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► To cite this version:

Célia Hadj Ali, Damien Roy, Louisa Amireche, Jean-Philippe Antoni. Development of a cellular automata-based model approach for sustainable planning of affordable housing projects: an application case study in Algiers. Land Use Policy, 2023, 125, pp.106468. 10.1016/j.landusepol.2022.106468 . hal-03932492

HAL Id: hal-03932492

<https://hal.science/hal-03932492>

Submitted on 27 Feb 2023

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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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Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest

none.

Acknowledgements

This study has been jointly operated between VRGT Laboratory - University of Sciences and Technology Houari Boumediene and ThéMA Laboratory - French National Centre for Scientific Research (CNRS), University of Burgundy-Franche-Comté. The shapefiles and the results produced in this study will be made available for university scientists and students and for decision makers, in order to facilitate the transition towards sustainable public housing policies and sustainable land use developments in general.

Title

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

Abstract

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

Keywords

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

Highlights

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

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

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

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

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

1.Introduction

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

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

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

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

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

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

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

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

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

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

2.Methodology

2.1. Study area

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

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

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

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

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

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

3. Spatial designation of LU/LC categories. In order to locate and map LULC categories, we exploited the vector data provided by Open Street map (OSM). OSM vector data are commonly used to identify LU/LC categories (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

Table 1. Classification of LULC categories of Algiers.

