GIS FROM A CULTURAL HERITAGE PERSPECTIVE

When past and future collide

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“Wisdom is like a clear and fresh lake, 
    one can enter it from any side”

Acharya Nāgārjuna
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ABSTRACT

Endangered cultural heritage is becoming nowadays a consequence of global change. With an increasing world population, urban growth seems to be a jeopardizing consequence for sustainable development coping with an already scarce number of resources and cultural resource management. This dissertation prompts the importance of pro-active monitoring of cultural heritage phenomena using Geographic Information Systems as tools for predicting ongoing change to take active measures in sustainable regional planning.

The research carried out in this context will use GIS to analyse the case scenario of the Algarve as foci of urban growth as well as region of abundant archaeological vestiges from the Roman era. Understanding the dynamics of past civilization activity in what seem the most endangered freguesias (parishes) in the Algarve using Archaeological Predictive Models and assessing urbanity in those areas, may lead to a direct impact on future planning strategies.

The choice of the Algarve for such study, relate to the availability of a large enough dataset of sites to create a predictive model of the Roman Algarve, as well as the significant regional importance of the region which historically has been used since the Phoenicians, up until now, where a massive tourist industry has led to a large urban sprawl in the last couple of decades endangering natural beauty of the environmental landscape.
SIG DE UMA PERSPECTIVA DE RECURSOS CULTURAIS

Quando o Passado e o Futuro Colidem

RESUMO

O património cultural em perigo é hoje em dia uma das graves consequências das mudanças globais existentes. Com o aumento significativo da população mundial, o crescimento urbano pode ser um fenómeno comprometedor para o desenvolvimento sustentado de recursos escassos bem como da gestão de recursos culturais. Esta dissertação indaga sobre a importância da monitorização pro-activa de fenómenos de recursos culturais, usando Sistemas de Informação Geográfica (SIG) como ferramentas poderosa na aplicação de medidas activas para um planeamento regional sustentável.

A investigação efectuada neste contexto utiliza SIG para analisar o caso do Algarve. Sendo a região como foco exemplar para a compreensão dos fenómenos de crescimento urbano bem como para a observação de numerosos vestígios da época Romana. Pretende-se compreender as dinâmicas de civilizações passadas localizando as nas freguesias em maior perigo no Algarve e, recorrendo simultaneamente a modelos de predição arqueológica bem como a modelos de crescimento urbano, foi possível analisar o seu impacto directo nas estratégias de planeamento futuro.

A escolha do Algarve para este estudo, está relacionada com a existência de uma base de dados subjacente de dimensão significativa para criar um modelo de predição para a região do Algarve em época Romana. A importância desta região que historicamente começou por ser utilizada pelos Fenícios para fins comerciais, e até aos dias de hoje ainda representa um amplo aproveitamento turístico, constitui justificativo para o estudo. Acresce a forte restrição ligada ao acelerado crescimento urbano das últimas décadas, excessivo e pondo em perigo a beleza natural da paisagem ambiental e histórica.
KEYWORDS

Archaeological Predictive Models
Algarve
Cellular Automata
Cultural Heritage Management
Environmental Sustainability
Regional Planning
Urban Growth

PALAVRAS-CHAVE

Modelos Arqueológicos De Predição
Algarve
Autómatos Celulares
Gestão de Património Cultural
Sustentabilidade Ambiental
Planeamento Regional
Crescimento Urbano
ACRONYMS

APM – Archaeological Predictive Models
ASCII – American Standard Code for Information Interchange
CA – Cellular Automata
CLC – CORINE Land Cover
CLC2000 – CORINE Land Cover 2000
CLC90 – CORINE Land Cover 1990
CORINE - Coordination of Information on the Environment
COS – Carta de Ocupação do Solo
CRM – Cultural Resource Management
DEM – Digital Elevation Model
EEA – European Environment Agency
GIS – Geographic Information Systems
ICNB – Instituto da Conservação da Natureza e da Biodiversidade
INE – Instituto Nacional de Estatística
K-S - Kolmogorov-Smirnov
LRM – Logistic Regression Models
LULCC – Land Use and Land Cover Change
MCE – Multi-Criteria Evaluation
MCM – Multi-Criteria Models
MURBANDY – Monitoring Urban Dynamics
MUU - Minimum Mapping Unit
NCGIA - National Center for Geographic Information and Analysis
PM – Predictive Modelling
PROT – Plano Regional de Ordenamento do Território
PROTAL - Plano Regional de Ordenamento do Território do Algarve
SDSS – Spatial Decision Support Systems
SRTM – Shuttle Radar Topography Mission
UGM – Urban Growth Models
WGS – World Geodetic System
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1. INTRODUCTION

1.1. Contextualization of the Thesis

Urban growth is a natural consequence of an ever increasing modern society. The effort of modernity is mainly to allow urban growth to develop in a sustainable manner and constant monitoring of sprawl\(^1\) without compromising land-use and maintaining a well balanced environmental and cultural landscape. This is not always an easy task, as urban growth may endanger valued patrimony as well as natural environment due to its progressive nature, thus prompting for a direct call of sustainability (Savard et al, 1999).

The last two years have been years of environmental awareness where problems as pollution, urban growth and sustainability have largely been discussed (Keiner, 2006; Costanza et al, 2007; EEA Report 10/2006; EEA Report 2/2007). These phenomena are an inherent consequence of demographic increase, boosted by a consuming population which must be made aware of a rising pollution and urbanization that may jeopardize life quality as well as natural and cultural landscapes if no monitoring and sustainable measures are taken (Camhis, 2006).

Geographic Information Systems (GIS) with their unique modelling capabilities may be very helpful as spatial decision support systems (SDSS) (Nijkamp and Scholten, 1993) as SDSS “embodies geomatics principles for situating decision making in space, often using a geographic information system (GIS) component to provide spatial analysis functionality.” (McCarthy et al, 2008).

