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Title

Development of a CA-based model approach for sustainable planning of affordable housing projects: an application case study in Algiers

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Declarations of interest

none.

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1 **Title**

2 **Development of a Cellular Automata-based model approach for** 3 **sustainable planning of affordable housing projects: an** 4 **application case study in Algiers**

5 **Abstract**

6 Being considered as a basic necessity and a key element in the development of sustainable communities, housing
7 is a major concern for the Algerian government. Algiers is facing for the last years a challenging housing
8 shortage and as a way to overcome this problem, many housing projects have been launched. However, the
9 pressing need to address this crisis has disregarded what the pattern of landscape will be, how the existing
10 infrastructures will accommodate with such housing projects and how they will impact on human well-being.
11 This research aims to advance the challenges of planning for sustainability by proposing a methodological
12 approach in a context of high lack of data to support decision-makers in the elaboration of affordable housing
13 projects. The main objective is to trade off urban growth with residential satisfaction and the preservation of
14 natural resources. We developed two Cellular Automata (CA) based residential development scenarios to
15 identify suitable locations for future affordable housing projects: Urban densification scenario (UD) and
16 Constrained urban sprawl scenario (CUS). Both scenarios are based on indicators of residential preferences and
17 measures taken in order to counter the negative effects of urbanization. Results reveal the low capacity of
18 Algiers to meet the housing shortage according to the conditions set for each scenario. The scenarios were
19 evaluated by quantifying their spatial patterns using a preselected set of six class-level landscape metrics. Results
20 show a combination of aggregated and dispersed patterns growth for both scenarios meeting trade-offs among
21 the advantages and the challenges of urban densification and urban sprawl. Then, Standard deviation and
22 regression analysis were conducted to assess the accuracy of CA simulation and the evaluation of pattern
23 changes in the simulated scenarios. The resulting values indicate the good performance of CA and confirm its
24 effectiveness in predicting the future locations of housing projects.

25 **Keywords**

26 Residential preferences; Housing projects locations; Sustainable Urban Planning; Cellular Automata; Landscape
27 metrics; Regression analysis.

28 **Highlights**

29 . The importance of spatial decision-behaviour process in the planification of affordable housing projects is
30 attested.

31 . A Cellular Automata-based model is developed and suitable locations for future housing programs are
32 identified.

33 . This innovative approach combines indicators of households residential preferences with measures to protect
34 natural and agricultural areas.

35 . Natural resources are protected and accessibility to public transport and amenities is optimised.

36 . The model can be adjusted according to local social and environmental demands to support the transition
37 towards sustainable and inclusive housing policies.

38 **1.Introduction**

39 Good housing is a key success element in provisioning human well-being and sustainable communities;
40 therefore, governments should afford adequate and well-located housing possibilities, meeting the needs of all
41 segments of existing and future society, offering equality of opportunities and good services for all, with a focus
42 on environmental issues and landscape functioning (Gopalan et al., 2015; Dillmana et al., 2017; Costarelli et al.,
43 2019). In accordance to the 2030 UN Sustainable Development Goals (SDG), cities today need to employ
44 sustainable strategies in housing policies and programs based on inclusion and participation.

45 Affordable housing is provided for households whose income is not adequate to afford appropriate housing
46 directly on the market based on government initiatives. However, apart from price, sustainability issues such as
47 land use efficiency, neighborhood environment, location, transportation, work opportunities and sense of
48 belongings are strongly discussed in such housing programs (Abdel Raheem et al., 2020; Saidu et al., 2020). Up
49 to now, the consideration of these components is often overlooked when addressing housing crisis, particularly
50 in developing countries due to their explosive population growth. Therefore, housing projects are planned mainly
51 on the basis of cost that can significantly increase when including social and environmental perspectives, and
52 thus, distort the adopted strategies to overcome the critical growing housing needs (Gan et al., 2017).

53 As a way to address the housing crisis and the prevalence of slums, as well as their impact on quality of life, the
54 Algerian government has allocated considerable budgets on different housing programs and policies through four
55 national development plans since 2001 (Djafri et al., 2019; Niang, 2019). They target all income levels
56 separately (low – middle – high), thus undermining the idea of social mix (Costarelli et al., 2019; Safar-Zitoune,
57 2020). However, there is still a gap in terms of housing supply, quality and affordability compared to the
58 effective demand (Aknouch, 2016). This is particularly relevant in the capital Algiers, where affordable housing
59 indicator Price to Income Ratio (PIR) (Sani, 2015) for the year 2021 is around 26.33 (> 5) (Numbeo, 2009). It
60 highlights the considerable gap that exists between the real estate market supply and the purchasing power of
61 households. So far, due to the weakness of instruments and unstudied policies (Belguidoum et al., 2010), these
62 housing projects have generally gone by hand with the disconnection of the end-users from their everyday urban
63 surroundings (Mebirouk et al., 2005; Msilta, 2009; Naceur, 2013; Djafri et al., 2021), challenging social
64 cohesion and revealing neighborhood effects such as insecurity and delinquency (Boutabbal, 2016; Safar-
65 Zitoune, 2020), residential segregation (Safar-Zitoune, 2009; Benazzouz-Belhai, 2018), the inadequacy of
66 dwellings to household's lifestyles (Souiah, 2005; Bendraoua et al, 2008), the lack of public facilities, amenities
67 and public transportation, and the difficulties in accessing workplaces (Msilta,, 2009; Semmoud, 2015). As a
68 result, many vacant dwellings have been identified as being unoccupied by their owners (Semyane, 2020).
69 Additionally, lack of transparency and coordination between government institutions and political interferences
70 (Belguidoum et al., 2010; Cheniki et al., 2020) have also contributed to the failure of these national housing
71 programs.

72 These housing projects play also a critical role driving the process of urban growth. They lead to an irreversible
73 land transformation through landscape fragmentation, shrinking of agricultural lands (Bellout et al., 2020) and an
74 increase of natural and man-made hazards (Boughazi et al., 2014; Boughedir, 2015). As well as an enhancement
75 in population mobility and traffic congestion, thus altering urban metabolism (Tabti-Talamali, 2018; Chaguetmi
76 et al.,2020). Therefore, there is a need to develop a framework that will support decision-makers in their spatial-
77 decision behaviours in order to best manage the spatial form of the urban footprint as well as to respond to
78 various households' residential preferences, aiming to reach residential satisfaction.