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

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

2.3. Design of future residential developments

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

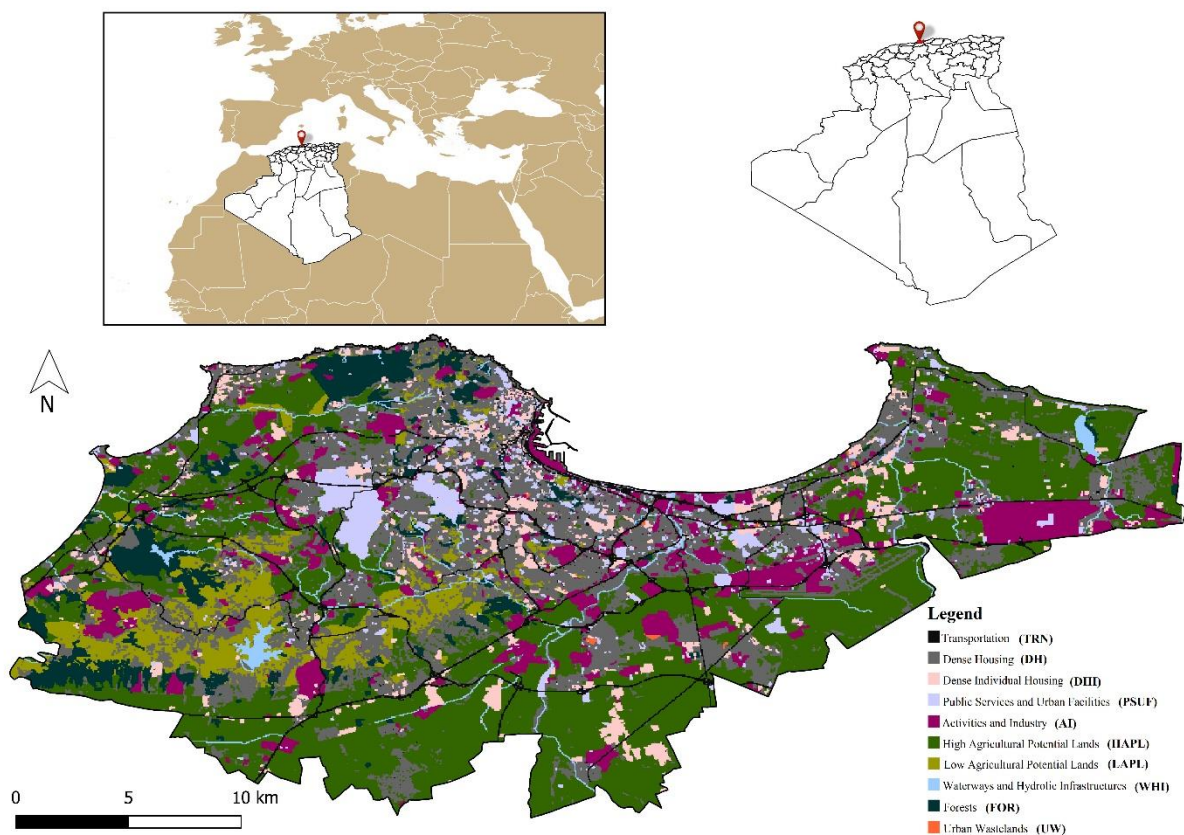


Fig 1. Study Area. Land Use/Land Cover and Political map of Algiers.

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

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

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

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

2.4. Simulation of future residential developments

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

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

Where,

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

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 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 radius r , at time t (Antoni et al., 2018).

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

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

- The proportion of DH and DIH must be over 30% in a radius of 200 meters.
- There must be at least 3 PSUF cells and 2 TRN cells in a radius of 1 km.
- There must be no AI cells in a radius of 1 km.
- There must be at least 1 AI cell in a radius of 2 km.
- There must be no HAPL, FOR and WHI cells in a radius of 1 km.
- There must be no SEA cells in a radius of 100 meters.

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

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

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

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

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

3. Results and discussion

3.1. Scenarios

Urban Densification Scenario (UD)

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

Constrained Urban Sprawl Scenario (CUS)