These characteristics seem to be the ideal combination for usage in a Cultural heritage context, where environmental and human risk factors may be analyzed through a GIS as a “place to think” (Gillings and Goodrick, 1996), leading us to the undermined theme of our study which relates to sustainable planning of city growth having attention to archaeological cultural heritage.

Understanding the environment and tracking its changes is, above all, the attempt to preserve the past for future generations developing a more modern and conscious society “ensuring that what we pass on to future generations reflects what we

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\(^1\) Urban sprawl may be defined as the spreading of cities into rural areas, leading the former to land use / land change.
ourselves inherited from the past and what we have contributed to and shaped in the landscape, whether tangible or intangible” (Schofield, 2008). Gaining further meaning in a context of the revised version of European Convention on the Protection of the Archaeological Heritage (European Community, 1992), which underlies the philosophical framework of this study, in which it becomes clear that new technologies and urban growth may help preserve cultural resources.

1.2. Objectives of the Thesis

The overall objective of the thesis is to assess historico-cultural heritage endangerment due to urban growth in the region of the Algarve. The first objective of this thesis is to aggregate a large enough database of archaeological sites that allowed the creation of two archaeological predictive models which measure site propensity spatially. The second objective is to create an urban growth model forecasting urban sprawl in the region until 2020 using cellular automata and spatial data inventories that allowed spatial cognition of land use / land change. The resulting intersection between archaeological predictive model and urban growth forecasting shall enlighten the higher or lesser cultural heritage endangered areas in the Algarve. It is our hope to provide stakeholders with helpful information for regional planning and develop a new methodology of analytical reasoning regarding cultural heritage endangerment, as well as shed some light on consequences of urban expansion for cultural heritage which remains modestly documented.

1.3. Assumptions

The ubiquitous possibilities of social sciences and new technologies in recent years, in some extent due to the recent and ongoing need of environmental protection and sustainability, have led to the usage of technology as a unique tool to assess the dynamics of change. The novelty of this transversal exercise, bring new ideas and concepts to previous definitions of social sciences that often may be refuted and at some extent become with the unveiling of information technologies, paradigms. Hence, the role of Geographic Information Systems (GIS) in social sciences is not
yet quite clear and is an ongoing debate which leads necessarily to different opinions. Thus, this study relies on the following assumptions, without which we could not justify the objectives of this study:

- The knowledge of the past is of extreme importance in a human social context. It is one of man’s fundamental roles to understand himself and thus, learn from his ancestors. Therefore, the preservation of human past in any form is crucial for keeping its socio-cultural identity and balance, justifying the importance of such research.

- It is of crucial importance that modern urban growth is sustainable and that this sustainability reflects also historical patrimonial value regarding urban planning. Urban growth is in fact of socio-cultural and economical manifestation as human species survival. Therefore it is necessary to develop forms that ease this phenomenon in a context of respect for the environment maintaining as much as possible the aptitude for social, environmental and economical survival.

- GIS and modelling can cooperate within the social sciences, helping to better understand reality about men and their past, present and future, contributing in a unique form to the monitoring of menaced environmental suitability.

1.4. Thesis Structure

Divided in six chapters, the thesis follows a deductive approach in an attempt to comprehend urban growth as well as to understand possible damage to cultural heritage sites in the Algarve region (Portugal). While chapter one contextualizes the thesis, chapter two provides an environmental and cultural background of the region of the Algarve. Chapter three and four express individual objectives (chapter three the creation of archaeological predictive models and chapter four the generation of an urban growth scenario) which in the fifth chapter form a critical analysis leading to the cognition of the most endangered municipalities in our study area. Chapter six discusses the generic conclusions as well as limitations of our study. Describing each of the chapters individually:

In chapter 2 the objective will be to contextualize the Algarve regionally, answering to its historical and environmental background in an attempt to justify the
anthropogenic interest of this area since the Roman era until the recent Tourist development.

In chapter 3, we will create two archaeological predictive models based on a classical and a new approach to understand Roman behaviour in the Algarve and archaeological site propensity in the study area.

In chapter 4, given the previously mentioned urban growth in the Algarve area, an Urban Growth Model will be created in an attempt to understand the characteristics of growth in the region, using common European datasets.

Chapter 5 will be a methodological suggestion regarding Cultural heritage risk areas. Given both constructed models, Archaeological Predictive Models and the Urban Growth Model, it is our objective to understand which areas are mostly at risk to lose permanently cultural heritage locally. The focus on this methodology lies in the attempt to give stakeholders a tool to premeditate cultural risk analysis using a spatial dimension.

Chapter 6 will lead us towards more generic conclusions in which we will try to explain and better understand the paradigm of past civilizations and the future possibilities of future development without compromising cultural assets. These different objectives discussed along the chapters, can be seen as individual dimensions that may raise future questions in each area _per se_. Those reasons, above all, lead us to the speculative nature of this work: It is not our objective to understand the exact location of Cultural heritage, nor predict the exact site of construction of a building ten years from now. Rather, the objective is much more to define a methodology to understand two different areas and how they as a whole may find a common ground in sustainable planning for a better future. Figure 1 illustrates the overall organization of the thesis structure.
1.5. Used Technology

The entire study employs GIS to reach its purpose: A mixture of ESRI ArcGIS 9.2 and Clark Labs IDRISI Andes software packages will serve as support for development and model our calculi. Regarding statistical analysis, Microsoft Office Excel is the software which will permit us to calculate statistical results. Spatial datasets rely on coordinate systems: Thus, all datasets at some stage will be converted or are already using a Lisbon Datum Hayford Gauss projection which is the common spatial reference system used for this study. The multiple spatial file
types that will be used are: ESRI shapefiles in vector format (polygon, polyline and point as exemplified in Figure 2) for representing discrete entities as well as ESRI GRID format for representing surfaces like elevation and slope. Some of these files were interchangeably exported between IDRISI Andes (RST format) and ArcGIS (GRID format) environment using ASCII files.

