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The relevance of physical forces on land-use change and planning process

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This study analysed the importance of physical forces on land-use change, on the planning framework in a Portuguese periurban area. A temporal matrix showing the trajectories of land transformation was obtained. A multivariate redundancy analysis explored the importance of physical parameters on temporal and spatial land-use change. A content analysis on urban or municipal master plans was made framing the importance of physical parameters on the planning process. The results highlighted a consistent trajectory of profound land-use changes with distinctive trajectories, with increasingly complex patterns with a limited dependence on physical variables. The trajectories were more related to the planning framework, where political actors and planning managers seemed to be most important. A theoretical model balancing three main components – physical forces, actors, and land transformation (DFA-C model) is proposed, reflecting the informal relationships between physical parameters and actors during the planning process.

Keywords: land-use change; physical parameters; planning framework; RDA

1. Introduction

Urban growth and urban land-use competition have led to deep structural changes in the composition and dynamics of the landscape, affecting the fragile rural-urban interdependency. The generation of a new set of patterns reflecting a dynamic process of transition from rural and urban areas to different urban forms highlights a representation of changes which imply a complex definition of driving forces (Gallent and Shaw 2007; Pickett and Cadenasso 2009; Li, Zhou, and Ouyang 2013).

The growth of the human population and its migration from rural to urban areas has forced cities to expand into the surrounding environments (e.g. to cropland, pastures and forests) (Forman 1995; Verheye 2009; Lambin and Meyfroidt 2011; Kroll *et al.* 2012; Wu *et al.* 2013). This creates significant environmental impacts on ecosystem functioning, meaning that this interface has to be recognised as a special spatial unit for planning proposals (Kasanko *et al.* 2006; Freiria and Tavares 2011; Dutta 2012; Gómez-Baggethun, and Barton 2013).

Understanding the physical and human causes and consequences of land-use and land-cover change has become a challenge (Lambin, Geist, and Rindfuss 2006; Hersperger

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et al. 2010), with land-change models serving as tools to help interpret the functioning of the land-use system and to support land-use planning and policies (Verburg *et al.* 2004; van Delden *et al*. 2011).

The discussion about the driving forces behind land-use change has intensified in recent decades (Bastian and Bernhardt 1993; Claessens *et al.* 2009; Feranec *et al.* 2010), reflecting efforts to monitor urban expansion and temporal dynamics. As pointed out by Verburg *et al.* (2004), Diogo and Koomen (2012), and Li, Zhou, and Ouyang (2013), these forces can be summarised as natural, economic, socio-cultural, technological and political or based on planning policies. Complex interactions between environmental and socio-economic factors are known to be responsible for the characteristics of landscapes and constrain spatial distribution and evolution (Hietel, Waldhart, and Otte 2005, 2007; Long *et al*. 2007; Serra, Pons, and Sauri 2008). The debate also stresses the importance of land-use history and its relation to the planning framework, as pointed out by Long, Gub, and Han (2012); Parcerisas *et al*. (2012); and Tavares, Pato, and Magalhães (2012).

Land-use change analysis informs spatial planning activities, as mentioned from McHarg (1971) to Steiner (2011), where complex consideration of physical parameters can be observed in strategic planning, addressing environmental constraints and restrictions, for example, or the protection of natural resources, building capacity, and susceptibility to natural hazards (Mulder 1992; El May, Dlala, and Chemini, 2010; Culshaw and Price 2011). Geological units, hydrology, slope, hypsometry and aspect features are frequently considered factors affecting planning, land-use transformation or the definition of regulatory principles for the conservation of specific areas (Tavares and Soares 2002; Randolph, 2004). They are important forces in the dynamics of land-use transformation, namely on the approval of new urbanisation settlements, on the definition of regulatory regimes for ecological and agricultural protection, and hydrographic basin management. Recent studies have made a significant contribution to the general landscape model, but there is a need for finer scale studies on a local level to improve our understanding of the relationships between these forces and land use, to discriminate between the main driving forces, and to obtain information on the role of environmental or planning factors. Studying and understanding the dynamics of relationships of driving forces is crucially important in enabling us to anticipate future territorial trends and help planners, managers, and decision-makers address the relevant driving forces involved in land-use transformation, particularly in periurban areas subjected to anthropogenic pressures. It may also contribute towards developing strategies supported by territorial driving forces adjusted to local dynamics (Gant, Robinson, and Fazal 2011; Barrico *et al.* 2012; Vargo, Habeeb, and Stone 2013).

The study area is a small-scale hydrological basin formerly considered a periurban area of a medium-sized city – Coimbra, located in the Central region of Portugal – with a trajectory (temporal sequence of land-use change) of increasing urban pressure (Figure 1). The area has contrasting physical characteristics and reflects the influence of urban pressure and the results of a series of Master Plans for the municipality. Nowadays it is fully included in the Coimbra municipality and is a representative example of the city's evolution.

The main goals of our work were firstly to explore if physical variables were important forces on land-use change and secondly to analyse if they have been relevant in the planning process at a local level of governance. We characterised the patterns of land-use change in two key periods (1958–1979 and 1979–2007) and analysed the planning

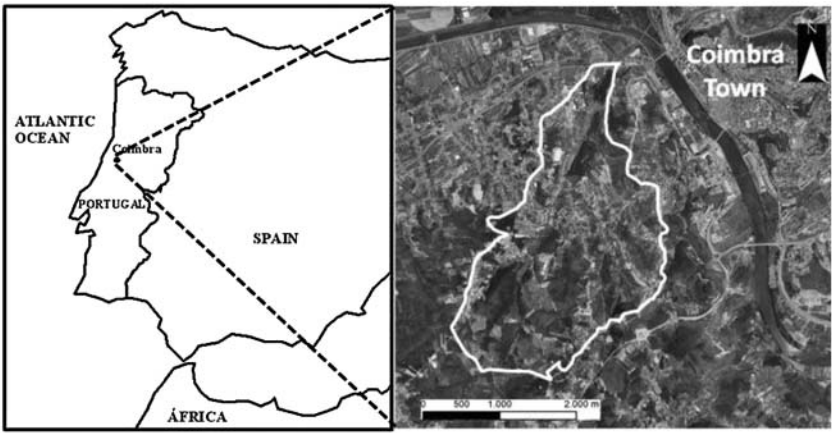

Figure 1. Location of the study area.

frameworks during this time to evaluate the importance of physical forces on the planning design and transformation of the periurban area.

2. Study area

The case study area is located on the left-hand bank of the River Mondego, about 6 km from the historic town of Coimbra, on the opposite side of the city main centre (Figure 1), but linked to it by important major roads/bridges and public transport facilities. The area is represented by a small-scale hydrological basin approximately 7 km^2 with S-N orientation that presents contrasting biogeophysical characteristics in a widening downstream valley and has approximately 26,700 inhabitants, according to the 2011 Census (INE 2012), with a contrasting local population density ranging from <25 inhabitants/km^2 to over 9900 inhabitants/km^2.

The water stream network reflects the lithological factors (carbonate or detritical subtract) and tectonic lineaments framing intermittent or ephemeral drainage. The hydrological input comes from annual precipitation, with average annual figures of close to 900 mm, associated with a wet Mediterranean climate in which more than 60% of the precipitation falls between November and March, producing an annual average of 138 rainy days and affecting land suitability classes.

The urban expansion of the old city did not affect the study area until the middle twentieth century, which remained as a surrounded area with agricultural lands and forests. Later, some informal neighbourhoods appear close to industrial plants and related to tertiary activities along the main roads and railway lines (Tavares 1999). Recent decades have seen a major increase in residential buildings, together with more health and educational facilities, including a central hospital and four Polytechnic schools and student residences, mostly since the 1990s. This development, complemented by a biotechnological industry, has led to the densification of the road network, including improvements to the main (IC2) route downstream of the watershed, a key road link in the municipality.

The area is thus characterised by profound changes in the dynamics of land use and occupation during the period 1958–2007, involving an increase in pattern complexity (Tavares, Pato, and Magalhães 2012) and reflected the effects of different master plans that were designed for Coimbra since 1940.

3. Methods

3.1. Characterisation of physical forces

This work includes the study of four physical parameters of the landscape (Figure 2): hypsometry, slope, aspect, and lithological units. These parameters have been identified as significant in several studies when correlated with land-use/land-cover changes (Pan *et al*. 1999; Fu *et al*. 2006; Reger, Otte, and Waldhardt 2007; Ye *et al*. 2011).

