Inv* compete in the *HM* to purchase houses built by the agents-*Dev*, who act as sellers in this *HM*. Figure 3 illustrates these organisation. The conceptual specification *MR POTATOHEAD* (*MPH - Model Representing Potential Objects Appearing in the Ontology of Humano-Environmental Actions and Decisions*.) is used in this case study to describe the complex socio-economic system of Corsica with two markets [14], [15, p.407]. It is a *Conceptual Design Pattern* (*CDP*) intended for the generic definition and organisation of key components and their relationships in the conceptual model of an *ABM/LUCC* [16]. The conceptual specification *MPH* allows for the standardised definition of *ABM/LUCC* with price formation processes between buyers and sellers and their decision-making processes, which combine deductive optimisation and inductive models of price expectation formation in generic agents. We use it here in its "*Property Market Edition* [17]" version to precisely characterise the *conRBB*. (For a more detailed article on the subject, interested readers can consult the following paper: [18].)

LM Market: Some *agent-Hse* own plots of land that are sold on the *LM* market. The decision-making process of an *agent-Hse* offering land for sale is based on the *conRBB Willingness to Accept* (*WTA*). In this example, the *WTA* considers the average (historical) selling prices $P_{t-1}(z_i)$ of similar plots with the same characteristics z_i according to 1.

$$WTA_{La}(z_i) = P_{t-1}(z_i) \tag{1}$$

In this same market, the decision-making process of an *agent-Dev* is based on the *conRBB Willingness to Pay* (*WTP*) for a given plot of land i. The *agent-Dev* make predictions about the price at which they can sell the house built on this plot and aim to achieve a profit margin rate on the total cost of the house.

$$WTP_m(z_i) = \frac{P_{H,i,t-1}(z_i, LivA_m) - C_{LivA}(z_i)\, LivA_m}{1+\pi_m} \tag{2}$$

where, $P_{H,i,t-1}(z_i, LivA_m)$ is the (past) average price paid for an equivalent house; $LivA_m$ is the living area of a house of a m type; π_m is the expected margin rate of the developer; $C_{LivA}(z_i)$ is the construction cost to build a house.

HM Market: In the *HM market*, *agent-Dev* sell the houses, i.e., *agent-Pr* fixed on the plan (properties), previously defined in the *LM market*, based on the *WTA* of 3.

$$WTA_{i,m}(z_i, LivA_m) = (1+\pi_m)\left(\overline{P_i}(z_i) + C_{LivA} LivA_m\right) \tag{3}$$

where $\overline{P_i}(z_i)$ is the cost incurred for acquiring the land parcel i.

In this housing market, the *WTP* (*conRBB*) of the sole *agent-Inv* is given by 4.

$$WTP_I(\eta) = \frac{1-(1+r)^{-T}}{r(1-\rho)(1+r)^{-T} + rT - 1 + (1+r)^{-T}}\gamma\zeta\varphi(\eta) \tag{4}$$

where $r \in [0,1]$ is the financial market interest rate, $\gamma \in [0,1]$ represents the net rental return coefficient (net of maintenance costs), ζ is the duration of the tourist season in days, $\varphi(\eta)$ is the average daily revenue for a tourist residence with corresponding characteristics, T denotes the average loan duration, $\rho(1+r)^{-T} P_I(\eta)$ is the house's residual value after T years, with $\rho \in [0,1]$.

Finally, in this market, the *WTP* (*conRBB*) of the *agent-Hse* is given by 5.

$$WTP_c(\eta) = \frac{(1+\delta_c)\left[(1+\delta_c)^T - 1\right]}{\delta_c}\frac{YD_c\left(V_c^{Max}\right)^2}{b^2 + \left(V_c^{Max}\right)^2} \tag{5}$$

where δ_c is the discount rate of the *agent-Hse*, V_c^{Max} is the maximal utility value the *agent-Hse* can obtained buying the house corresponding to this maximal value, YD_c is the amount of money that the *agent-Hse* spends on housing each period and b is the slope of the bid function. (For a more detailed presentation of the *conRBB* in this conceptual model, interested readers can refer to the articles [13], [18].) To quickly and easily obtain a functional *ABM/LUCC* prototype with these characteristics, featuring immediately usable objects and modules, we chose to integrate the conceptual model using the *NetLogo Design Pattern* (*NetLogo-DP*) proposed by *Seth Tisue* and *Uri Wilensky* [19].