79 However, despite the government's aim to introduce smart approaches into decision-making processes, notably
80 through the "Algiers Smart City" project (Aït-Yahia, 2019), as yet, it is rather difficult to take into account
81 sustainable actions in Algerian urban plans and policies at different scales. The main cause is the low technical
82 capacity of municipalities to manage their local urban growth (Berezovska-Azzag et al., 2015), driven by

83 political arbitrary decisions in order to avoid socio-political tensions (Hocine, 2021). Moreover, this problem is
84 often associated with the lack (or usually non- existence) of time series spatial data, especially at a fine scale
85 (Rabhi et al., 2019). Data is in most cases not digitized and impossible to access, while data that capture
86 household patterns and individual's decision behaviours usually do not exist. In addition to this, public
87 administrative systems are weak and not computerized, despite the "E-Algeria" project launched in 2013 by the
88 government to move towards e-governance and introduce ICTs in public administrations (Taib, 2015; Fortas,
89 2017). Up to now, there is still a strong reluctance and multifaceted resistance (Aït-Yahia, 2019) as ICTs provide
90 more information and transparency, and play a key role in the renewal of forms of democracy and citizens'
91 participation in the decision-making process (Taib, 2015; Aït-Yahia, 2016; Cheniki et al., 2020). This makes it
92 difficult to assess the current situation as well as to forecast future changes for impact minimization.

93 Nowadays, the need to use urban modeling approaches in the study of urban systems has become vital to shift
94 towards sustainable and efficient planning. There are variety of approaches and methods developed for this aim
95 including Markov chain, Logistic regression, Potential Model, Cellular Automata (Dabbaghian et al. 2010;
96 Yulianto et al., 2018; Antoni et al., 2019; Liao et al., 2019; Wang et al., 2019; Asfaw et al., 2020; Priem et al.,
97 2021; Zhang et al., 2021) and Agent-based models (Crooks et al., 2014; Bharath et al. 2016; Guangjin et al.,
98 2016; Wahyudi et al., 2019). These models and methods can be used alone or in combination with one another or
99 with other statistic models. The flexibility of CA-based models and their ability to integrate GIS technologies to
100 model complex urban systems have contributed to their common use in urban growth modelling (Santé et al.,
101 2010; Liu, Yan et al., 2019; Liu, Yunqiang et al., 2019). In geography, the territorial dimension of Cellular
102 Automata was supported by Tobler 1979 (Tobler, 1979), through his pioneering work in the geographic systems
103 domaine. Several approaches and models were subsequently proposed to modify standard CA to make it suitable
104 to simulate land use changes from a bottom-up perspective, particularly in urban and peri-urban areas. Cellular
105 Automata (CA) is a discrete computer model (Jen, 1990) composed of a cellular grid where each cell is classified
106 as one of a number of predefined states. In geography and land planning applications, these states usually
107 correspond to land use categories (transportation, dense housing, individual housing, etc.). Within the CA grid,
108 each cell's state can evolve in time t according to the states of the neighborhood cells. Transition rules are then
109 applied iteratively as many times as desired.

110 In Algeria, only very rare studies have worked on urban modeling. Two notable studies can be cited (Nedjai et
111 al., 2016 and Rabhi et al., 2019), where urban growth was predicted as a whole. In this research, we consider the
112 city as a system that can be defined by synergies among various components, where land use changes are the

113 consequence of multiple drivers that include human behaviours and decisions such as housing choices (Liu et al.,
114 2019).

115 This study adopts a Cellular Automata based modeling approach to produce prospective scenarios of residential
116 developments of the capital Algiers. The main objective is the identification of suitable locations for future
117 affordable housing projects that will best sustain natural resources, especially in a context of shortage of capital
118 and land supply for urbanization, while seeking to provide human well-being (Yigitcanlar et al., 2015). The
119 generated outcomes will also allow to evidence the role and impact of spatial-decision behaviours in reshaping
120 landscape structure using landscape metrics.

121 **2.Methodology**

122 **2.1. Study area**

123 The study was carried out in Algiers, the capital of Algeria, it is located on the Mediterranean coast,
124 geographically between 36°42'N and 3°03'E. It covers an area of 1190 km² and is comprised of 57
125 municipalities, with a population of 3.154 million in 2015. During the last decades, urbanization has increased
126 significantly in the city of Algiers, the growth of urban areas increased from about 13 597 hectares in 1987 to
127 over 19 629 hectares in 2000 and over 33 400 hectares in 2014, with an average growth of 707 hectares per year
128 (Bouchachi, 2017). Most of the changes in land use have been on the expense of the agricultural lands belonging
129 to the Mitidja plain, which is very problematic because of its very high agricultural potential and gently sloping
130 lands (Bellout, 2020).

131 Algiers has a Master Plan of Urban Planning and Development (PDAU 2000-2029). It provides a set of actions
132 to achieve suitable management and development of the city (Ammara, 2014; Bachar, 2016). It is supported by a
133 Strategic Development Plan (PSDA 2029) elaborated in 2006 by the municipality of Algiers within the
134 framework of the revision of the PDAU as well as the creation of a development plan for Algiers Bay. Through
135 these tools, public authorities express major interest in launching massive housing programs. However, the
136 deficiencies currently experienced by the housing industry and housing market advance the weaknesses in the
137 methodological approaches of these tools. They remain evasive and overcome by local realities (Ammara, 2014;
138 Djermoune, 2014; Kehal-Boucherit, 2019).











139 **2.2. Land Use and Land Cover (LULC) mapping of Algiers**

140 Unlike land cover, which represents the physical elements of the landscape (vegetation, water, urban patch etc.),
 141 land use cannot be determined by analysing satellite and aerial imagery, as it represents the consequences of
 142 anthropogenic actions on landscape and how it is used (housing, facilities, etc.) (Singh, 2021). In this context of
 143 non-availability of LULC map of Algiers, we were constrained to produce the geographic information
 144 (shapefiles) needed for this study, following the stages below.