![Figure 2 - Example of vector and raster (grid) layers](image)

1.6. Urban Growth and Historico-Cultural Heritage

Urban Growth has been a widespread phenomenon in Europe in the last decades. It can be defined as the “physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas.” (EEA Report 10/2006).

The exodus from agricultural areas has led to a larger amount of people living in urban areas benefitting from services and facilities of modernity. A quarter of Europe’s territory has been affected by urban land use while 80% of Europeans will be living by 2020 in urban areas, reaching in some areas up to 90% (EEA Report 10/2006).

Notwithstanding the benefits of urban growth population in general as well as a of construction of large infrastructures working as regional networks, urban growth if
not articulately and not properly planned, may peril existing cultural and environmental landscapes.

Recent European objectives have considered the constant monitoring of urban growth as measures towards preservation within city boundaries as well as protected areas which are clearly defined. Also, academic initiatives related to Geographic Information Science (Goodchild, 1997) and Remote Sensing, have been actively engaged in monitoring and creating consciousness on global change awareness (Longley, 2002).

Global change, in fact, is a phenomenon which is confronting man’s response regarding pollution, environmental sustainability and preservation. If no measures are taken in near future, the environment and quality of living as we know may very well become jeopardized for future generations.

The importance of geographic acknowledgment of urban sprawl has become clear in the 1999 European Spatial Development Perspective, where management of cultural and natural resources were one of the key topics of discussion: “Natural and cultural heritage in the EU is endangered by economic and social modernization processes. European cultural landscapes, cities and towns, as well as a variety of natural and historic monuments are part of the European heritage. Its fostering should be an important task for modern architecture, urban and landscape planning in all regions of the EU.” (European Community, 1999).

Although the endangerment of natural environment is no novelty, as several different species are becoming currently extinct due to pollution and environmental change, action must be taken to allow a balanced and sustainable urban growth which avoids further threat of those species and their ecosystems.

Capello (2001) suggests a two-fold approach of management dynamics to cope with change: Short term and long term. Whilst the short term targets on the change of direct urban action choosing more sustainable local options, the long term dynamic should focus on a common structural change of urban change promoting new global behaviours and technologies. As the panorama of loss regarding ecosystem is analyzed, in recent years the equation considers another aspect: cultural landscape.

The above mentioned two-fold approach could be an interesting solution for Cultural heritage which is continuously becoming endangered. Due to the means how urban
growth has destroyed many different archaeological sites and historical buildings, on one site, the short-term perspective of changing at local level may focus stakeholders on promoting and creating cultural awareness supporting for instance tourist products related to monument visits while allowing the possibility to finance conservation of buildings and monuments in latent danger due to air pollution natural of city habitat. As locally cultural heritage becomes manageable, long term regional policies may reflect on undiscovered and peripheral patrimony. These measures would benefit further academic discussions of cultural backgrounds as well as allow having in thought at the long run heritage management problems regarding urban development and expansion.

As a consequence, measures in a cultural heritage preservation context regarding urban growth forecasting may be seen in the following framework: (1) Short-run, local change measures: For instance, the protection from existing urban patrimony often endangered due to air pollution - a consequence of human activity within city due to gas emissions - may be created by developing an interesting, within urban area, tourist cultural heritage offer. (2) Long-run, regional change measures promote the analysis of future urban growth leading to a sounder choice of future urban development which may as a consequence benefit directly urban planning sparing at the long run large economic investments. For example, the recent case of Stonehenge, which due to poorly planned infrastructures 40 years ago may become on UNESCO’s list of endangered world heritage sites very soon (Webster, 2007).

These advantages of planning sustainability put modelling capabilities and spatial analysis in an important position for future assessments. As “Models are, perhaps, the best way of understanding the land change phenomenon and anticipate correct planning activities for sustainable cities.” (Cabral, 2006).

In spite the uncertainty of the possibilities of preservation of this specific site, Stonehenge could very well be a lesson in future preservation and assessment of the importance of urban growth regarding cultural heritage.

This is a lesson to be learned that could be used to establish new trends regarding cultural heritage endangered by urban areas. The Valley of the Kings in Egypt (Burns, 2007) which shows a significant increase of urban area due to the tourist
industry is an example of a cultural heritage where no active measures regarding urban growth are currently being taken.

2. THE STUDY AREA: AN ENVIRONMENTAL AND HISTORICAL PERSPECTIVE

The Algarve has been since ancient times a region of historical and environmental diversity. This chapter tries to abridge these aspects as well as contextualize the cultural and environmental potential of this area.

2.1. The Algarve Region

The Algarve region is the most southbound region of Portugal and has a total area of 4960 km² (Figure 3). To the south and west, its littoral coasts are bathed by the Atlantic Ocean whereas to the north, the massive mountain range called Serra do Caldeirão, separates this region from the Alentejo and the rest of Portugal.

![Figure 3 - Study Area (source Google Earth)](image)

The location of the Serra do Caldeirão has not only brought socio-cultural differences from this region from the rest of Portugal, but has allowed a very unique
microclimate, different from the rest of continental Portugal and more similar to the Mediterranean neighbours.

The Algarve can be divided into three distinct ecosystems Barrocal (located at the Serra do Caldeirão), Interior (between the Serra do Caldeirão and the coast area) and Litoral (the coastal area). Those distinct areas have diverse fauna and flora, largely influenced by each one of the particular climatic and morphological characteristics.