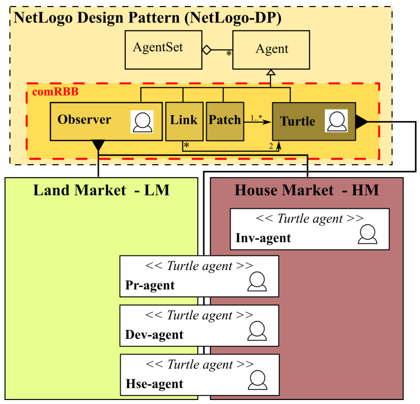

Figure 4. The *NetLogo-DP* allows for the simple construction of an *ABM/LUCC* with just four types of *comRBB*: an *omniscient observer* (*Observer*), *cells* (*Patches*), *turtles* (*Turtles*), and *links* (*Links*).

The *NetLogo-DP* is characterised by the generic agents of an *ABM* that can be easily implemented in the generic part of the executable model within the *NetLogo* simulation environment. In the presented case study, the agents of the *ABM/LUCC* are derived through increasing specialisation from four *comRBB* (highlighted in red in Figure 4) of the *NetLogo-DP*: an *omniscient observer* (*Observer*), *cells* (*Patches*), *turtles* (*Turtles*), and *links* (*Links*). The *comRBB* "*Observer*" should be considered as a unique agent responsible for monitoring the environment and issuing commands to the various other agents (mobile or fixed) present in the *ABM/LUCC* space. The *comRBB* "*Patches*" are space agents that represent fixed locations (cells). Thus, the *NetLogo-DP* offers a simple and effective means to construct an *ABM/LUCC* prototype (computer model) from just four *comRBB*. The implementation phase is the final step of modelling (Recall that the remaining steps (4) and (5) respectively deal with *simulation* and *data analysis* as illustrated in Figure 1.) the complex system in the *5-SSIMP* modelling process. In our case study, this step involves producing the code for the executable model using the *NetLogo* programming language. This requires us to adhere to the numerical schema of objects, modules, and links defined in the previous *computer model* (cf. Figure 4). The agents of the executable model are thus implemented in accordance with the *exeRBB breed* specific to the *NetLogo* programming environment.

Figure 5 is a code snippet showing how to use the generic syntax `breed[householdsAgt householdAgt]` of the *exeRBB* `breed` to define the *agent-Hse* of the *ABM/LUCC*. In this snippet, each *agent-Hse* has its own attributes specified using the `-own` command of the *exeRBB* `breed`. In

```
;HouSEhold Agents (HSE)
breed[householdsAgt householdAgt]
householdsAgt-own[
  HI_isHouseOwner?; Property owner
  H_isLandowner?; Landowner
  H_houseHoldCat; Socio-pro category
  H_disposable-budget; Budget prop. purchase
  HDI_leeway; Leeway
  H_discountRate; Discount rate
  H_maxValueHouseUtility; Maxi. utility value
  H_houseRef; Pro. rel. - Maxi. utility
  H_wealth; Non-wage income
  H_quarterlyInterestRate; Q.Int.rate]
```

Figure 5. Implementation of the *-Hse* agents in the computer model using the `breed` *exeRBB* from *NetLogo*.

NetLogo, using the `breed` directive allows for the simple and efficient prototyping of all agents in the *ABM/LUCC* within an executable model, thereby facilitating the exploration of behaviours and socio-economic properties within the complex system under study.

We simulate five policy scenarios designed to address Corsica's unique challenges and opportunities as a tourist destination, focusing on sustainable urban development and environmental sustainability:

1) Business As Usual (BAU): This baseline scenario extrapolates the continuation of current trends, providing a comparative benchmark to evaluate the effects of more interventionist policies.

2) Total Ban on Tourist Rental Investments (BTRI): Reflecting drastic yet plausible policy measures to curb the overdevelopment of tourist accommodations, this scenario evaluates the impact of entirely prohibiting new tourist rental investments.