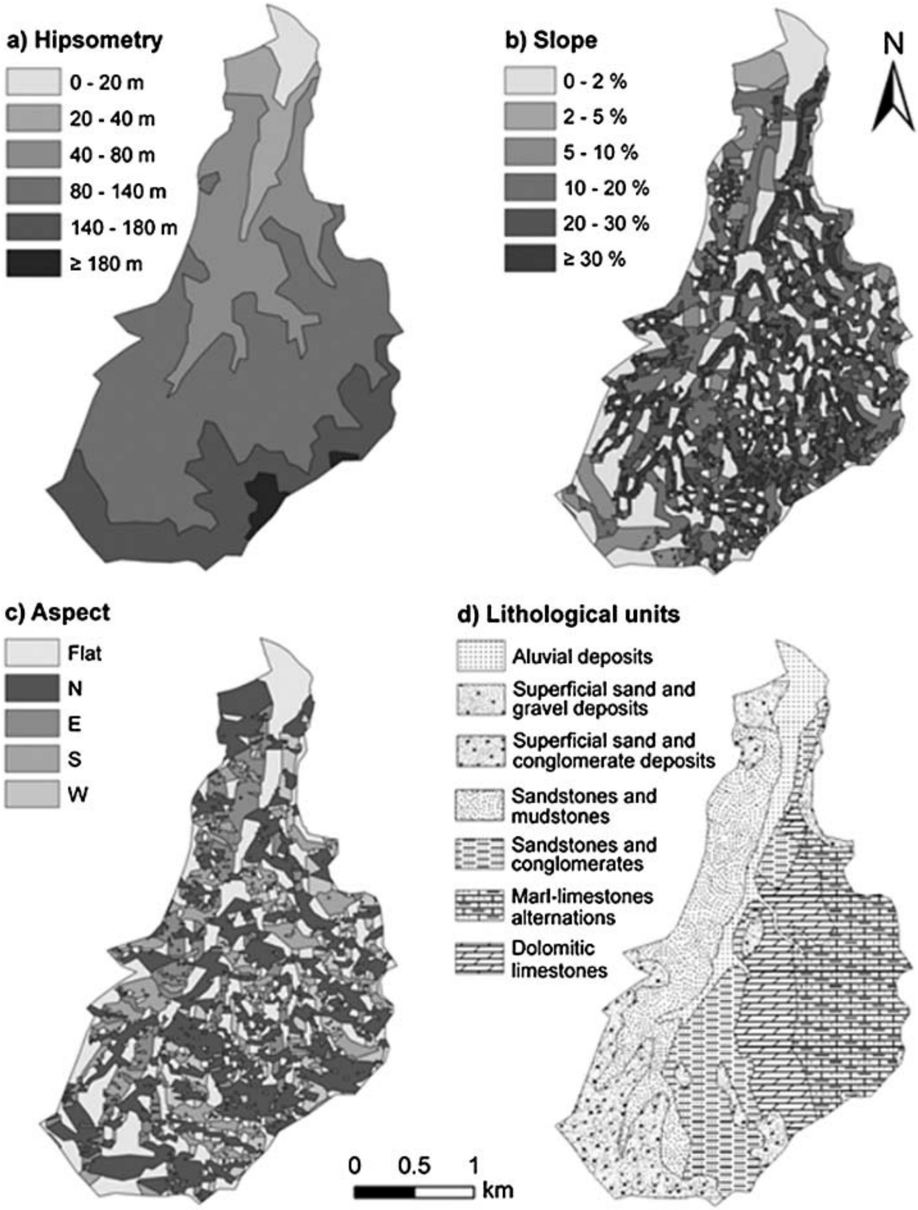

Figure 2. The physical parameters in the Covões catchment area: (a) hypsometry; (b) slope; (c) aspect; (d) lithological units.

The hypsometry, slope, and aspect maps were obtained from a digital topographic and cartographic information system provided by the Portuguese Army Geographic Institute (PAGI), series M888, on a scale of 1:25,000 (IGeoE 2002), and by spatial analysis. These parameters were then organised in different categories (Figure 2). The hypsometry and slope maps were classified into six categories (Figure 2(a) and 2(b)) according to the critical gradients for land-use and land-cover soil (Cox 1981), the aspect map (Figure 2(c)) included five categories, expressing the direction a slope faces, and seven lithological units were identified (Figure 2(d)) in accordance with the Geological Map from the National Institute of Engineering, Technology and Innovation, on a scale of scale 1:50,000 (INETI 2005).

The physical parameters' database, layer development, and attribute table construction were performed using ArcGIS® 9.1 software.

3.2. Patterns of land-use transformation

Land-use changes from 1958, 1979 and 2007 were interpreted from black and white aerial photographs on a scale of 1:26,000 and digital colour aerial photographs on an approximate scale of 1:10,000, provided by the PAGI and by the Portuguese Geographic Institute. The oldest images (1958 and 1979) had to be cross-referenced with other topographic representations and information from people who had witnessed the development of the area (the local population). Land-use mapping was also supported by fieldwork control whenever necessary.

Based on the Corine Land Cover data for 2006 (Caetano *et al*. 2009), land use was classified into four major types: (a) artificial surfaces (including the urban fabric, industrial, commercial and transport units, mine, dump and construction sites and artificial and non-agricultural vegetated areas); (b) agricultural areas (including arable land, permanent crops, pastures and heterogeneous agricultural areas); (c) forests (containing broad-leaved coniferous and mixed forest, and scrub and/or herbaceous vegetation associations); (d) open spaces with little or no vegetation (consisting of bare rocks, sparsely vegetated areas and burnt areas). The selection of these land-use types also followed a previous work (Tavares, Pato, and Magalhães 2012) where it was referenced as a general land use that followed the periurbanisation processes.

By overlaying 1958, 1979 and 2007 land-use data, a temporal matrix showing the trajectories of the transformations was obtained, which measured the rate of changes in land use occurring during each period. The layers of land use in 1958, 1979 and 2007 and the 1958−1979 and 1979−2007 trajectories were then used for subsequent spatial and statistical analysis. The spatial-temporal database was also developed using ArcGIS® 9.1 software.

3.3. Multivariate analysis

Redundancy analysis (RDA), the constrained multivariate linear response method, was then carried out to explore the relationships between temporal and spatial land-use distribution (species, in statistical terminology) and the multiple environmental measurements (environment, in statistical terminology). Monte Carlo permutation tests, involving 499 permutations, were carried out to estimate the significance of the species−environment relationship. Both the RDA and Monte Carlo permutation tests were performed using the software CANOCO® version 4.5 (Ter Braak and Smilauer 2002). Land-use distributions were forced into linear combination with the environmental variables using direct ordination techniques. The strength of the relationships between the different land-use data sets or the land-use transformation data set and the explanatory variables were assessed according to the percentage of the constrained eigenvalue of the total variance (trace).

In order to perform the RDA, all the parameters and combinations of parameters were coded on the basis of the methodology presented by Fu *et al*. (2006), using ArcGis 9.1®. The three temporal land-use spatial distributions (1958, 1979 and 2007), two transformation matrices (1958–1979, 1979–2007) and degree of slope, aspect, hypsometry, and lithology type matrices were generated by sampling grid cells in the river basin area, with a raster resolution of 25 × 25 m per cell. All the matrices resulted from the P × N combination, in which P was the number of classes attributed to each physical parameter and item of land-use data and N was the number of cells. In this study, N was 11,262, and P was 4, 6, 6, 5, and 7 for the land use, hypsometry, slope, aspect, and lithology matrices, respectively.

3.4. The planning framework: 1948–2013

Five plans for the municipality of Coimbra were analysed, corresponding to the documents from 1948, 1959, 1974, 1993, and 2013. The first one was a project for the urbanisation, enhancement and extension of the city of Coimbra – the historical city and rural boundaries; in 1959 a Master Plan for urban city regulation was elaborated – the historical city and surrounding urban expansion areas; another Master Plan for the urbanisation of the city of Coimbra was created in the middle 1970s – the municipal area with a focus on urban areas; in 1993, a Municipal Master Plan, focusing on urban consolidation and infrastructures, was produced (in 1984 previous studies were presented); more recently, a Revised Municipal Master Plan is pending approval.

For each of those plans, a content analysis (GAO 1996; Elo and Kyngäs 2008) was produced focused on the planning documents and associated reports. We also analysed the thematic and planning cartography used in each plan. In total, a frame of 12 reports and a set of over 40 cartographic representations were examined (e.g. Figure 3 represents some extracts from the analysed maps).

The content analysis included: (1) a preparation phase, (2) an organisation phase which comprised the design of a structured analysis matrix and the categorisation of concepts, and (3) an ending phase of conceptual mapping of categories. All selected sub-categories corresponded to 108 concepts, which were then grouped in seven generic categories specifically described for the study area whenever possible (general objectives of the plan, aesthetic values, planning tools, physical forces considered – with or without cartographic representation, type of physical maps [both base and thematic maps], scale of the maps, and actors involved in the planning process – internal municipal departments, external planners, external thematic contributions). This enabled us to assess the importance of the different physical parameters in each planning framework and how they may have affected land-use changes, and the range of actors and their cultural and political contexts.