The Algarve region has been a very attractive tourist area since the beginning of the 1960s having led to a large mass-tourism industry. This has both, been economically positive for the region which grew to be one of the richest regions of Portugal, but also a paradigm to sound and sustainable urban planning. The ongoing tourism strategies for the Algarve region which are discussed in the PROTAL 2007 emphasize the importance of the tourist sector for this region and remind us, of an overpowering number of five million tourists which the Algarve receives annually.

The municipality of Faro has according to the INE (Instituto Nacional de Estatística) has a total of 58664 inhabitants and borders with the municipalities of São Brás de Alportel, Loulé and Olhão facing to the south the Atlantic Ocean is the administrative centre of the Algarve. Its coastal proximity has made of Faro an interesting settlement since protohistoric times.

2.2. The Roman Algarve

Homers Odyssey is proof that Homers Heroes already knew the west of the Mediterranean (Maia, 1987). “But the other cliff, thou wilt note, Odysseus, is lower – they are close to each other; thou couldst even shoot an arrow across – and on it is a great fig tree with rich foliage, but beneath this divine Charybdis sucks down the black water.” (Homer, 1984) This unique region extending almost to half of the Iberian Peninsula as far from the south lands of the Tagus river to the Spanish Andalusia was cradle for many civilizations.

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2 The PROTAL (Plano Regional de Ordenamento do Território) is one of the instruments for regional territorial development which according to nationally defined directives integrates municipal strategies for local development creating guidelines for sustainable and sound territorial developing defining networks for infra-structures, transportation and services.

3 Sea monster daughter of Poseidon and Gaia. Taking form as a monstrous mouth, she swallows huge amounts of water creating whirlpools.
The region of the Algarve belonged to the so-called Tartessos\(^4\) region, and has been described by 63 BC to 24 AD geographer Strabo, in his work Geographica which depicts an accurate historical, social and geographical description of the ancient world.

The existences of different civilizations are diverse and archaeological remains from as early as the times of the Celts (Maia, 1987) and also from the Palaeolithic are visible and abundant. (Veiga, 2005).

During the Roman occupation due to administrative boundaries which were created by Augustus in the first century, the region became a part of the province of Lusitania. It is only much later, in the beginning of the XII century that the region former known as Lusitania, became segmented in different provinces. One of those provinces was the Al-Garb, from the Moorish meaning “The Occident”. Later, in 1250 that the Al-Garb province, conquered by the Christians becomes the region of the Algarbe and is incorporated in Portugal.

The heterogeneous morphology of the Algarve was quite similar in the times of the ancient Algarve as described by Strabo:

“Turdetanium\(^5\) is a prosperous country, with all kinds of products and in large quantity. This richness is duplicated by exportation. The existing estuaries allow routes of transportation which are carried out by small boats that allow the connections from the river deltas to the open sea. The abundance of rivers and estuaries makes almost the entire region sailable.” (Strabo, 2007)

Strabo also gives us a clear idea of the inhabitant’s behaviour in Roman days mentioning also some of the major cities in the times of the Romans:

“The inhabitants built their cities with great proximity to their rivers and estuaries. Those cities are Asta, Nabrissa, Onuba, Ossonoba, Mainoba and a few others. The existing channels that connect those cities also ease the already abundant commerce. Commerce is carried out with the entire Italy and Rome being navigation quite accessible.” (Strabo, 2007).

The Algarve was not only an important region in the antiquity since pre-roman times but also during the Imperial Rome period where it was regionally auto-sufficient and

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\(^4\) Greek name of the first civilization of the occident
\(^5\) Ancient civilization of Hispania which existed in the proximities of the Guadiana in nowadays Algarve and western Andalusia.
had an active role regarding wealth distribution through the entire Roman Empire. One of the main exportations was *garum*, a salted fish mixture, often used as a sauce in the entire Empire of which the most appreciated was *Gades*, distributed at the Golf of Cadis and included the multiple production areas in the Algarve (Silva, 2007). The popularity of this ingredient is obvious due to the existence of different brands (Figure 4) that commercialized this product and were found in different archaeological excavations.

*Figure 4 - Example of *garum* Brands (Silva, 2007)*

This strong commercial activity as well as Strabo’s mentioned descriptions are a clear indication of a cultured, cosmopolitan society existing in the first centuries of our era with a vast network all throughout the entire Roman Empire (Marques, 1999) that allowed impaired circuits for trade and commerce which were a consequence of a unique geo-morphological location, explored since the Phoenicians. The networks of the Romans in the Algarve were diverse. Not only did the Romans connect by sea to the rest of the Empire and to near cities, but also, existence of fortified roads partially still visible indicate robust roads that connected all the way to Rome. (Rodrigues, 2004) The ancient city of Ossonoba nowadays known as Faro dates to IV BC. Regarding Ossonoba, in the last 100 years an Archaeological debate has taken place concerning its exact location. No one knew until the mid of the twentieth century for sure whether this ancient city was located on the exact urban area of Faro or rather, the outskirts of the current city.
This dilemma, justifies a special attention from the Archaeological and scientific community, as Ossonoba with already pre-roman influence became capital of the Roman civitas\(^6\).

Ossonoba was in fact a rich city and one of the most important ones in Roman days. The ruins of Milreu as well as other archaeological sites found in the last decades show us an immense and powerful heritage of wealth and splendour in the region, as cited in Frei Vicente Salgado, 1786, “Memórias Eclesiásticas do Reino do Algarve” (Salgado, 1786), who cited André de Resende, 1593, “Livro das Antiquidades da Lusitania”, quoting in Latin Médico Rhafes who lived in 10\(^{th}\) century in the following way: “(…) soil was fertile and abundant, plane and full of kitchen gardens, to which many water sources shed surrounded by cattle pastures and two small isles where many boats and ships sailed, in fact, one of the grandest in the world”. Thereof, this city was “a city of major importance in any historic moment, showing since the Bronze Age vestiges of different civilizations” (Gamito, 1997).