145 1. Delimitation of urbanized areas. We performed an NDVI index on a sentinel 2A image of the region of Algiers
 146 with a resolution of 1m to separate areas with vegetation cover from areas with rock/concrete cover. Then we
 147 conducted a photo-interpretation approach to increase the accuracy between the classes. The very low NDVI
 148 values (≤ 0.1) correspond to barren rock surfaces. Intermediate values (0.2 to 0.3) represent shrub and grassland
 149 areas. High values (0.6 to 0.8) indicate temperate or humid tropical forests.

150 2. Delimitation of agricultural lands according to their agricultural aptitudes. In order to define the agricultural
 151 lands that must be protected, we reclassified the categories of the agricultural aptitudes provided by the Master
 152 Plan of Urban Planning and Development of Algiers (PDAU) into two principal categories: (1) Low agricultural
 153 potential lands, (2) High agricultural potential lands.

154 3. Spatial designation of LU/LC categories. In order to locate and map LULC categories, we exploited the vector
 155 data provided by Open Street map (OSM). OSM vector data are commonly used to identify LU/LC categories
 156 (Kunze et al, 2015; Sertel et al, 2018; Sertel et al, 2021). However, we were constrained to conduct an urban land

| LU/LC Categories | Cells | % | Color | Code | Description |
|--|--------|-------|---|------|--|
| Transportation | 16359 | 3.51 |  | TRN | Public transport stations and stops and highways |
| Dense Housing | 107540 | 23.12 |  | DH | high density housing typologies |
| Dense Individual Housing | 18796 | 4.04 |  | DIH | Dense individual single and/or multi-family housing typologies |
| Public Services and Urban Facilities | 17990 | 3.86 |  | PSUF | Schools, hospitals, recreations, green infrastructures, administrations... |
| Activities and Industry | 32740 | 7.04 |  | AI | Industrial areas and factories |
| High Agricultural Potential Lands | 209473 | 45.05 |  | HAPL | Lands with high agricultural aptitude |
| Low Agricultural Potential Lands | 19340 | 4.15 |  | LAPL | Lands with low agricultural aptitude |
| Waterways and Hydrolic Infrastructures | 8703 | 1.87 |  | WHI | waterways, wetlands, hydraulic stations and infrastructures |
| Forests | 33775 | 7.26 |  | FOR | Forests, nature parks |
| Urban Wastelands | 251 | 0.05 |  | UW | Land gaps and brownfields |

157

158

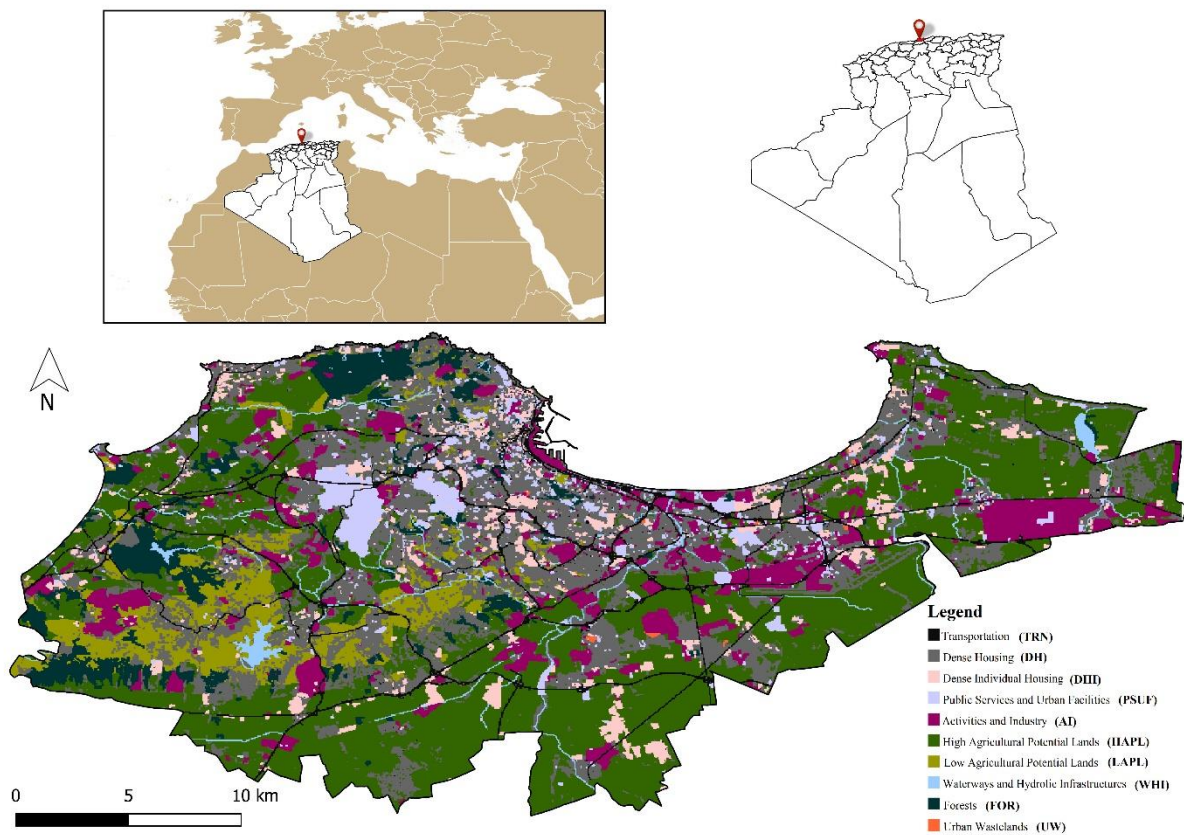
Table 1. Classification of LULC categories of Algiers.

159 survey in order to verify, update and complete the OSM data. (Pissourios, 2019).

160 On the basis of the shapefiles produced by the previous stages, 10 categories of LULC were defined (Tab.1) and
161 stored in a grid map with a resolution of 50m*50m per cell (Fig.1).