4. Results

4.1. Land-use and transformation patterns

An analysis of land-use patterns in two periods (1958–1979 and 1979–2007) reveals a huge decrease in areas used for agriculture by almost 42% from 1958 to 2007 (Table 1).

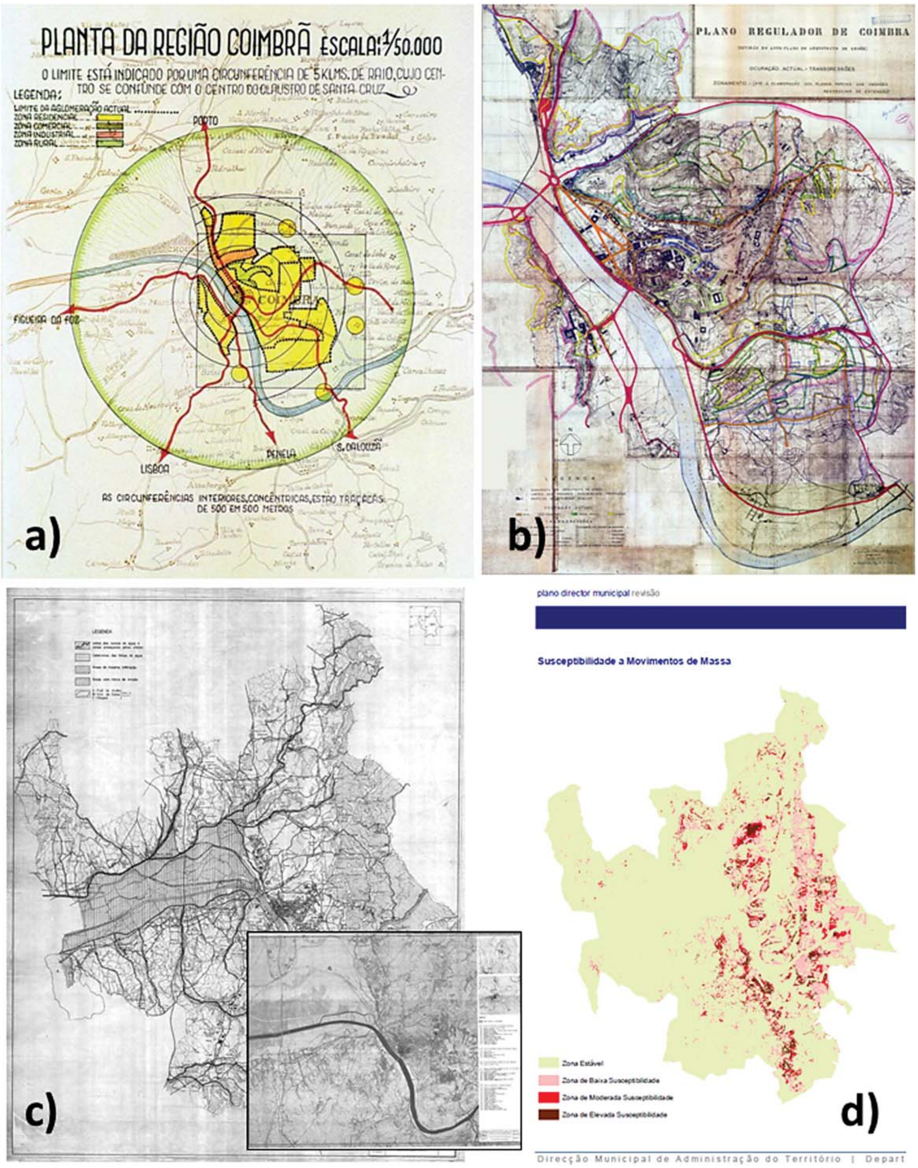

Figure 3. Some examples of maps used to analyse the thematic and planning cartography: (a) 1948 zoning city plan, 1/50000; (b) 1959 rational city plan for urban expansion and regularisation of illegal settlements, 1/5000; (c) physical constraints for the 1993 regulatory master plan – global view (1/25000) and extract for the study area (1/10000); (d) thematic map with mass movements susceptibility for the 2012 master plan, 1/25000. (See online colour version for full interpretation.)

The 1979 analysis showed the transformation of agricultural areas to forest areas, involving a reduction in olive grove spaces, whilst in 2007 the change to artificial areas revealed a step-by-step transformation (Pato, Tavares, and Magalhães 2008).

Conversely, in 1979 artificial surfaces were 1.8 times higher than in 1958, rising to 3.7 in 2007. In the 1950s, artificial surfaces were mainly restricted to a discontinuous urban

Table 1. The proportion of land-use types in the study area in 1958, 1979, and 2007.

	1958		1979		2007	
Land use/year	km^2	(%)	km^2	(%)	km^2	(%)
Artificial surfaces	0.7	9.2	1.2	17.0	2.4	34.3
Agricultural areas	3.6	50.8	2.0	28.4	0.6	8.9
Forests	2.8	40.0	3.7	53.0	2.8	40.4
Open spaces with little or no vegetation	_	_	0.1	1.6	1.2	16.5

fabric along the major roads, but were later extended to other regions in the basin. This expansion was particularly significant in the east of the hydrographic basin close to the historic town of Coimbra, where good, accessible road networks were available.

The temporal and spatial land-use trajectories in the periods 1958–1979 and 1979–2007 (Figure 4) highlighted the dominant dynamic changes during the study period, namely the conversion of agricultural areas to forest land and artificial surfaces (Table 2), which was more evident in the upstream basin (Figure 4).

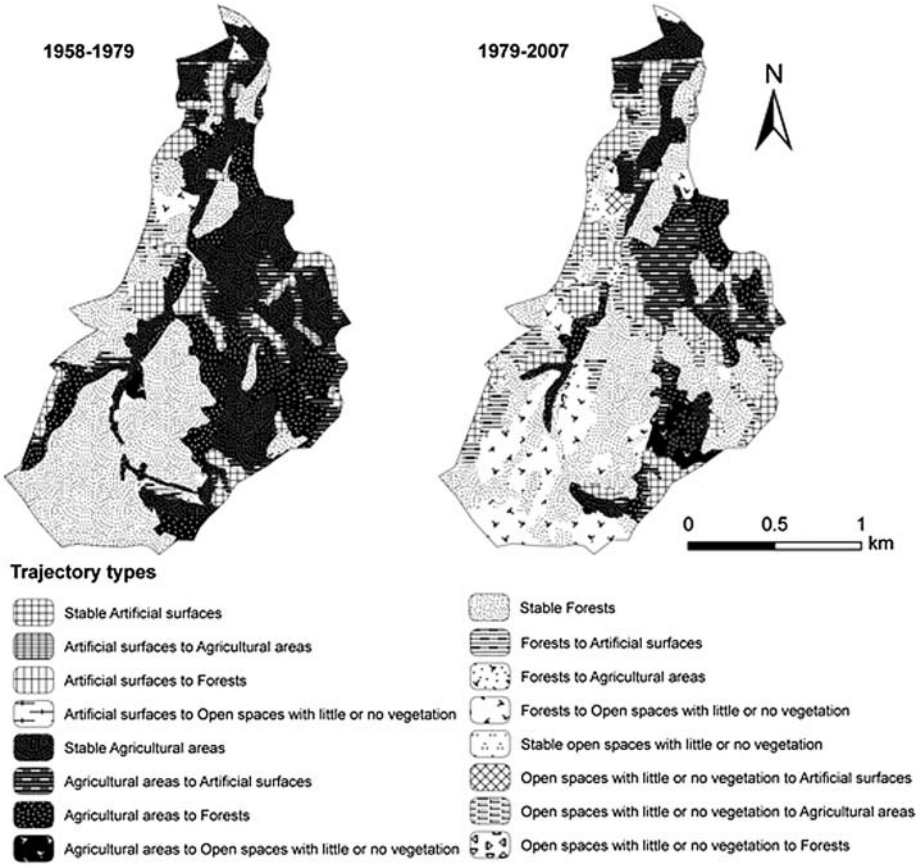

Figure 4. Land-use trajectory types between 1958, 1979, and 2007.

Table 2. Land-use transformation in the Covões catchment area.