2.3. The Endangerment in the Algarve

Compared to Stonehenge and the Valley of the Kings, the Algarve does not represent an as important cultural phenomenon. Albeit this difference which is naturally imposed by the magnitude and historical character of those sites, the Algarve as discussed in earlier chapters, merits our attention due to the unprecedented urban sprawl as well as the extent of cultural Mediterranean spoils situated in the past region known as Hispania. Sharing a common European identity which defines a common cultural value, we had the chance in chapters three and four to predict both: archaeological site propensity and urban growth. The most interesting question raised by both predictions is one of intersection, which may prospect knowledge of urban planning in the region, giving an opportunity to protect vestiges of the past as well as broaden a chance of sustainable cultural landscapes for future generations (Sen et al, 2006).

\(^6\) Vast Roman administrative region
The call for proactive measures reaching a region like the Algarve which is shaped by a massive tourist industry, would allow stakeholders to monitor locally and regionally as well as improvement of cities at short, medium and long period.

2.4. Remembering the Past to protect the future

The cultural richness in the Algarve justifies the importance of performing studies that relate cultural heritage to current urban growth. As we have seen from this chapter, the Algarve shows a diverse geomorphologic and cultural milieu. This vast cultural and heterogeneous geography, have made it a region that not only know in the past, but also with rich present and future perspectives, with interesting cultural tourism possibilities surrounded by many natural and artificial cultured assets, worthwhile of being considered and protected.

Understanding the regional context and historical value of the region as a whole may lead future stakeholders to develop sounder strategies to acknowledge a sustainable tourism industry and develop services which relate to other products than sun and beach traditionally offered.

As mentioned by Vaz and Nijkamp (2008) “(...) Urban growth, an unavoidable reality, may jeopardize a fragile cultural background which shares valued patrimony. Spatial cognition of such archaeological sites and better notions of urban growth and sprawl based on urban growth models and spatial analytical processes have shown in the Faro / Olhão (...)” region in the centre of the considered area and administrative municipality of our study, the authors further argue to be “(...) important tools for an ongoing research agenda of historic and patrimonial protection. They continue considering that “(...) It is our hope, that with the accuracy of urban growth models, historico-cultural heritage endangered by growth of urban peripheries may be better analyzed, leading to sounder and more sustainable cities which should never lose their asset of cultural identity, passing them to future generation to cherish.”
3. PREDICTIVE MODELS FOR ARCHAEOLOGY

3.1. Introduction

Predictive Modelling (PM) is becoming of extreme importance for the Archaeological Sciences. The possibility to understand the patterns that may have existed in the past, allow stakeholders to take direct action regarding cultural heritage or historians to understand long disappeared civilizations underpinned by the importance of spatial data (Renfrew and Bahn, 2004). Since the 70’s GIS have had an active role in Archaeological Predictive Modelling (APM). Although not as much used in southern Europe, due to a more historical oriented Archaeology, these models are much explored in the United States, England and in the Netherlands where predictive modelling is seen as an asset that complements sustainability and preservation.

In this chapter we will introduce the paradigms of APM by developing two distinct Predictive Models (one based on Logistic Regression and the other based on Multi-Criteria Evaluation) which will allow judging of the accuracy for regional archaeological prediction based on a collected site sample of the Algarve.

3.2. Evolution of predictive modelling in Archaeology

Models can be used for dynamic simulation, providing decision makers with vivid visualizations of alternative futures (Longley et al, 2006). This ubiquity in visualization, sheds light not only on alternative realities but may help to understand the past, and thus becomes particularly interesting for archaeological studies (Espa et al, 2006).

APM may express those aspects as they are considered a technique to “(...) predict, at a minimum, the location of archaeological sites or materials in a region, based either on the observed pattern in a sample or on assumptions about human behaviour” (Kohler, 1988). This resource is also a result of the inherent capability of mathematical representation of real world phenomena (Burrough and McDonnell, 1998) in which the available Archaeological datasets may help the quantification and
“(…) spatial patterning of archaeological remains which reflect the spatial patterning of past activities” (Schiffer, 1972).

Hence, with an over thirty years old history, APM are becoming a accepted tool for site prediction and are a frequent application for GIS in Archaeology (Wheatley and Gillings, 2002). Though Human Sciences tend to have an opposite scope than Information Technologies and quantitative methodologies, GIS and Archaeology due to the availability of commercial GIS packages (Ebert, 2004) and the increasing easiness of use as well as the cost effectiveness of conducting surveys (Groover, 2002) seem to have reached a common ground with Archaeological Sciences.

Most of the APM are environmental deterministic models and rely primarily on environmental variables for the prognostic analysis. This characteristic favours the usage of GIS systems with their capacity to evaluate spatial data (Longley et al, 2006). As much as this may bring a methodological approach to prospective modelling, human behaviour does not exclusively rely on environmental factors. Also other human socio-cultural factors share importance remaining a problem of representation in a GIS environment and may influence the spatial patterns to be solved (Ingold, 1993; Tilley, 1994; Bradley, 1998) and should be considered.

Nevertheless for Cultural Resource Management (CRM) Archaeological Predictive Models may be highly recommended, as CRM deals not with the contribution of an explanation of site location but rather with the prediction of site location and its environmental impact. (Conolly and Lake, 2006).

3.3. Literary review on Archaeological predictive models

Since 1970 an ongoing scientific debate regarding archaeological predictive modelling has existed. This debate has been accompanied by technological advances which led to possibilities of better understanding and predicting archaeological past. The initial models proposed strong statistical backgrounds (Savage, 1990) mainly as a result of Archaeological processualism.

It is in the beginning of the 90s that APM reach ongoing discussions in an attempt to withdraw new conclusions. This pragmatic decade of Modelling, is marked by the fact in which Archaeologists become quite certain that Predictive Modelling may not
only rely on correlations towards environmental factors, but also historic non-quantifiable data has an important meaning for prediction.