162 2.3. Design of future residential developments

163 Literature review indicates that the traditional urban-rural divide is the main driving force behind households'
164 residential preferences, as it gives each a broad set of features that influence household choices (Vasanen, 2012;
165 Ströbele et al., 2017; Foelskea et al., 2019; Jansen, 2020). In this study, attention was focused on preferences
166 related to landscapes and infrastructures. Landscape preferences are driven by two main trends: (i) A trend
167 generated by preferences for dense housing typologies in dense urban surroundings (Howley, 2009; Caplan et
168 al., 2021). (ii) A trend generated by preferences for individual – single family housing typologies in open spaces,
169 and for rural and natural amenities (Foelskea et al., 2019). Meanwhile, infrastructures preferences are related to
170 mobility behaviour based on the means of transport used, and to the availability and proximity to everyday
171 services



172

173

Fig 1. Study Area. Land Use/Land Cover and Political map of Algiers.

174 and facilities (Walks, 2008). These indicators are interrelated as their overlap defines the final residential
175 preferences of households.

176 Based on the produced digital LULC map of Algiers (section 2.2.) and the indicators of residential preferences
177 mentioned above, two scenarios of residential developments have been elaborated to identify the suitable
178 locations of future affordable housing projects. However, preferences have been constrained by measures taken
179 in order to counter the negative effects of urbanisation towards a planning for sustainability. These measures
180 include the protection of agricultural lands, natural and green landscape elements, as well as the promotion of the
181 use of public transport (Westerink et al., 2013; Simard, 2014; Artmann et al., 2019; Yang et al., 2021).

182 *(UD) Urban Densification.* This scenario aims to develop Dense Housing (DH) land use category by meeting the
183 preferences for high density housing typologies in urban surroundings. It depicts the densification of the existing
184 urban areas and the availability of public transports means and everyday urban facilities and services in the
185 immediate surroundings (Teller, 2021). This will lead to a relative mixed land use that can help to promote
186 walkability (Meijer, 2020). This scenario expresses also a local concern for natural environment and agricultural
187 lands.

188 *(CUS) Constrained Urban Sprawl.* This scenario is designed for households with preferences for individual
189 housing in peri-urban and rural areas. However, given that the existing typologies of individual housing are
190 already dense in Algiers, we will settle for orienting the development of Dense Individual Housing (DIH) land
191 use category on the edges of existing urban areas. It also considers preferences for recreation in natural
192 landscapes. It provides relative proximity and access to urban areas and amenities to create opportunities to
193 balance protection of the natural landscape and outdoor living aspirations.

194 **2.4. Simulation of future residential developments**

195 In this study, we used Lucsim CA Software (Antoni, 2017) to simulate the scenarios designed. It is a
196 geographical Cellular Automata, its major functionality is based on P. Torrens's definition (Torrens, 2000). It is
197 based on the assumption that the state of each cell is determined by its neighborhood, or in our case, by the
198 LULC categories of surrounding cells within a given radius:

$$199 \quad \forall i \in E, V_{i,kl} = f(V_{ik}(t), \Omega_i(t))$$

200 Where,

$$201 \quad \Omega_i = f(V_{k=1}^r, V_{k=2}^r, \dots, V_{k=N}^r) \text{ and } r \in \{0, \dots, \infty\}$$

202 where E is a set of cells that can undergo a transition (nonlocked), V_i is the land use of the cell i , Ω_i is the
203 neighborhood of the cell i within a radius r (at time t), and C_n^r is the number of cells with a land use S within a
204 radius r , at time t (Antoni et al., 2018).

205 To guide CA during simulation, particular sets of transition rules were defined to achieve the goals of each
206 scenario. We based our two scenarios on the assumption that housing projects will only be developed on low
207 agricultural potential lands (LAPL) (Forsyth et al, 2021) in accordance with the Law 90 - 29 (Official Journal of
208 Algerian Republic, 1990) on urban planning and development. This law prohibits urban development on high
209 agricultural potential lands (HAPL) to protect the Mitidja plain. It also prohibits any construction within 100
210 metres of the coastline that does not require immediate proximity to water. The law 04 – 05 (Official Journal of
211 Algerian Republic, 2004), which requires the implementation of a safety perimeter for zones exposed to
212 technological risks (AI) was also taken into consideration. We assumed that no housing projects will be planned
213 on urban wastelands (UW), considering them as flexible spaces, opening various opportunities. They are
214 particularly interesting for urban green systems and provide real potential to promote biodiversity in the city
215 (Bonthoux et al, 2014; Brun et al, 2018; Draus et al. 2020).

216 (UD) Locations of future housing projects corresponding to urban densification scenario are determined by the
217 transition rules translated as follows:

218 – The proportion of DH and DIH must be over 30% in a radius of 200 meters.

219 – There must be at least 3 PSUF cells and 2 TRN cells in a radius of 1 km.

220 – There must be no AI cells in a radius of 1 km.

221 – There must be at least 1 AI cell in a radius of 2 km.

222 – There must be no HAPL, FOR and WHI cells in a radius of 1 km.

223 – There must be no SEA cells in a radius of 100 meters.

224 (CUS) Locations of future housing projects corresponding to constrained urban sprawl scenario are determined
225 by the transition rules translated as follows:

226 –The proportion of DIH must be over 30% in a radius of 200 meters.

227 –The proportion of DH must be over 30% in a radius of 500 meters.

228 – There must be at least 1 TRN cell and 1 PSUF cell in a radius of 1 km.

229 – There must be no AI cells in a radius of 1 km.

230 – There must be no FOR, WHI and HAPL cells in a radius of 500 meters.

231 – There must be at least 1 AI cell in a radius of 2 km.

232 – There must be at least 1 FOR cell, 1 WHI cell and 1 HAP cell in a radius of 1 km.

233 – There must be no SEA cells in a radius of 100 meters.

234 **2.5. Landscape metrics and statistical analysis**

235 Landscape metrics are mathematical indices developed to quantify various patterns of landscape from a
236 categorical map of a defined geographic area, depending on the spatial scale of interest: (i) landscape level, (ii)
237 class level, (iii) patch level. They are grouped into different structural categories (Area and edge metrics, Shape
238 metrics, Aggregation metrics, etc.). However, most metrics can belong to more than one category (Uuemaa et al.,
239 2009; McGarigal, 2012).