Land use transformation	Artificial surfaces	Agricultural areas	Forests	Open spaces with little or no vegetation
			%	
1958-1979				
Artificial surfaces	87.0	7.0	6.0	_
Agricultural areas	13.3	53.3	32.6	0.9
Forests	5.1	2.0	89.9	3.0
1979-2007				
Artificial surfaces	95.9	0.7	2.1	1.3
Agricultural areas	34.8	27.0	31.7	6.5
Forests	14.1	1.6	57.9	26.0
1958-2007				
Artificial surfaces	91.1	1.1	5.3	2.4
Agricultural areas	39.1	15.8	37.5	7.6
Forests	15.0	1.9	52.2	31.0

Although the area allocated to forest land has remained the same over this 50-year period (Table 2), considerable changes have taken place with regard to occupation. In 1958, these areas were essentially covered with native species such as oaks (*Quercus* sp.), which have gradually been replaced by coniferous forest (*Pinus pinaster* L.) in the west and by broad-leaved forest (*Eucaliptus globulus* L.) in the upstream basin. These transformations were also associated with modifications to the size of the agricultural and forest areas. In fact, it can be observed that the decrease in agricultural use was followed by an increase in the continuity of forests. This process was particularly visible in the eastern and upstream areas of the basin (Figure 4). The changes to forest occupation brought serious environmental risks to the area, which suffered two major wildfires (in 1994 and 2004), and also increased erosion in the form of rills and gullies, or affected critical hydraulic flow points.

The transformation trajectory showed the stabilisation of forest occupation areas, especially in the upstream basin and in some remaining areas within artificial surfaces (Figure 4). The analysis also revealed an expansion in forest areas between 1958 and 1979 and the significant process of transforming forests into open spaces with little or no vegetation (in upstream areas of the basin) between 1979 and 2007 (Figure 4), indicative of the potential development of new land uses/occupations and economic activities. In 1958, the existing infrastructures and facilities were almost always associated with green spaces in the surrounding area (e.g. parks, gardens), which were gradually disappearing, replaced by other types of uses. The Census results (2011) at municipal level also revealed a sharp decline in activities related to the primary economic sector (agriculture, forestry), amounting to 57% in the period 1950−1970 and 91% in the period 1970−2011, together with an 81% and 170% increase in new facilities.

The significant development in the continuous urban fabric, predominant in the middle of the basin, was related to an increase of approximately 54% in the resident population of the parishes in the study area from 1960 to 1981 and approximately 11% in the period 1980-2011, whereas the average for the municipality of Coimbra was 31% and 3%, respectively. This trend was accompanied by an increase in new buildings (22% and 38%), and accommodation numbers (INE 1960, 1981, 2012).

4.2. Relationships between physical parameters and land use using RDA

The relationships between spatial and temporal land-use patterns and physical variables parameters in 1958, 1979 and 2007 were assessed using RDA. Correlation coefficients of physical parameters with the first two redundancy axes allowed us to know which variables were the most important to explain each axis (Table 3). According to the Monte Carlo permutation tests, all the environmental variables shown in the ordination diagrams (Figure 5) were significantly correlated with RDA axes (p = 0.002), although the correlation coefficients were sometimes small (Table 3).

In 1958, physical variables explained 28.9% of the variance in land-use data (Figure 5(a)) (p = 0.002). This decreased to 18.3% and 12.3% in 1979 and 2007, respectively (Figure 5(b) and 5(c)) (p = 0.002). Analysis of the two temporal trajectories (Figure 5(d) and 5(e) revealed a similar pattern, with the correlation value falling from 17.6% in 1959−1979 to 11.9% in 1979−2007 (p = 0.002). Amongst the explanatory variables, lithology (l) and hypsometry (h) were the parameters that contributed most to the variation in land-use types and transformation in the earlier decades. After the 1980s, slope appears to restrict these changes more (Table 3).

While in 1958 the RDA biplot showed that artificial areas (u1) were negatively related to hypsometry (h) (Figure 5(a)), in the following decades a change in this pattern occurred. These areas began to occupy other lithological units and became more related to aspect classes a3 (east) and a4 (south) (Figure 5(b) and 5(c)). Agricultural areas (u2) initially were more closely related to medium hypsometry, marl-limestone alternations (l6), and dolomitic limestone (l7) (Figure 5(a)). In more recent years, agricultural land became more correlated to flat areas (a1) occupying other lithological units as well (Figure 5(b) and 5(c)). Forests (u3) correlated more positively with superficial sand and conglomerate deposits (l3) during the study period and were less related with hypsometry and slope (Figure 5(a)−(c)). In 2007, a new land-use type emerged − open spaces with little or no vegetation (u4)− which was positively related to hypsometry (h) and slope (s), and appear closer together to aspect classes a2 (north) and a5 (west) (Figure 5(c)).

The ordination diagram for the relationship between physical environmental variables and land-use trajectories revealed interesting dynamics for the main transformations that occurred in the periods 1958−1979 and 1979−2007 (Figure 5(d) and 5(e)). In the first phase, the transformation of the areas initially occupied by agriculture into artificial areas was more significant (T3), occurring primarily on gentle slopes or flat areas (Figure 5(d)). Another clear trend was the conversion of forest to agricultural land (T1), which, occurred mainly in the lithology classes l3 (superficial sand and conglomerate deposits) and l5 (sandstones and conglomerates). Weak relationships were found for the other transformation patterns (Figure 5(d)).

Strong relationships between physical variables and land-use transformations can be seen in the land-use classes that remained stable during the period 1979−2007 (Figure 5(e)). Agricultural areas that maintained their function were found in lower areas with gentle slopes. Stable artificial areas (T4) can be seen in the south (a4) and east (a3), mainly in l4 (sandstone and mudstone) and l6 (marl-limestone alternation) lithologies.

4.3. Planning framework vs. physical forces

The selected seven categories from the five plans (explained in point 3.4) are summarised in Table 4. This conceptual mapping of categories enabled the understanding of how

Table 3. Correlations of physical parameters with the first and second redundancy axes of the ordination analysis.

	1958		1979		2007		1958–1979		1979–2007	
Physical variables	Axis I	Axis II	Axis I	Axis II	Axis I	Axis II	Axis I	Axis II	Axis I	Axis II
h: Hypsometry	–0.126	–0.248	–0.285	–0.016	–0.319	–0.116	–0.272	–0.153	–0.122	0.011
s: Slope	0.018	–0.129	–0.098	0.024	–0.157	–0.039	–0.049	–0.086	–0.310	0.186
a: Aspect										
a1: Flat	–0.015	0.090	0.067	0.031	0.079	0.068	0.038	0.055	0.067	0.031
a2: North	–0.016	–0.050	–0.078	–0.005	–0.098	–0.007	–0.066	–0.037	–0.078	–0.005
a3: East	–0.047	0.038	–0.012	–0.045	0.054	–0.031	–0.025	0.012	–0.012	–0.045
a4: South	0.014	–0.051	0.003	–0.019	0.020	–0.051	0.009	–0.009	0.003	–0.019
a5: West	0.081	–0.041	0.030	0.029	–0.046	–0.004	0.061	–0.028	0.030	0.029
l: Lythological units										
l1: Alluvial deposits	0.096	0.225	0.199	0.094	0.210	0.223	0.204	0.092	0.199	0.094
l2: Superficial sand and gravel deposits	0.097	0.012	0.139	–0.005	0.150	0.087	0.113	0.083	0.139	–0.005
l3: Superficial sand and conglomerate deposits	–0.285	0.004	–0.260	–0.004	–0.141	–0.004	–0.326	0.021	–0.260	–0.004
l4: Sandstones and mudstones	–0.234	0.075	–0.098	–0.146	0.101	–0.096	–0.160	0.021	–0.098	–0.146
l5: Sandstones and conglomerates	–0.228	–0.102	–0.227	0.101	–0.222	0.170	–0.265	0.007	–0.227	0.101
l6: Marl-limestone alternations	0.396	–0.064	0.227	–0.057	0.002	–0.112	0.338	–0.124	0.227	–0.057
l7: Dolomitic limestones	0.248	–0.081	0.165	0.059	0.053	–0.140	0.227	–0.011	0.165	0.059