As the main question is, if a specific location contains Archaeological vestiges, the argument becomes one of available theories of spatial distribution of archaeological material as well as empirical and historical observations of site records (Wheatley and Gillings, 2002). It is in this scenario that disagreement occurs more often, as scientists do not agree yet on a common methodology and a general theory which entwines correlative and cognitive approaches.

Nonetheless, in this spirit of controversy, deductive and inductive approaches for APM have risen over the past decades. The inductive Models are considered to be more spatially related, and as a consequence of empirical and analytical tools related to environmental variables. Deductive modelling focuses mainly on the available historical data leading towards a more cognitive nature.

The predisposition of correlative models, primarily based on environmental variables seems to exclude the importance of cognitive / anthropological backgrounds. This fact led to the appearance of cognitive models, which unfortunately still lack on mathematical and empirical explanation.

Regarding CRM, as no specific knowledge of prior historical behaviour seems in order, an inductive modelling approach relying on environmental variables seems more adequate. One of the classic inductive models has been Logistic Regression Models (LRM) while lately Multi-Criteria Evaluation (MCE) methodologies have shown some utility for APM. In our study two APM will be assessed: Logistic LRM and Multi-Criteria Models (MCM). LRM have been used since the 70’s for Archaeological evaluation. Considered as a classical approach towards modelling (Kvamme, 1991; Wheatley and Gillings, 2002) those models present a lack of capability to understand anthropological change due to their simple stochastic methodologies (Sebastian and Judge, 1988). On the other hand, Multi-Criteria Models which have been used largely in regional planning (Nijkamp and Delft, 1977, Nijkamp et al, 2007) can be easily allied with GIS (Malcezewski, 1999). As information sciences are important tools for prediction, the spatial variable brought by GIS allows Multi-Criteria Models to become handy resources for Archaeological
Predictive Modelling (Verhagen, 2007). While LRM only reason in a deductive approach, MCM may consider inductive and social data as well.

3.4. Applications of APM – Advantages and Failures

APM have reached diverse applications in many different subtypes of the archaeological sciences. Albeit many unclear directions due to the lack of a common theoretical background (Wheatley and Gillings 2002), a few sound examples of application of APM models have been created recently using GIS as tools for spatial analysis.

An ongoing debate on the usefulness of inductive and deductive models has increased related to the fact that prospecting past historic vestiges is an unclear task and arguments linked to methodologies for highly accurate prospecting seem yet uncertain. Nevertheless, if APM are to be analyzed as a hypothetical tool for regional planning, rather than historico-archaeological prompting based on previous environmental assessment they are elegant tools and very useful tools. Those tools lead to successful cases of preservation of artificial cultural heritage (archaeological sites, monuments etc.) protection as studies in the case of the protection of Forest Management Planning in Ontario (Bona, 2000).

This allows us to conclude APM should in nowadays be seen as supplementary assets of great potential (Hill, 2007) for regional planning rather than a methodology per se, as no sound theoretical background is still defined and divergences related to the analytical processes exist.

3.5. Methodology for APM

The APM was developed based on the existence of a site location dataset ranging 100 years of Archaeological investigation of the Roman period in the Algarve region. Data was collected from many different bibliographical sources and compiles with their mentioned geographical coordinates. These data were assembled into a common database with several attributes such as: type of finding, period, location, materials, geographical location, and bibliographical support. Finally, assembled data was
confirmed and validated with the Instituto Português de Arqueologia, which confirmed the correct location of the mentioned archaeological vestiges. This task was executed by the University of the Algarve, Faculty of Human and Social Sciences without which this work would not have been possible. Figure 5 shows the overall methodology for data preparation and assembly.

The Predictive Model consists of a sensitivity analysis of high to low site location using three distinct methodologies. Bibliographical research has shown the importance of topography, proximity to water (Brandt et al, 1992) and the importance of trading circuits in the Algarve area for model forecasting. Other variables which are normally used for such models as slope, hillshade, aspect, land cover and soil type and respective location tendencies related to the sites were stochastically analyzed. This was done by creating a ratio to measure the relation for each one of the variables to the sites. In the process 70 out of the 370 sites were
chosen based on a well spread distribution and were used for accuracy assessment (Figure 6).

![Figure 6 - Random Site Location](image)

The generated datasets permitted the creation of two different models, which will be explained in this chapter (Logistic Regression Model and Multi-Criteria Evaluation Model).

The inductive relation of site location given environmental determinants will consented the conception of a relationship between the information about plausible location of sites and the independent environmental variables that may be expressed in a function as follows (Altshul, 1988):

\[ A = D + F_1B + F_2C + F_3x \ldots + E \]

Where \( A \) equals site density; \( B, C \) and \( x \) represent the independent variables we have considered; \( F_1, F_2 \) and \( F_3 \) represent the weights for \( B, C \) and \( X \) respectively; \( D \) is a constant; and \( E \) is an error term. Thus, \( B \) and \( C \) represent independent variables in which the relationship to the sites is of utmost importance for our model and becomes the key for the parameterization of a propensity map, in which the different probabilities of finding a site in a given location may be assessed.