240 Our objective is to assess the spatial processes of residential developments in order to quantify the impact of
241 each simulated residential scenario on the spatial patterns of the region of Algiers. This quantification allows to
242 determine the role of the spatial distribution behaviour of housing projects in the configuration and composition
243 of the spatial structure for each scenario. To achieve this goal, Landscape metrics were calculated at the class
244 level so that each LULC category is represented by its corresponding value of each spatial metric computed, as
245 they are calculated from all patches of each category (Aguilira, 2011; McGarigal, 2012; Sertel et al, 2018). It is
246 critical to select appropriate landscape metrics when analysing landscape patterns since many of them are
247 redundant and provide similar information because they rely on the same basic measures (area, edges, adjacency,
248 distance, etc.). There are some methods used to help identify a relevant set of landscape metrics, including
249 statistical methods and expert knowledge (Griffith et al., 2000; Plexida et al., 2014; Yang et al., 2019). In this
250 study we used principal component analysis (PCA) and Spearman's rank correlation (SRC).

251 A total of 26 class level landscape metrics were initially selected and computed using Fragstat software
252 (McGarigal et al., 2012): SHAPE_MN, FRAC_MN, PARA_MN, CIRCLE_MN, CONTIG_MN, PAFRAC,
253 GYRATE_MN, PLAND, LPI, TE, ED, GYRATE_MN, ENN_MN, PROX_MN, CONNECT, NP, PD, LSI,
254 CLUMPY, PLADJ, IJI, COHESION, DIVISION, SPLIT, AI, NLSI. At first, we performed a PCA to help

255 identify a smaller set of landscape metrics. The results identify 4 components that explain 76% of the variance of
 256 the whole dataset. The first and second components include area-edge, shape and aggregation metrics, the third
 257 component includes shape and aggregation metrics and the fourth component includes shape metrics only.
 258 Metrics that were not strongly correlated with the first 4 components were excluded from the analysis:
 259 GYRATE_MN, NP, PD, CLUMPY, IJI and NLSI. SRC was then conducted to create a correlation coefficient
 260 matrix of the landscape metrics selected after PCA. Landscape metrics with correlations greater than 0.80 were
 261 considered to be redundant. However, it was decided to include at least one core metric for each structural group.
 262 IJI was added back into the list because it is critical to quantify the intermixing of classes. In this way, a final set
 263 of 6 class-level landscape metrics was defined (Table 2.) out of 26.

| Metric | Range | Unit | Description |
|---|------------------------|-----------------|---|
| Mean Shape Index (SHAPE_MN) | SHAPE_MN \geq 1 | None | Each class is summarised as the mean of each patch belonging to class <i>i</i> . SHAPE describes the ratio between the actual perimeter of the patch and the hypothetical minimum perimeter of the patch. The minimum perimeter equals the perimeter if the patch would be maximally compact. |
| Edge Density (ED) | ED \geq 0 | Meters/ hectare | This metric describes the configuration of the landscape, e.g., because an aggregation of the same class will result in a low edge density. The metric is standardized to the total landscape area, and therefore comparisons among landscapes with different total areas are possible. |
| Largest Patch Index (LPI) | 0 < LPI \leq 100 | Percent | This metric is the percentage of the landscape covered by the corresponding largest patch of each class <i>i</i> . It is a simple measure of dominance. |
| Aggregation Index (AI) | 0 \leq AI \leq 100 | Percent | This metric equals the number of like adjacencies divided by the theoretical maximum possible number of like adjacencies for that class summed over each class for the entire landscape. The metric is based on the adjacency matrix and the single-count method. |
| Mean-Proximity Index (PROX_MN) | PROX_MN \geq 0 | None | This metric characterizes the degree of spatial isolation of patches, high proximity values indicate that neighbouring patches, of the same type of class <i>i</i> , are less isolated and aggregated, low values are indicative of fragmentation. |
| Interspersion and Juxtaposition Index (IJI) | 0 < IJI \leq 100 | Percent | This metric describes the intermixing of classes (i.e., without considering like adjacencies - the diagonal of the adjacency table). The number of classes to calculate IJI must be \geq than 3. |

264

265 **Table 2. Description of the selected class level landscape metrics for the study adapted from McGarigal, et**
 266 **al. (2012) and Hesselbarth et al. (2021).**

267 In order to assess the implications of the simulated residential developments on the real landscape, we calculated
268 the standard deviation between landscape metrics values for each LULC category from the real landscape with
269 each of the produced scenarios. This allows to measure the dispersion of values around their mean, the lower the
270 standard deviation, the more homogeneous the values. Then, a linear regression was performed for each class
271 metric. Adjusted r^2 values allow to determine the relationship among each class level landscape metric for each
272 scenario and the real landscape in order to verify the accuracy of the spatial patterns recreated by the scenarios,
273 and thus, determine how the strategies on spatial decision-behaviour are associated with potential changes in
274 landscape patterns of the study area.