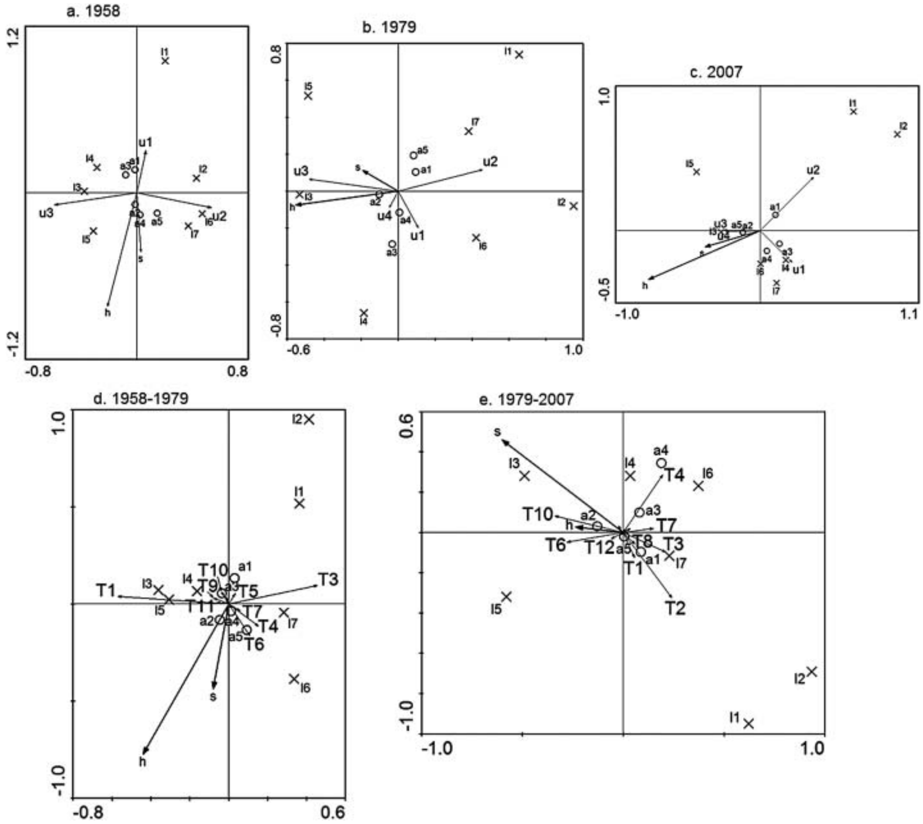

Figure 5. RDA ordination of land-use data set in 1958 (a), 1979 (b), 2007 (c), and trajectory types 1958–1979 (d), 1979–2007 (e). Horizontal axes correspond to the first redundancy axis and vertical axes correspond to the second redundancy axis, which explained most of percentage of variation in the data. h – hypsometry; s – slope; a – aspect: a1–flat, a2 – north, a3 – east, a4 – south, a5 – west; l – lithology: l1 – alluvial deposits, l2 – superficial sand and gravel deposits, l3 – superficial sand and conglomerate deposits, l4 – sandstones and mudstones, l5 – sandstones and conglomerates, l6 – marl-limestone alternations, l7 – dolomitic limestones; u1 – artificial surfaces, u2 – agricultural areas, u3 – forests, u4 – open spaces with little or no vegetation; T – Trajectory types: T1 – forests to agricultural areas, T2 – stable agricultural areas, T3 – agricultural areas to artificial surfaces, T4 – stable artificial surfaces, T5 – forests to artificial surfaces, T6 – stable forests, T7 – agricultural areas to forests, T8 – artificial surfaces to agricultural areas, T9 – artificial surfaces to forests, T10 – forests to open spaces with little or no vegetation, T11 – agricultural areas to open spaces with little or no vegetation, T12 – artificial surfaces to open spaces with little or no vegetation.

planners used physical forces in the study area's planning and how they were considered in the planning restrictions. The planning evolved according to different political and social contexts, as well as through different planning frameworks and aesthetic values, which may be described as positive values, with tangible and intangible dimensions, representing the political, societal, and cultural contexts (Durham 1958; Duncan and Duncan 2004), and subsequently for municipal planning.

The sequence and values of the planning framework and the relation with the artificial surface areas representativeness at the point of analysis (Figure 6), showed that, regardless of the type and characteristics of the plans, there was a doubling of artificialised surfaces.

Table 4. General characteristics of the Coimbra plans.

Date of approval	Name	Political and social context	General planning objective and aesthetic values	Approach to study area	Physical forces considered
1948	Project for urbanisation, enhancement, and extension of the city of Coimbra	Plans for urban image of city under authoritarian political regime	Garden city and zoning principles	Mainly included in the rural circle, with a small workers' neighbourhood	Slope, Aspect, Water stream proximity.
1959	Master Plan for urban city regulation		Urban expansion and regularisation of illegal housing settlements, based on rational planning of neighbourhood units. Units from rational planning model	Residential areas along major roads and urban consolidation from satellite villages	Flat areas, Aspect, Water stream proximity, Flood prone areas.
1974	Master Plan for the urbanisation of the city of Coimbra	Comprehensive municipal plan under transitional political regime	Urban extension based on urban cells, applying a zoning model using rational comprehensive planning	Urban consolidation	Slope, Aspect, Hydrography, Flood prone areas, Soils, Green areas.
1993	Municipal Master Plan	Municipal regulatory plan under democratic political regime	Regulation of urban sprawl, as a new framework for urbanism, supported by a constraints map and city urban planning map	Urban consolidation, road infrastructure and planning for facilities	Hypsometry, Slope, Aspect, Geology, Hydrogeology, Soil capabilities.
2012 (proposal)	Municipal Master Plan (revision)	Strategic municipal plan under democratic political regime	Urban consolidation, supported by a constraints map and city urban planning map, using an open, flexible territorial approach	Urban consolidation, design of industrial nucleus, road infrastructure and planning for access to facilities	Slope and Aspect, Geology and Hydrogeology, Soil capabilities, Flood, mass movement and wildfire susceptibility.

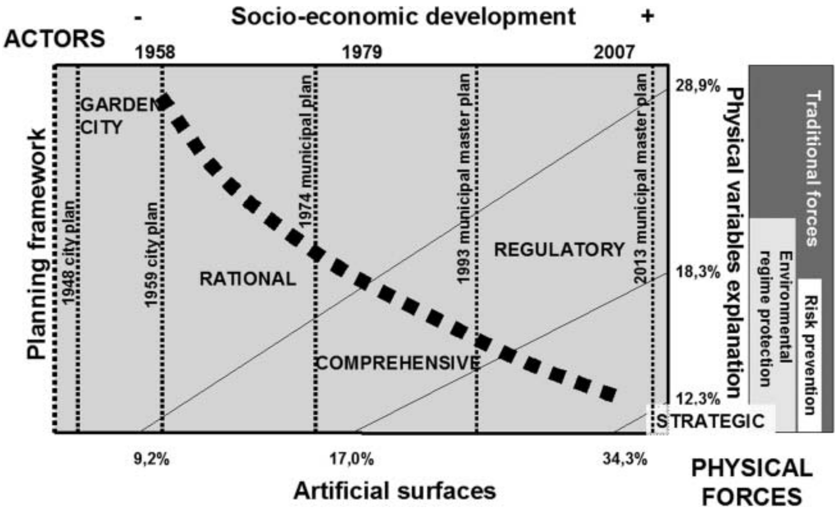

Figure 6. The evolution of land use in the study area as a function of physical variables and planning processes.

This analysis also emphasised the constant presence of physical factors at the time of planning and the relevance of morphological and hydrological forces. Taking these parameters into consideration, this allowed limits for new urban areas and building capacity to be defined. Hydrography was more relevant in the older plans (1948 and 1959), whereas features related to hazardous processes have become more important in later plans, despite the high historical local impact of floods, slope mass movements, and forest-urban interface fires (Tavares and Cunha 2002/04). The geology and geotechnical suitability of materials were referenced, but only the final plan contains an adequate municipal scale map which regulates the exploitation of mineral resources, aquifer recharge capacity and foundation and excavation capacity. In the oldest plans, physical parameters were identified as forces that could protect ecological or agricultural assets. However, this is not the case in the more recent plans, since they contain supplementary protective regulations, clearly focusing on the management of natural hazards.

We may observe from the older plans that traditional forces were expressed (e.g. slope, geology, hydrology) (Figure 6). In more recent municipal plans we may also perceive the presence of rules for environmental (agriculture and ecological) protection and the production of several hazard maps. Surprisingly, the graphic also expressed the decrease in the physical variables' explanation on land-use change, in spite of the inclusion of new variables and thematic physical maps (Figure 6).

Whereas the first two plans (1948 and 1959) were supported by a centralised authoritarian political regime, the 1974 plan reflected the political opening up of the late 1960s and the economic and social progress that led to the 1974 Revolution. A transition can be observed from urban plans and policies, based on image and centred on the city, to comprehensive rational plans incorporating urban pressure and new standards for quality of life, within the framework of these regional planning units. The social/political/military revolution and the return of hundreds of thousands of people from the former Portuguese overseas colonies, together with the rural-urban migration, led to great urban pressure, reflected in a timeline with a lack of planning and building regulation and the emergence of a new school of planners.