3) Tax on Tourist Rental Investment Incomes (TTRI): This scenario introduces a tax, ranging from 0.01 to 0.5, on incomes derived from tourist rental investments. The rationale behind this measure is to deter excessive investment in tourist rentals by reducing their profitability, thereby influencing land market dynamics.

4) Coastal Zoning (CZ): This scenario mandates a minimum required distance from the coastline, ranging from 1 to 50 units, for any new tourist rental investments. Its objective is to preserve coastal regions and reduce the concentration of developments near the sea, which are often high-demand areas. Furthermore, considering the ecological sensitivity of Corsica's coastline, this policy imposes restrictions on new tourist rental investments near coastal areas to protect these vital habitats and maintain their accessibility for future generations.

5) CBD Zoning (CBD-Z): Similar to the coastal distance policy, this scenario mandates a minimum distance ranging from 1 to 50 units from the *CBD* for new tourist rental investments. The objective of this policy is to distribute tourist accommodations more evenly across the territory, thereby alleviating pressure on urban centres and promoting the development of underutilised areas. The Table II lists the

TABLE II. FIXED PARAMETERS

Input	Value
Percentage of low revenue households	54%
Percentage of middle revenue households	20%
Percentage of high revenue households	26%
Percentage of households that own their home	52%
Percentage of households that own a buildable parcel of land	87%
Share of households income spent on housing	0.3
Time Horizon (year)	20
Transport cost (€/km)	0.5404
Number of buildable parcels of land	2,500
Number of resident households	5,625
Number of developers	4
Number of Rent days	220
Slope of the bid function	0.8

fixed parameters used in the experiments. These values remain constant throughout the simulations to serve as a benchmark.

TABLE III. RANDOM UNIFORM VALUE PARAMETERS

Input	Value
Land Area (m^2)	$[500, 2500[$
Sea view Index	$[0.75, 23.25[$
Disposable budget of low revenue households	$[6200, 23200[$
Disposable budget of middle revenue households	$[10000, 40000[$
Disposable budget of high revenue households	$[11500, 71500[$
Disposable budget of Investor	$[900000, 1100000[$
Interest rate	$[0.02, 0.04[$
Discount rate	$[0.01, 0.11[$
Leeway	$[0.05, 0.09[$
Net return of rental	$[0.65, 0.75[$
House loss value	$[0.08, 0.12[$
Margin rate	$[0.02, 0.024[$
Cost Parameter (€/m^2)	$[750, 1000[$
Max Building sites	$[1, 3[$
Number of Bedrooms	$[1, 6[$
House surface : $a + b$(N. of Bedrooms $- 1$)	$a : [18, 31[$,$a : [24, 33[$
Building time : $8 + BTSup$	$BTSup : [0, 4[$

Table III showcases parameters that are assigned random uniform values to introduce variability and observe its impact on the outcomes. The data sources of this example also include the *PERVAL Database*, a comprehensive dataset produced by the Chamber of Notaries, providing insights into various housing and land metrics, and the *AirDNA*, which is a dataset that offers information related to housing demands and valuations. We also use other Datasets to incorporate *INSEE* (*Institut National de la Statistique et des Études Économiques* is the "*French National Institute of Statistics and Economic Studies*".) data, providing demographic and economic parameters. Others additional datasets include: [20] for building sector data, [21] for commuting costs to the *CBD*, and valuable insights from focus groups with real estate agents and developers.

The outputs obtained from the executable *ABM/LUCC* model allow us to visualise and analyse the dynamics and impacts of interactions between economic agents and the virtual spatialised socio-economic environment. The various policy scenarios highlight the impacts of interventions on urban development and real estate dynamics in Corsica. By meticulously examining developer bankruptcies, market price variations, distances to key landmarks, such as the *Central Business District* (*CBD*) and the beach, as well as the *Mean Seaview Index*, we have gathered useful information on the effects of policy levers. The data generated coupled with appropriate statistical indicators and graphs, enable a better understanding of territorial dynamics of the socio-economic system, identification of emerging trends, and assessment of the impacts of simulated policies and interventions. As an example, we present below the results obtained through the different scenarios concerning the number of bankruptcies and average prices on the two markets. In Figure 6, we observe a pronounced divergence in developer outcomes across the different scenarios. Developer bankruptcies number 2,791 in the *BAU* scenario, surge to 27,333 in the *BTRI* scenario, and show marginal increases or decreases in other scenarios. The *BTRI* scenario precipitates a significant increase in bankruptcies, underscoring the crucial role of tourist rentals in the developer economy. Conversely, scenarios such as the *TTRI* and *CBD-Z* exhibit a comparatively stable or slightly improved environment for developers, indicating a delicate balance between regulatory stringency and market sustainability. As shown in Figure 7, the *LM* exhibits resilience, with minor price fluctuations across scenarios, suggesting a stable market where external influences or policy changes have marginal impacts on land prices (outliers are not displayed.). However, the *BTRI* scenario significantly elevates *HM* prices, indicating a constrained supply amidst unwavering demand. This elevation, a more common economic phenomenon, reflects the pronounced effect of restrictive policies on market dynamics.