275 **3. Results and discussion**

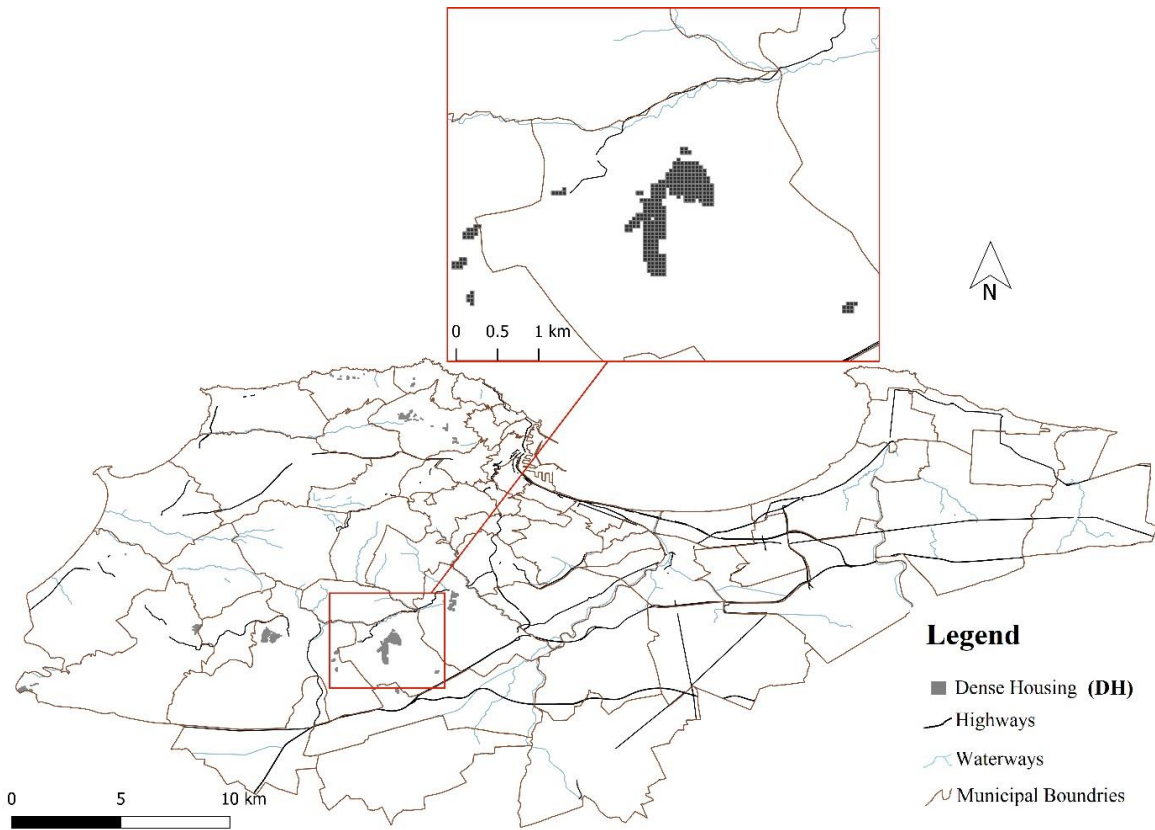
276 **3.1. Scenarios**

277 *Urban Densification Scenario (UD)*

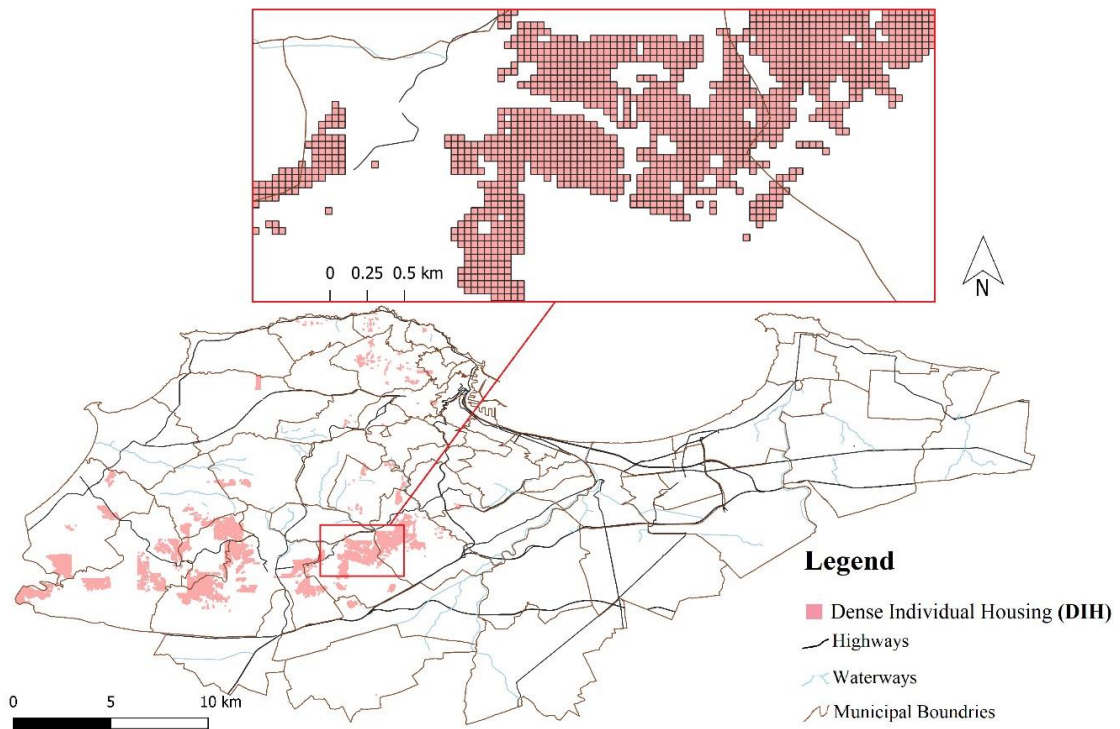
278 The simulation identified 808 new Dense Housing (DH) cells (202 Ha) that fit the rules required by the UD
279 scenario in 9 iterations spread over 8 municipalities (Fig.2). It corresponds to 4.17% of the total Low
280 Agricultural Potential Lands (LAPL). The restricted number of cells identified within a high number of iterations
281 indicates that Algiers is already very dense. The results indicate also that the existing facilities and public
282 transport will not be subject to any extra pressure given the very limited number of cells that will be able to
283 accommodate housing projects. These results also show that urban densification is unlikely to meet housing
284 needs on its own, and thus the need for urban expansion cannot be excluded.

285 *Constrained Urban Sprawl Scenario (CUS)*

286 The simulation identified 9645 new Dense Individual Housing (DIH) cells (2411,25 Ha) that fit the rules
287 required by the CUS scenario in 16 iterations. The process is slower and involves more iterations than the UD
288 scenario because the rules for this configuration meet many more constraints in order to counter the negative
289 effects of conventional urban sprawl. The identified cells are spread over municipalities located mainly in the
290 West of Algiers (Fig.3) because of their low agricultural potential lands. It corresponds to 49.87% of the total
291 LAPL. As an alternative to dispersed sprawl, it presents tradeoffs among residential aspirations for rural
292 amenities and objectives related to sustainable land management as the identified cells are close to the existing
293 urban areas. This may help reduce car dependency while being surrounded by natural elements.