Urban pressure and the need to curb illegal construction, together with the growing focus on measures to protect natural assets, created a regulatory framework that included a system for ecological and agricultural protection and regulations for urban buildings, which underpinned the design of the 1993 Master Plan. The growth of infrastructures, particularly after Portugal joined the European Community, together with economic development and an improvement in general living standards, as well as the establishment of a top-down regulatory framework for planning, led to new planning options that focused on strategic options and urban requalification and are, at the moment, awaiting for approval.

5. Discussion

The dynamics of land-use change during the periods 1958–1979 and 1979–2007 demonstrated profound changes with increasingly complex patterns, when analysing land trajectory types and the rearrangement of patchy areas, but distinctive trajectories for different sectors. The results highlight a consistent trajectory of land-use change involving the systematic conversion of agricultural areas to forest land and artificial surfaces. Urban growth was achieved mainly by reclaiming areas used for agriculture, which can be explained by the fact that these soils were more suitable for urbanisation. Similar observations were also reported by Kasanko *et al*. (2006), Serra, Pons, and Sauri (2008), and Shi *et al*. (2012), or even for the national context (Caetano *et al*. 2009; Petrov, Lavalle, and Kasanko 2009; Araya and Cabral 2010; de Noronha Vaz *et al*. 2012). Another important finding was the pattern of forest trajectory, which indicated that significant conversions may be expected in the near future, initially to open spaces with little or no vegetation, then gradually to artificial surfaces, unless regulatory principles focussing on conservation of the ecosystem or hazard mitigation are implemented.

Mulder (1992), Malczewski (2004), and Culshaw and Price (2011) emphasise physical variables as triggering factors for suitable urban occupation. In this case study the RDA proved to be useful in determining how physical variables affected land use and whether they were decisive factors in the artificialisation process. Hypsometry and lithology were the variables which most explained land-use change, followed by slope, which became a critical technical and economic factor for urbanisation. The data illustrated that the trajectory of land use, in particular the artificialisation of the study area, had a limited dependence on physical variables. However, these parameters affected the technical options for occupation, particularly using classes which are more favourable and suitable for urbanisation (in geotechnical and economic terms). This is particularly relevant in technical building foundation, in slope stability, and in the construction of sewage and water pipes.

This finding showed that the land-use trajectory was closely related to the prior use, although this was not assumed at the time of planning. Despite this, it can be observed that the influence of physical factors on land transformation was weak. This was true for any of the plans analysed here regardless of whether they were predominantly image, functional, or regulatory plans, since physical variables never explained more that 28.9% of the transformations. Based on the RDA results, it seemed that land-use change depended on other factors, which may be economic, socio-cultural, technological, or political, as noted by Hietel, Waldhardt, and Otte (2004), Parcerisas *et al*. (2012), and Tavares, Pato, and Magalhães (2012).

The trends in the trajectories observed in land use and occupation can be understood in relation to the planning framework adopted for the area. De Gröer, the head of urban planning in Coimbra in 1948, proposed a 5 km rural circle surrounding the urban area to maintain agricultural land use, which included the study area. These planning objectives and values were contested in the next decade, leading to the redesign of land occupation to include urban settlements in the 1959 plan, which became more pronounced in the comprehensive 1974 Master Plan. After 1983, the implementation of restrictive measures for land-use transformation in areas with ecological and agricultural assets, in conjunction with a more extensive regulatory planning framework, promoted the artificialisation process in periurban areas, increasing them to twice in the studied basin (17%−34.3%), corresponding to a significant development in the amount of constructions. These combined forces, together with aesthetic planning values, may explain to some extent, the general decrease in importance of the physical variables in land transformation obtained from the RDA, supporting the demand for available areas for urbanisation which pushed artificialisation into steeper areas. Indirectly, the importance of physical variables also declined due to construction technical advances as well as the trend to a more consolidated urban fabric.

According to the methodological approach of Hersperger *et al*. 2010 for evaluating the relationships between physical parameters and the planning actors involved in land-use changes in the study area, the planning process follows a DFA-C Model (Driving Force-Actor-Land Change). The conceptual approach of this model addresses interrelations between three main components – driving forces, actors, and land transformation. A DFA-C model may be recognised in which the driving forces were represented by the physical parameters and the actors were represented by the planners. There was no specific focus on individual components, but rather on the interplay between driving forces and actors. This interpretation of actors, who may be represented by individuals, agencies, and institutions, reflect the whole range of organisational scales, supported by the work of Bürgi, Hersperger, and Schneeberger (2004).

These results also clearly showed that the increase in artificial surfaces during the two periods of analysis was accompanied by a decrease in the influence of physical variables on land transformation. The reason for this development was mainly due to: (1) the onset of factors conditioning land use emerged from environmental conservation regimes and hazard prevention, overlapping the traditional role of physical factors considered in planning; and (2) the fact that municipal plans with regulatory characteristics do not reduce the rate of artificialisation, and use less and less in their framework the physical variables, unless acquired from thematic cartography.

This work showed that interrelationships between physical factors and actors during the planning process existed. However, this does not explain the decrease in their importance (RDA) and, at the same time, continue to be considered in thematic and regulatory cartography. The planning framework evolved from plans based on zoning which followed specific regulations considering the safeguard of historic, picturesque, architectural, and aesthetic characteristics to a planning marked by regulations targeting landowners and landholders (Gonçalves 2008). This evolution was framed by a socio-economic development which supported the strengthening of public interest, namely introducing regulatory instruments for land-use changes as well as for the conservation of environmental resources. With the comprehensive and rational planning, the role of managers was incremented and supported the inclusion of new actors such as risk and civil protection managers, representing a new framework of community interests. This broad approach and involvement of actors supported the sequent strategic framework for municipal planning.

Answering to the initial research questions proposed about the importance of physical forces we may now observe that the presence of physical parameters are reflected on the transformation of the land and in the planning framework, however, with a limited expression. Politicians and planning managers involved in the planning process are important actors for land-use changes regardless of the characteristics and aesthetic values of the plans.

The case study showed how the planning processes in medium-sized cities can be only slightly marked by physical variables, although these are present in the land-use and occupation constraints, and influence the planning thematic cartography. This finding is particularly relevant in these areas given the accelerated processes of land-use change in the form of active disturbance (Toy and Hadley 1987; Aguilera, Valenzuela, and Botequilha-Leitãoet 2011; Franck-Néel *et al.* 2015). This also highlights how different characteristics of the planning framework determine the use of physical variables in planning, especially in areas with periurbanisation processes. These areas present, in general, high territorial vulnerability where the decision to use the physical variables in the planning framework must be a deep cause for reflection and discussion for managers.

The protection of periurban areas, together with other development models, such as multifunctional agriculture (also in combination with urban land use), risk reduction, or the identification of suitable areas for development (based on the physical factors), could be sustainable solutions to contain the urban expansion phenomenon and to maintain vital ecosystem services (Bragagnolo and Geneletti 2014). It is also considered that land-use histories and their relation to the planning framework influence urban expansion processes.

This study demonstrated the complex interactions that existed between environmental and socio-economic factors on land-use change, reinforcing the reasons identified by Verburg *et al.* (2004), Claessens *et al.* (2009), and Li, Zhou, and Ouyang (2013), leading us to rethink sustainability of local urban settlements (Turcu 2014). For future sustainable development and prevention of hazardous events it is important to take the following into account (1) the design and implementation of a Master Plan must consider the physical parameters of the landscape, which are essential in producing thematic mapping and support land-use restrictions and constraints, (2) given the role of actors in the transformation processes, measures should be implemented that effectively involve different actors and levels of expertise in the planning process.

6. Conclusions

The holistic assessment carried out in this work, based on a systematic examination of land-use change over 50 years measured by RDA, together with plan content analysis, showed that interrelationships between physical parameters and actors during the planning process occurred at the local level of governance. This also helped to interpret the real importance of physical parameters in land-use change. Despite being taken into account in the planning framework, they showed little relevance in explaining the transformation of the periurban area that took place between 1958 and 2007. A more clear understanding of the systematic representation of the different driving forces affecting land-use change was achieved, opening up, therefore, new forms of analysis which may potentially be applied to other territorial contexts, in particular periurban areas, with a high incidence of land-use change, involving complex interactions and multiple relationships between factors.

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References

Aguilera, Francisco, Luis Valenzuela, and André Botequilha-Leitão. 2011. “Landscape Metrics in the Analysis of Urban Land Use Patterns: A Case Study in a Spanish Metropolitan Area.” *Landscape and Urban Planning* 99 (3): 226–238.

Araya, Yikalo, and Pedro Cabral. 2010. “Analysis and Modeling of Urban Land Cover Change in Setúbal and Sesimbra, Portugal.” *Remote Sensing* 2 (6): 1549–1563.