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

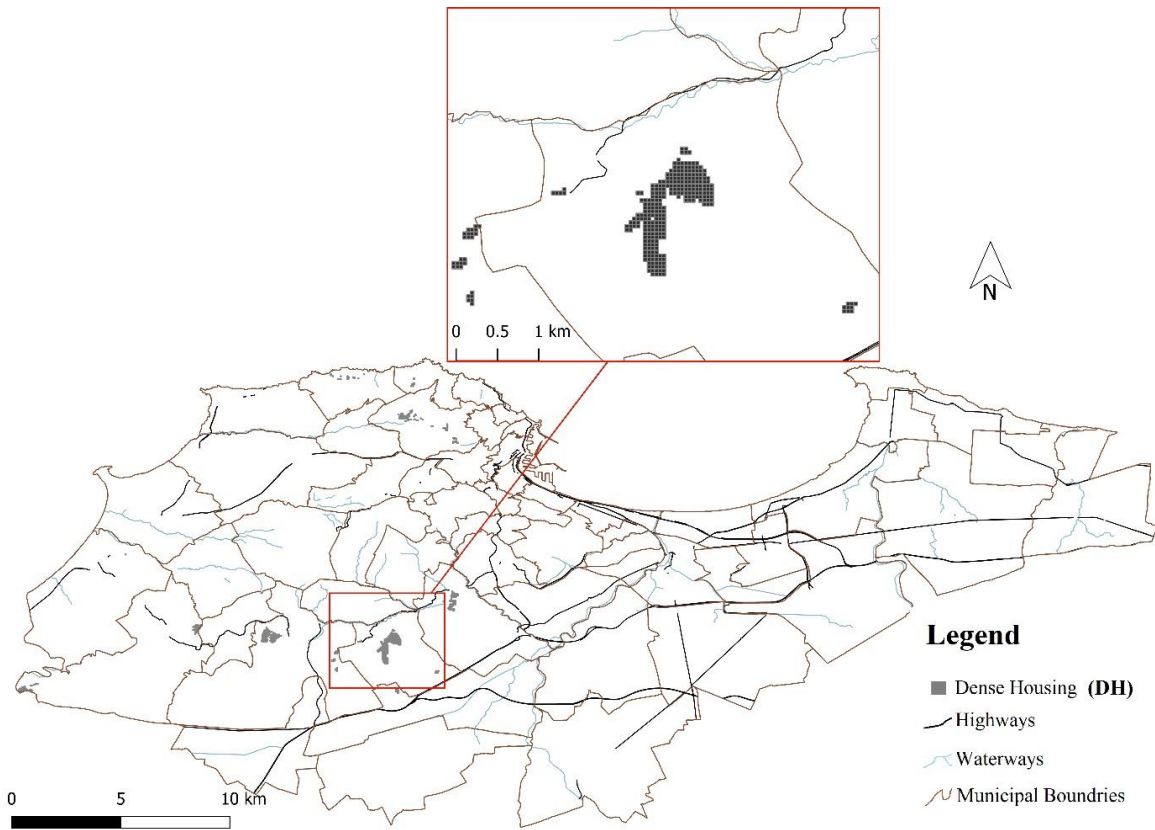


Fig 2. UD Scenario. Location of new Dense Housing (DH) cells according to UD simulation.

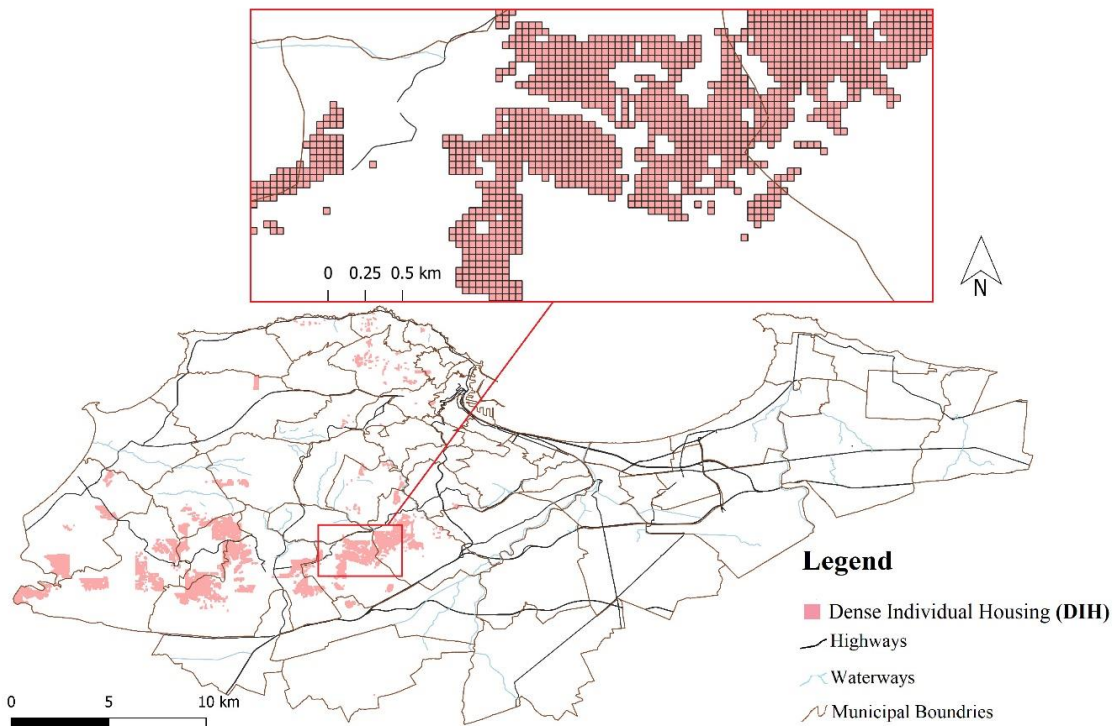


Fig 3. CUS Scenario. Location of new Dense Individual Housing (DIH) cells according to CUS simulation.

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

3.2.Landscape patterns analysis

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

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



— UD Scenario — CUS Scenario

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

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

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

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

3.3. CA performance

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

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

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

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

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

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

4. Conclusion

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

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

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

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