295 **Fig 2. UD Scenario. Location of new Dense Housing (DH) cells according to UD simulation.**



297 **Fig 3. CUS Scenario. Location of new Dense Individual Housing (DIH) cells according to CUS simulation.**

298 Each scenario generates different impacts. The results obtained within the UD simulation reveal the limited
299 capacity of Algiers to meet the housing shortage in the long term. This is due to the low land supply close to
300 facilities and infrastructures coupled with the scarcity of LAPL compared to HAPL in dense areas. Thus, CUS
301 scenario appears to be a relevant alternative to meet housing needs in a sustainable manner. As it allows the
302 identification of suitable locations for residential developments, improving both accessibility to public transport
303 and urban facilities, while avoiding the fragmentation of natural and agricultural areas. Moreover, current
304 Algerian housing policies do not include the different social demands. Therefore, the proposed model enables to
305 overcome this deficiency, as it meets the specific preferences of each category of population. This opens up
306 realistic prospects to shift towards sustainable and inclusive housing policies in Algiers.

307 **3.2.Landscape patterns analysis**

308 Figure.4 shows the results for the calculated class-level landscape metrics for each scenario. Classes that present
309 significant variations in metric values are: Dense Housing (DH), Dense Individual Housing (DIH) and Low
310 Agricultural Potential Lands (LAPL). The other classes remain stable for both scenarios, except for IJI where all
311 classes show variations in values. DH land use shows more aggregative patterns in UD scenario than in CUS
312 scenario due to the increase in number of patches resulted from UD simulation (+202 Ha). However, the
313 difference remains very slight (79.97 in AI for UD and 79.84 in CUS). This result is confirmed with LPI values
314 (1.0054 for UD and 0.9987 for CUS) as new DH patches cluster together with the existing patches in their
315 neighborhood to form patches of bigger size. It is accompanied with higher value in PROX_MN for UD
316 compared to CUS (128.78 and 125.44 respectively) which is reflected in a more contiguous distribution of DH
317 patches. So far, these results indicate that the growth is driven by an aggregative process. In contrast, higher
318 values in ED and SHAPE_MN (1552475,086 for UD, 1551128,39 for CUS, and 1,3512 for UD and 1,3501 for
319 CUS respectively) for UD are indicative of a growth in dispersion, as the class is more patchy with more
320 complex patch shapes. This can be interpreted as the appearance of new, more elongated DH patches in addition
321 to the contiguous ones as the simulation was not only concerned with spatial densification, but mainly with the
322 identification of the best locations that correspond to the preferences related to dense surroundings with the best
323 living conditions. DIH land use presents the same patterns in CUS scenario as for DH land use in UD scenario,
324 due also to the appearance of new patches resulted from CUS simulation (+2411,25 Ha). Its growth is reflected
325 in more aggregated patches with less isolation (79,9571 in AI, 0,218 in LPI and 17,0735 in PROX_MN for CUS
326 and 78,4254 in AI, 0,2055 in LPI and 6,761 in PROX_MN for UD). Some of these patches come with irregular
327 shapes which make them less compact as reflected in the higher value of mean shape index (1,2801 for CUS and

328 1,2561 for UD) and more heterogeneous as suggested in Edge density values (412337,1561 for CUS and
 329 294394,9081 for UD). The increase in DIH land use density can be interpreted as a consequence of the
 330 mitigation of some of the negative effects of conventional urban sprawl. The fact that the CUS simulation
 331 consumed more LAPL than UD simulation contributed to decrease aggregation as shown in AI and LPI values
 332 (74,5806 in AI and 0,1887 in LPI for CUS and 80,6071 in AI and 1,1459 in LPI for UD), and reduce patch
 333 connectivity as highlighted by PROX_MN values (14,9837 for CUS and 111,405 for UD). Despite this higher
 334 level of dispersion, it is important to mention that the progression of DH and DIH on LAPL has contributed to



335
336

— UD Scenario — CUS Scenario

337

338 **Fig 4. Results of the calculated Landscape metrics at the class level for each scenario.**

339 smooth the edges of the remain patches, leading to more rounded shapes as evidenced by lower values in
 340 SHAPE_MN (1,2505 for CUS and 1,2703 for UD) and in edge density (180988,9004 for CUS and 262782,9834
 341 for UD). IJI metric gives information about the degree of mixing present between LULC categories. IJI value for

342 DH land use is higher in UD scenario than in CUS scenario (78.92 and 78.44 respectively) and for DIH land use
343 in CUS scenario than in UD scenario (69.33 and 66.49 respectively). This suggests that these classes are better
344 distributed and highly intermingled with the other LULC categories after simulations. The higher IJI values for
345 TRN and PSUF in UD scenario (68.65 and 68 respectively) suggest that they were important components in the
346 simulation as they are more evenly distributed than in CUS scenario (68.29 and 67.76 respectively). This result
347 indicates an urban densification towards homogeneity as defined by the transition rules in the calibration phase.
348 Similar effects are observed with CUS scenario, as suggested by the higher IJI values for the natural classes
349 (66.02 for LAPL, 63.41 for WHI and 76.95 for FOR), indicating that they are more adjacent and connected to all
350 other classes compared to UD scenario (57.06 for LAPL, 62.30 for WHI and 75.60 for FOR) since the CUS
351 simulation favours preferences for peri-urban and rural areas. Overall, the use of class-level landscape metrics
352 helped identifying pattern changes in the simulated scenarios. The results demonstrate a combination of
353 aggregated and leapfrogging patterns growth for both scenarios. This indicates that the proposed model favours
354 efficient land use for residential developments given the simultaneous increase in aggregation and dispersion
355 metrics values of residential land uses. It also optimises the preservation of natural and agricultural areas given
356 their stable landscape metrics values. As they are so far undergoing continuous fragmentation due to the massive
357 construction of housing projects to meet the growing needs.

358 This underlines the effectiveness of landscape metrics in assessing spatial and environmental consequences of
359 spatial-decision behaviour in the planification of affordable housing projects.