Barrico, Lurdes, Anabela M. Azul, M. Cristina Morais, António P. Coutinho, Helena Freitas, and Paula Castro. 2012. “Biodiversity in Urban Ecosystems: Plants and Macromycetes as Indicators For Conservation.” *Landscape and Urban Planning* 106: 88–102. doi:10.1016/j.landurbplan.2012.02.011.

Bastian, Olaf, and Arnd Bernhardt. 1993. “Anthropogenic Landscape Changes in Central Europe and the Role of Bioindication.” *Landscape Ecology* 8: 139–151. doi:10.1007/BF00141593.

Bragagnolo, Chiara, and Davide Geneletti. 2014. “Dealing with Land Use Decisions in Uncertain Contexts: A Method to Support Strategic Environmental Assessment of Spatial Plans.” *Journal of Environmental Planning and Management* 57 (1): 50–77. http://dx.doi.org/10.1080/09640568.2012.735990.

Bürgi, Matthias, Anna Hersperger, and Nina Schneeberger. 2004. “Driving Forces of Landscape Change – Current and New Directions.” *Landscape Ecology* 19: 857–868. doi:10.1007/s10980-004-0245-8.

Caetano, Mário, António Araújo, António Nunes, Vasco Nunes, and Maria Pereira. 2009. “Accuracy Assessment of the CORINE Land Cover 2006 Map of Continental Portugal.” Technical Report. Lisbon: Geographic Portuguese Institute. http://dgterritorio.pt/e-IGEO/egeo_downloads.htm.

Claessens, Lieven, Jeroen M. Schoorl, Peter H. Verburg, Lieke Geraedts, and Tom A. Veldkamp. 2009. “Modelling Interactions and Feedback Mechanisms Between Land Use Change and Landscape Processes.” *Agriculture, Ecosystems and Environment* 129: 157–170. doi:10.1016/j.agee.2008.08.008.

Cox, Nicholas. 1981. “Hillslope profiles.” In *Geomorphological Techniques*. Edited for the British Geomorphological Research group by A. Goudie, M. Burt, J. Lewin, K. Richards, B. Whalley, and P. Worsley, 104–109. London: George Allen & Unwin.

Culshaw, Martin G., and Simon J. Price. 2011. “The 2010 Hans Cloos Lecture: The Contribution of Urban Geology to the Development, Regeneration and Conservation of Cities.” *Bulletin of Engineering Geology and the Environment* 70: 333–376. doi:10.1007/s10064-011-0377-4.

de Noronha Vaz, Eric, Peter Nijkamp, Marco Painho, and Mário Caetano. 2012. “A Multi-Scenario Forecast of Urban Change: A Study on Urban Growth in the Algarve.” *Landscape and Urban Planning* 104 (2): 201–211.

Diogo, Vasco, and Eric Koomen. 2012. “Land Use Change in Portugal, 1990–2006: Main Processes and Underlying Factors.” *Cartographica* 47 (4): 237–249. doi:10.3138/carto.47.4.1504.

Duncan, James S, and Nancy G. Duncan. 2004. *Landscape of Privilege: The Politics of the Aesthetic in a American Suburb*. New York: Routledge, 315p.

Durham, Allison. 1958. “City Planning: An Analysis of the Conte of the Master Plan.” *Journal of Law and Economics* 1: 170–186.

Dutta, Venkatesh. 2012. “Land Use Dynamics and Peri-Urban Growth Characteristics: Reflections on Master Plan and Urban Suitability from a Sprawling North Indian City.” *Environment and Urbanization Asia* 3 (2): 277–301.

El May, Moufida, Mahmoud Dlala, and Ismail Chenini. 2010. “Urban Geological Mapping: Geotechnical Data Analysis for Rational Development Planning.” *Engineering Geology* 116: 129–138. doi:10.1016/j.enggeo.2010.08.002.

Elo, Satu, and Helvi Kyngäs. 2008. The Qualitative Content Analysis Process. *Journal of Advanced Nursing* 62 (1): 107–115. doi:10.1111/j.1365-2648.2007.04569.x.

Feranec, Jan, Gabriel Jaffrain, Tomas Soukup, and Gerard Hazeu. 2010. "Determining Changes and Flows in European Landscapes 1990–2000 Using CORINE Land Cover Data." *Applied Geography* 30: 19–35. doi:10.1016/j.apgeog.2009.07.003.

Forman, Richard T. T. 1995. *Land Mosaics, the Ecology of Landscapes and Regions*. New York: Cambridge University Press.

Franck-Néel, Catherine, Wolfgang Borst, Camille Diome, and Philippe Branchu. 2015. "Mapping the Land Use History for Protection of Soils in Urban Planning: What Reliable Scales in Time and Space?" *Journal of Soils and Sediments.* Advance online publication. doi: 10.1007/s11368-014-1017-y.

Freiria, Susana, and Alexandre O. Tavares. 2011. "Towards the Acknowledgment of the Urban-Rural Interface as a Spatial Category." *International Journal of Energy and Environment* 5 (2): 292–300.

Fu, Bo-Jie, Qiu-Ju Zhang, Li-Ding Chen, Wen-Wu Zhao, Hubert Gulinck, Guo-Bin Liu, Qin-Ke Yang, and Yong-Guan Zhu. 2006. "Temporal Change in Land Use: Its Relationship to Slope Degree and Soil Type in a Small Catchment on the Loess Plateau of China." *Catena* 65: 41–48. doi:10.1016/j.catena.2005.07.005.

Gallent, Nick, and Dave. Shaw. 2007. Spatial Planning, Area Action Plans and the Rural-Urban Fringe. *Journal of Environmental Planning and Management* 50: 617–638. doi:10.1080/09640560701475188.

Gant, Robert, Guy M. Robinson, and Shahab Fazal. 2011. "Land Use Change in the 'Edgelands': Policies and Pressures in London's Rural–Urban Fringe." *Land Use Policy* 28: 266–279. doi:10.1016/j.landusepol.2010.06.007.

GAO. 1996. *Content Analysis: A Methodology for Structuring and Analyzing Written Material*. Washington DC: Program Evaluation and Methodology Division, United States General Accounting Office, 77 p.

Gómez-Baggethun, Erik, and David Barton. 2013. "Classifying and Valuing Ecosystem Services for Urban Planning." *Ecological Economics* 86: 235–245.

Gonçalves, Adelino. 2008. "Which Urban Plan for an Urban Heritage: An Overview of Recent Portuguese Practice on Integrated Conservation." *City and Time* 3 (2): 67–79.

Hersperger, Anna, Maria-Pia Gennaio, Peter H. Verburg, and Mattias Bürgi. 2010. "Linking Land Change with Driving Forces and Actors: Four Conceptual Models." *Ecology and Society* 15 (4): 1. http://www.ecologyandsociety.org/vol15/iss4/art1/.

Hietel, Elke, Rainer Waldhardt, and Annette Otte. 2004. "Analysing Land-Cover Changes in Relation to Environmental Variables in Hesse, Germany." *Landscape Ecology* 19: 473–489. doi:10.1023/B:LAND.0000036138.82213.80.

Hietel, Elke, Rainer Waldhardt, and Annette Otte. 2005. "Linking Socio-Economic Factors, Environment and Land Cover in the German Highlands, 1945–1999." *Journal of Environmental Management* 75: 133–143. doi:10.1016/j.jenvman.2004.11.022.

Hietel, Elke, Rainer Waldhardt, and Annette Otte. 2007. Statistical Modelling of Land-Cover Changes Based on Key Socio-Economic Indicators. *Ecological Economics* 62: 496–507. doi:10.1016/j.ecolecon.2006.07.011.

IGeoE (Geographic Army Institute), 2002. *Portugal Military Charts: Charts 230 and 241.* Lisbon: Geographic Army Institute.

INE (National Institute of Statistics), 1960, 1981, 2012. *Population Census.* Lisbon: National Institute of Statistics.

INETI. 2005. *Carta Geológica de Portugal [Portugal Geological Chart], Folha 19-D, Coimbra-Lousã (1/50000).* Lisbon: National Institute of Technology Engineering and Innovation) (Explanatory report, 2007).

Kasanko, Marjo, Jose I. Barredo, Carlo Lavalle, Niall McCormick, Luca Demicheli, Valentina Sagris, and Arne Brezger. 2006. "Are European Cities Becoming Dispersed? A Comparative Analysis of 15 European Urban Areas." *Landscape and Urban Planning* 77: 111–130. doi:10.1016/j.landurbplan.2005.02.003.

Kroll, Franziska, Felix Müller, Dagmar Haase, and Nicola Fohrer. 2012. "Rural–Urban Gradient Analysis of Ecosystem Services Supply and Demand Dynamics." *Land Use Policy* 29 (3): 521–535.