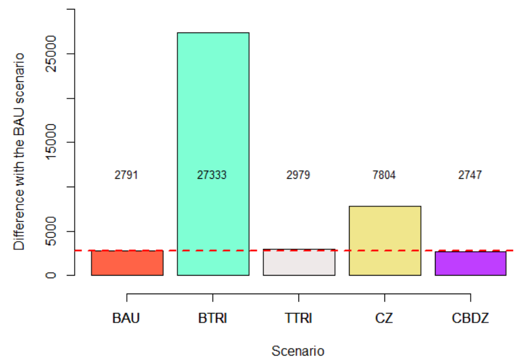

Figure 6. Number of developer bankruptcies by scenario.

V. CONCLUSION AND PERSPECTIVES

The *5-SSIMP* modelling method presented in this paper illustrates a structured and iterative approach to developing modular and reusable *ABM/LUCC*, while facilitating interdisciplinary collaboration. The introduction of *Reusable Building Blocks* (*RBB*) at different stages of the *5-SSIMP* process enhances the modularity, reusability, and robustness of executable *ABM/LUCC* models. The practical example of *ABM/LUCC* applied to the socio-economic tourism system in

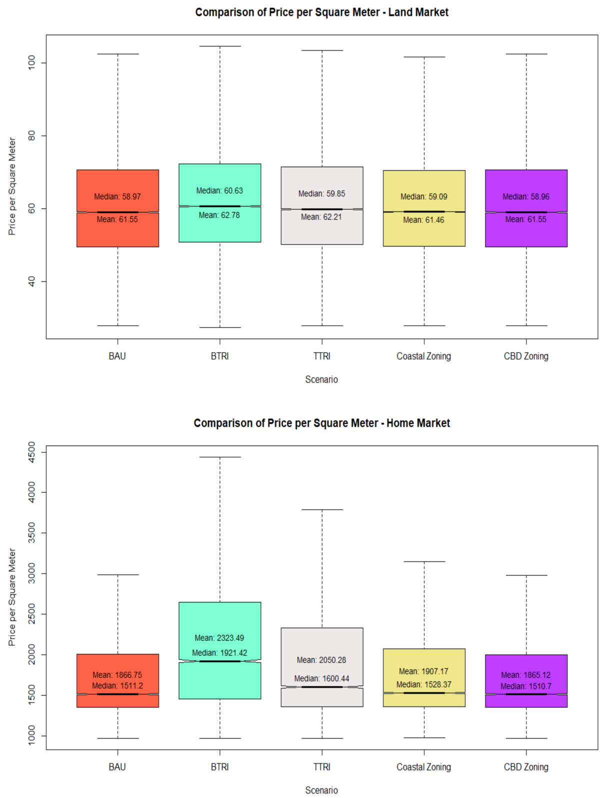

Figure 7. Dispersion of price per square meter for *LM* and *HM*.

Corsica demonstrates the effectiveness of this method, showing how generic conceptual (*conRBB*), computational (*comRBB*), and executable (*exeRBB*) components can be defined, integrated, and implemented. The simulated market dynamics presented as an example reveal complex interactions between economic agents, suggesting valuable insights for analysis and decision-making in Corsica [22]. To continue improving and developing the *5-SSIMP* method and its applications, several research directions will be explored in the coming years. We aim to integrate *Artificial Intelligence* (*AI*) and *Machine Learning* techniques to enhance the predictive and adaptive capabilities of *ABM/LUCC*.

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