Leusen (2002) shows that different methods of APM have demonstrated to be more robust than others in conformity with the environmental context and above all with
the different sets of data that are available. This is the reason why in our study two
distinct models for predicting the location of Roman sites will be applied. The
attempt of two different approaches is related to the need to find the most adequate
model for predicting sites in the Algarve for cultural resource management induced
by swift changing urban landscapes.
The propensity maps produced by the independent variables are based on a 370 sites
sample, where 70 sites will remain for calculating the accuracy of each of the
generated models as mentioned later on.
Therefore, environmental variables as slope, hillshade, elevation and river distance
may very well be independent variables for a dependent site location dataset in the
creation of an APM as they are chiefly for environmental planners concerned mainly
in the presence or absence of Archaeology (Kamermans and Rensink, 1998).
Once the models are successfully build and allow interpretation archaeological site
propensity as Kvamme (Kvamme, 1999) suggests, a jack-knife approach should be
used to validate ground truth of the Predicted Model. This will inherently answer the
models predictive power and capability.
A jack-knife approach consists of excluding to the statistic interpretation of the
predictive model a set of random archaeological sites, which are afterwards added to
confirm the accuracy of the modelled result.
The next figure (Figure 7) represents a diagram for the working methodology of the
predictive models. Starting with the primary coverage and resulting secondary
coverage leading to the statistical analysis which integrates both predictive models
and respective propensity maps.
3.5.1. Datasets

According to Kincaid (1988), the very possibility of coping with the modelled reality and the archaeological environment is not only due to the availability of information of a sample inventory but also to:

1. detailed analysis of existing information
2. preparation and choice of environmental data
3. development and execution of successive phases of model testing (using independent data)
4. collection and processing of supplemental information about site variability

Table 1, shows all data, their source, original projection, usage, scale, geometric and model type used for our study.
3.5.2. Preliminary Data Preparation

It is of extreme importance to allow a rigorous analysis by undertaking the conversion of the available datasets into a common coordinate system. This is not always an easy task, as often data providers are unknown and not all the necessary information is available.

In our case the following transformations were introduced:

Regarding the existent dataset for the Portuguese municipalities, only the Algarve was used for our study, thus creating a shapefile with only this area. The Portuguese

<table>
<thead>
<tr>
<th>Data Layer</th>
<th>Source</th>
<th>Original Projection</th>
<th>Used for</th>
<th>Scale / Resolution</th>
<th>Model Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARCHAEOLOGICAL DATA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roman Site Location</td>
<td>University of the Algarve</td>
<td>WGS1984</td>
<td>Dependent Variable for Multi-Criteria Analysis Model 1 and 2 and Logistic Regression Model</td>
<td>Not Applicable</td>
<td>Vector</td>
</tr>
<tr>
<td><strong>ENVIRONMENTAL DATA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algarve DEM 90m resolution</td>
<td>SRTM (Shuttle Radar Topography Mission - NASA)</td>
<td>WGS1984</td>
<td>For creation of slope, hillshade, aspect and elevation datasets which are important independent variables for our models.</td>
<td>90 metres per cell</td>
<td>Raster</td>
</tr>
<tr>
<td>Slope</td>
<td>SRTM (secondary data)</td>
<td>WGS1984</td>
<td>Significant Layer for APM</td>
<td>90 metres per cell</td>
<td>Raster</td>
</tr>
<tr>
<td>Hillshade</td>
<td>SRTM (secondary data)</td>
<td>WGS1984</td>
<td>Significant Layer for APM</td>
<td>90 metres per cell</td>
<td>Raster</td>
</tr>
<tr>
<td>Aspect</td>
<td>SRTM (secondary data)</td>
<td>WGS1984</td>
<td>Significant Layer for APM</td>
<td>90 metres per cell</td>
<td>Raster</td>
</tr>
<tr>
<td>Elevation</td>
<td>SRTM (secondary data)</td>
<td>WGS1984</td>
<td>Significant Layer for APM</td>
<td>90 metres per cell</td>
<td>Raster</td>
</tr>
<tr>
<td>Hydrographical Basins</td>
<td>Downloaded from SNIG (Sistema Nacional de Informação Geográfica)</td>
<td>Hayford-Gauss</td>
<td>Significant Layer for APM</td>
<td>1:1000000</td>
<td>Vector</td>
</tr>
<tr>
<td>Portuguese Rivers</td>
<td>Downloaded from SNIG (Sistema Nacional de Informação Geográfica)</td>
<td>Hayford-Gauss</td>
<td>Significant Layer for APM</td>
<td>1:1000000</td>
<td>Vector</td>
</tr>
<tr>
<td>Soil Types for Portugal</td>
<td>Downloaded from SNIG (Sistema Nacional de Informação Geográfica)</td>
<td>Hayford-Gauss</td>
<td>Significant Layer for APM, dataset was simplified to have the soil types for the Algarve only.</td>
<td>1:1000000</td>
<td>Vector</td>
</tr>
<tr>
<td>Land use for Portugal</td>
<td>Requested from Portuguese Environmental Institute, belonging to CORINE Land Cover 2000 Project.</td>
<td>Hayford-Gauss</td>
<td>Significant Layer for APM, dataset was simplified to have the soil types for the Algarve only.</td>
<td>1:1000000</td>
<td>Vector</td>
</tr>
<tr>
<td>Portuguese Administrative Chart</td>
<td>Portuguese Geographic Institute</td>
<td>Hayford-Gauss</td>
<td>Definition of Municipality and Freguesias Boundaries</td>
<td>1:25000</td>
<td>Vector</td>
</tr>
</tbody>
</table>

Table 1 - Datasets used in study
CAOP (Carta Administrativa Oficial de Portugal, Portuguese Administrative chart) was downloaded in digital format from the Instituto Geográfico Português with a Lisbon Hayford – Gauss Projection at a 1:25000 scale. The area corresponding to the Algarve was filter and later, using the dissolve function, these polygons were dissolved to origin a homogenous shapefile which served as mask for our scope of analysis.

Lisbon Hayford-Gauss was defined as a common coordinate system for all data and thus, initial input data such as Roman sites, Hydrographical Map, Altimetry data, CORINE Land Cover and Soil Type were projected into the same coordinate system as the CAOP. The different originating layers which encompassed more than the area of study were extruded by the study area layer derived from the CAOP information. This originated our analysis layers and allowed us to calculate slope, hillshade and aspect based on our generated Digital Elevation Model of the study area. The overall schema and methodology for this process may be observed in Figure 8.