Lambin, Eric F, and Patrick Meyfroidt. 2011. “Global Land Use Change, Economic Globalization, and the Looming Land Scarcity.” *Proceedings of the National Academy of Sciences of the United States of America* 108 (9): 3465−3472. doi:10.1073/pnas.1100480108.

Lambin, Eric F, Helmut Geist, and Ronald R. Rindfuss. 2006. “Introduction: Local Processes with Global Impacts.” In *Land Use and Land Cover Change: Local Processes and Global Impacts,* edited by Eric F. Lambin, and Helmut J. Geist, 1−8. Berlin: Springer.

Li, Xiaoma, Weigi Zhou, and Zhiyun Ouyang. 2013. “Forty Years of Urban Expansion in Beijing: What is the Relative Importance of Physical, Socioeconomic, and Neighborhood Factors?” *Applied Geography* 38: 1−10. doi:org/10.1016/j.apgeog.2012.11.004.

Long, Hualou, Guoping Tang, Xiubin Li, and Gerhard K. Heilig. 2007. “Socio-Economic Driving Forces of Land Use Change in Kunshan, the Yangtze River Delta Economic Area of China.” *Journal of Environmental Management* 83: 351−364. doi:10.1016/j.jenvman.2006.04.003.

Long, Ying, Yizhen Gub, and Haoying Han. 2012. “Spatiotemporal Heterogeneity of Urban Planning Implementation Effectiveness: Evidence from Five Urban Master Plans of Beijing.” *Landscape and Urban Planning* 108: 103−111. doi:org/10.1016/j.landurbplan.2012.08.005.

Malczewski, Jacek. 2004. “GIS-Based Land Use Suitability Analysis: A Critical Overview.” *Progress in Planning* 62: 3−65. doi:10.1016/j.progress.2003.09.002.

McHarg, Ian L. 1971. *Design with Nature*. New York: American Museum of Natural History, 198p.

Mulder, Eduardo F. J. 1992. “Urban Geology: Present Trends and Problems: Planning the Use of the Earth’s Surface.” In *Lecture Notes in Earth Sciences*, edited by Antonio Cendero, Gerd Lüttig, and Fredrik Wolff, 125−140. Berlin: Springer. doi:10.1007/BFb0038634.

Pan, Daiyuan, Gérald Domon, Sylvie de Blois, and André Bouchard. 1999. “Temporal (1958−1993) and Spatial Patterns of Land Use Changes in Haut−Saint−Laurent (Quebec, Canada) and Their Relation to Landscape Physical Attributes.” *Landscape Ecology* 14: 35−52. doi:10.1023/A:1008022028804.

Parcerisas, Lluís, Joan Marull, Joan Pino, Enric Tello, Francesc Coll, and Corina Basnou. 2012. “Land Use Changes, Landscape Ecology and Their Socioeconomic Driving Forces in the Spanish Mediterranean Coast (El Maresme County, 1850−2005).” *Environmental Science & Policy* 23: 120−132. doi:org/10.1016/j.envsci.2012.08.002.

Pato, Rosinda L, Alexandre O. Tavares, and M. Carmo Magalhães. 2008. “Developments in Land Use in a Periurban Area of Central Portugal: The Importance of Biophysical Parameters.” *Geo−Environment and Landscape Evolution III* 100: 109−117. WIT Transactions on Built Environment. The New Forest, UK. doi:10.2495/GEO080111.

Petrov, Laura, Carlo Lavalle, and Marjo Kasanko. 2009. “Urban Land Use Scenarios for a Tourist Region in Europe: Applying the MOLAND Model to Algarve, Portugal.” *Landscape and Urban Planning* 92 (1): 10−23.

Pickett, Steward T. A, and Mary L. Cadenasso. 2009. “Altered Resources, Disturbance, and Heterogeneity: A Framework for Comparing Urban and Non-Urban Soils.” *Urban Ecosystem* 12: 23−44. doi:10.1007/s11252-008-0047-x.

Randolph, Jonh. 2004. *Environmental Land Use Planning and Management*. Washington, DC: Island Press, 667p.

Reger, Birgit, Annette Otte, and Rainer Waldhardt. 2007. “Identifying Patterns of Land-Cover Change and Their Physical Attributes in a Marginal European Landscape.” *Landscape and Urban Planning* 81: 104−113. doi:10.1016/j.landurbplan.2006.10.018.

Serra, Pere, Xavier Pons, and David Saurí. 2008. “Land-Cover and Land Use Change in a Mediterranean Landscape: A Spatial Analysis of Driving Forces Integrating Biophysical and Human Factors.” *Applied Geography* 28: 189−209. doi:org/10.1016/j.apgeog.2008.02.001.

Shi, Shi, Xiang Sun, Xiaodong Zhu, Yangfan Li, and Liyong Mei. 2012. “Characterizing Growth Types and Analyzing Growth Density Distribution in Response to Urban Growth Patterns in Peri-Urban Areas of Lianyungang City.” *Landscape and Urban Planning* 105 (4): 425−433.

Steiner, Frederick. 2011. “Landscape Ecological Urbanism: Origins and Trajectories.” *Landscape and Urban Planning* 100 (4): 333−337. doi:org/10.1016/j.landurbplan.2011.01.020.

Tavares, Alexandre O. 1999. “Condicionantes físicas ao planeamento. Análise da susceptibilidade no espaço do concelho de Coimbra.” PhD thesis. Coimbra University.

Tavares, Alexandre O, and António F. Soares. 2002. “Instability Relevance on Land Use Planning in Coimbra Municipality (Portugal).” In *Proceedings of International Conference on Instability – Planning and Management,* edited by Robin G. McInnes, and Jenny Jakeways, 177−184. London: Thomas Telford.

Tavares, Alexandre O, Rosinda L. Pato, and M. Carmo Magalhães. 2012. “Spatial and Temporal Land Use Change and Occupation Over the Last Half Century in a Periurban Area.” *Applied Geography* 34: 432−444. doi:org/10.1016/j.apgeog.2012.01.009.

Tavares, Alexandre O, and Lúcio Cunha. 2002/2004. “Espaços de Planeamento no Concelho de Coimbra. A Importância Das Variáveis Biofísicas, Demográficas e Sociais.” *Cadernos de Geografia* 21/23: 241−254.

Ter Braak, Cajo, and Petr Smilauer. 2002. *CANOCO Reference Manual and User’s Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.52)*. Ithaca, NY: Microcomputer Power.

Toy, Terrence, and Richard Hadley. 1987. *Geomorphology and Reclamation of Disturbed Lands*. Orlando, FL: Academic Press. 480p.

Turcu, Catalina. 2014. “Re-Thinking Sustainability Indicators: Local Perspectives of Urban Sustainability.” *Journal of Environmental Planning and Management* 56: 695−719. doi:10.1080/09640568.2012.698984.

van Delden, Hedwig, Jasper van Vliet, Daniel T. Rutledge, and Mike J. Kirkby. 2011. “Comparison of Scale and Scaling Issues in Integrated Land Use Models for Policy Support.” *Agriculture, Ecosystems and Environment* 142: 18−28. doi:org/10.1016/j.agee.2011.03.005.

Vargo, Jason, Dana Habeeb, and Brian Stone Jr. 2013.“The Importance of Land Cover Change Across Urban and Rural Typologies for Climate Modelling.” *Journal of Environmental Management* 114: 243−252. doi:org/10.1016/j.jenvman.2012.10.007.

Verburg, Peter H, Paul P. Schot, Martin J. Dijst, and Tom A. Veldkamp. 2004. “Land Use Change Modelling: Current Practice and Research Priorities.” *GeoJournal* 61: 309−324. doi:10.1007/s10708-004-4946-y.

Verheye, Willy H, ed. 2009. “Land Use, Land Cover and Soil Sciences.” In *Encyclopedia of Life Support Systems (EOLSS)*, edited by W.H. Verheye, 1−44. Oxford: EOLSS.

Wu, Kai-ya, Xin-yue Ye, Zhi-fang Qi, and Hao Zhang. 2013. “Impacts of Land Use/Land Cover Change and Socioeconomic Development on Regional Ecosystem Services: The Case of Fast-Growing Hangzhou Metropolitan Area, China.” *Cities* 31: 276−284.

Ye, Yuyao, Hongou Zhang, Kai Liu, and Qitau Wu. 2011. “Research on the Influence of Site Factors on the Expansion of Construction Land in the Pearl River Delta, China: By Using GIS and Remote Sensing.” *International Journal of Applied Earth Observation and Geoinformation* 23: 66−373. doi:org/10.1016/j.jag.2011.1010.1012.