360 **3.3. CA performance**

361 Standard deviation and regression analysis allow assessing the accuracy of CA simulation and the evaluation of
362 pattern changes in the simulated scenarios. As can be seen in Table.3 and .4, the variability between the
363 scenarios and the real landscape is low given the low standard deviation values for most all class level landscape
364 metrics (>7.29) except for LAPL land use in CUS scenario with the PROX_MN as CUS simulation consumed
365 49.87% of the total LAPL. This led to an increase in dispersion which is reflected in the elevated standard
366 deviation value (75,02). As for ED metric, the elevated standard deviation for DH and LAPL land uses in UD
367 scenario and for DIH and LAPL land uses in CUS scenario can be explained as ED increases without limit
368 (Table 2.), and thus the values are not significant.

369 As can be seen from the high values of adjusted r^2 , the real landscape has not been much affected by the two
370 simulations. In UD scenario, we found that the patterns were stable (adjusted $r^2 \geq 0.99$ for all the metrics). In

371 contrast there are slight pronounced changes in CUS (adjusted $r^2 \geq 0.93$) for all the metrics except for IJI with an
 372 adjusted r^2 value of 0.79. In this study IJI is the metric measuring intermixing of land use categories and this low
 373 adjusted r^2 value indicates that there are differences in the adjacency of land use categories due to the spatial
 374 redistribution of the patches in the landscape after simulation. Overall, the low sensibility of the real landscape
 375 patterns to the simulations indicates the good performance of CA in predicting future residential developments,
 376 including satisfactory results regarding the objectives associated with the sustainable land use management of
 377 Algiers.

378 **Table 3.**

| Landscape Metrics | Standard deviation between landscape metrics values from real landscape and UD scenario | | | | | | | | | | Adjusted r^2 | P value |
|-------------------|---|---------|------|------|------|------|---------|------|------|------|----------------|---------|
| | TRN | DH | DIH | PSUF | AI | HAPL | LAPL | WHI | FOR | UW | | |
| SHAPE_MN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | < 0,001 |
| ED | 0.00 | 1102,61 | 0.00 | 0.00 | 0.00 | 0.00 | 4535,75 | 0.00 | 0.00 | 0.00 | 1 | < 0,001 |
| LPI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0,03 | 0.00 | 0.00 | 0.00 | 0,99 | < 0,001 |
| AI | 0.00 | 0,09 | 0.00 | 0.00 | 0.00 | 0.00 | 0,23 | 0.00 | 0.00 | 0.00 | 0,99 | < 0,001 |
| PROX_MN | 0.00 | 2,46 | 0.00 | 0.00 | 0.00 | 0.00 | 6,84 | 0.00 | 0.00 | 0.00 | 0,99 | < 0,001 |
| IJI | 0,06 | 0,04 | 0,13 | 0,12 | 0.00 | 0,06 | 0,52 | 0,18 | 0,05 | 0.00 | 0,99 | < 0,001 |

379

380 **Table 4.**

| Landscape Metrics | Standard deviation between landscape metrics values from real landscape and CUS scenario | | | | | | | | | | Adjusted r^2 | P value |
|-------------------|--|--------|----------|------|------|------|---------|-------|------|------|----------------|---------|
| | TRN | DH | DIH | PSUF | AI | HAPL | LAPL | WHI | FOR | UW | | |
| SHAPE_MN | 0.00 | 0.00 | 0,01 | 0.00 | 0.00 | 0.00 | 0,01 | 0.00 | 0.00 | 0.00 | 0,99 | < 0,001 |
| ED | 0.00 | 150,35 | 83397,76 | 0.00 | 0.00 | 0.00 | 62372,9 | 25,05 | 0.00 | 0.00 | 0,98 | < 0,001 |
| LPI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0,71 | 0.00 | 0.00 | 0.00 | 0,93 | < 0,001 |
| AI | 0.00 | 0.00 | 1,08 | 0.00 | 0.00 | 0.00 | 4,49 | 0.00 | 0.00 | 0.00 | 0,95 | < 0,001 |
| PROX_MN | 0.00 | 0,09 | 7,29 | 0.00 | 0.00 | 0.00 | 75,02 | 0.00 | 0.00 | 0.00 | 0,97 | < 0,001 |
| IJI | 0,31 | 0,29 | 1,87 | 0,29 | 0.00 | 0,25 | 5,80 | 0,59 | 1,27 | 0.00 | 0,79 | < 0,001 |

381

382 **Table 3. and 4. Standard deviation and Regression analysis between landscape metrics values from real**
 383 **landscape and UD and CUS scenarios. All calculated Adjusted r^2 are significant (P < 0,001), and all values**
 384 **of their Prob (F) = < 0.001.**

385 4. Conclusion

386 The present work proposes a methodology for decision-making to address the lack of sustainability frameworks
387 to guide the planification of affordable housing programmes in Algiers. The proposed CA-based model has
388 proven its effectiveness in identifying suitable locations of future housing programs by focusing on the spatial
389 decision-behaviour process. The model shows how this process can be affected by measures related to residential
390 preferences (Dense Urban landscapes or Rural and Natural landscapes), human well-being (proximity to
391 transportation, everyday facilities and services and green spaces) and sustainable spatial development
392 (preservation of natural and agricultural areas). We simulated two scenarios, each corresponding to particular
393 residential preferences. They have both demonstrated aggregative and dispersed growth patterns simultaneously
394 meeting tradeoffs among the advantages and the challenges of urban densification and urban sprawl. Thus,
395 effectively promoting sustainable residential developments, since accessibility to everyday amenities is
396 enhanced, and natural areas remain contiguous, as evidenced by the results.

397 However, the limited number of cells identified by both simulations highlights the fact that Algiers is unlikely to
398 meet housing needs in a sustainable manner in a long-term perspective. In contrast, the construction of new
399 infrastructures (transportation and public amenities) as a part of the improvement of the living environment of
400 citizens in the surrounding areas, may provide new land opportunities for new housing projects.

401 Overall, the model is an effective tool to support the transition towards sustainable housing policies in Algiers. It
402 is flexible, and can be modified according to the available LULC categories. It can also be adjusted according to
403 local social and environmental demands. Furthermore, the model can be improved by embedding an agent-based
404 model and households individual housing choices input data. This will allow local authorities to regulate
405 residential dynamics in order to control the forms of land use changes and promote quality of life.

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