Figure 8 - Data Preparation
3.5.3. The Models Variables

3.5.3.1. Dependent Variable\textsuperscript{7} – Roman Sites

The present Archaeological dataset, consequential of the data collection mentioned previously, are vector point locations of several different types of artefacts, grind stones, mosaics and a large variety of fine and common ceramics. This was, in fact, the first attempt to cover the entire bibliographical roman site location reference for the Algarve and is, among other, constituted by the main reference of historians who studied the region.

A database was generated with the provided attributes; simplifying the process of academic prospecting of available bibliographical information. The Access database comprehended the X and Y coordinate that conferred a spatial location to the site attributes those were implemented in a GIS to allow the mapping and future prospective modelling of Roman culture in the Algarve (Vaz et al, 2007).

The site datasets correspond to our dependent variable, as its behaviour will depend on the environmental (independent) variables. This detail relates to our notion of an environmental deterministic model as we already described.

The dependent variable will allow us to quantify the densities of each independent variable and assess its relation. These important relationships have been established by simple stochastic methodologies explained later.

3.5.3.2. Independent Variables\textsuperscript{8} – Environmental Data

GIS and its capacity to cope with environmental variables and datasets, allow us to approach archaeology in the sense that the past (and present) cultures are somehow functions of environmental pressure: favourable conditions for specific cultural systems induce higher probabilities to find similar systems in different locations with the same set of conditions.

\textsuperscript{7} Variables observed to change in response to independent variable.

\textsuperscript{8} Variable deliberately manipulated to create a change in the dependent variables.
3.5.3.2.1. Digital Elevation Model

The Digital Elevation Model (DEM\(^9\)) (Figure 9) became of extreme importance for spatial analysis as other altimetry features such as slope, hillshade and aspect must be derived from it. The DEM was generated based on NASA’s Shuttle Radar Topography Mission (SRTM, 24.11.07). The product downloaded was at Latitude min. 35 N max 40 N with Longitude 10 W to max 5 W with centre point Lat: 37.50 N and Long: 7.50 W, with 90m elevation data per cell.

The downloaded file in ASCII\(^{10}\) was converted into GRID Raster format in IDRISI and the available WGS 1984 coordinate system converted into the common feature coordinate system, Lisbon Hayford-Gauss. Those processes are considered as pre-analysis measures which are of paramount importance for GIS spatial analysis.

![Figure 9 - Generated Elevation of the Algarve Area](image)

From the Elevation Model, four important layers were acquired: slope, hillshade and aspect using ArcGIS ® spatial analyst tools (Figure 10).

---

\(^9\) “A raster Digital Elevation Model (DEM) records height above sea level for a set of cells arranged in a regular grid retrieving an elevation value for each cell.” (Conolly and Lake, 2006).

\(^{10}\) American Standard Code for Information Interchange
3.5.3.2.2. Slope and Aspect

These variables are considered as first-order from the DEM. Slope (Figure 11) calculated by GIS software tools is the maximum level of change of the elevation at a given location as the aspect may be defined as the azimuth (compass direction) of this rate of change in downhill direction. Those variables are usually included in archaeological predictive models for site location (Conolly and Lake, 2006). Both of these variables are estimated from a local neighbourhood and values are applied to a cell of the same size as the DEM models (Wheatley and Gillings, 2002).
The importance of this variable is quite understandable, as it measures the amount of energy it takes to move from one location to another. Making it perfectly clear that areas where less amount of energy is spent are preferable, hence areas with low slope are more desirable as they are less hostile. The result is a statistical sum of sites for a specific slope class the normalized result is obtained by the site per class dividing by the total number of sites.

“Aspect” is calculated in degrees with either 0 – 360 representing North. It is often reclassified from degrees (or radians) into the eight primary compass directions (N, NE, E, SE, S, SW, W and NW) (Wheatley and Gillings, 2002). “No Aspect” data (i.e., data with flat slope and with no correspondent Aspect) was removed for the calculation of our ratio as those values may hinder the correct categorization of site tendencies per slope and may lead us to an inconclusive analysis regarding this variable.

“Aspect” may be an influencing environmental factor in two main ways. First, south facing slopes receive more sun and are therefore warmer on average than more northerly facing slopes. In the Southwest, increased temperatures may not necessarily have been as desirable as in the higher latitudes, but increased duration of available sunlight may have played a role. Secondly, sun-loving plants are highly correlated with “Aspect”, and may have influenced the availability of edible seeds, the desirability for planting cultigens at a location, or the habitat of an animal resource.

3.5.3.2.3. Hillshade

Hillshade (Figure 12) is a spatial analysis component capable of representing sun exposure. The adequate sun exposure may be important for agricultural activity and social welfare and “lower sun may represent protection from wind” (Santos, 2006).
3.5.3.2.4. Land use

The used environmental dataset was CORINE Land Cover 2000 (CLC2000) for Portugal (Painho and Caetano, 2006). The CORINE Land Cover project is a project that originated in the eighties by the European commission with the objective to start a land cover map for all of Europe. Based on Landsat imagery it comprehends a total of 44 classes and a minimum unit of 25 ha. Its original scale is at 1:100000. In this study, the five Level 1 classes were used which are: Artificial Surfaces, Agriculture areas, Forest and Semi-Natural areas, Wetlands and Water bodies.

Past land use is an ambiguity that can only be interpreted deductively by historical narratives and some material evidence. Our available site locations as well as historical descriptions that evidence the location of protohistoric towns as having the same location as our days. Example of this, would be the location of the city of Balsa (in our days Tavira), Porto Hannibalis (Portimão), Ossonoba (Faro). Besides, archaeological sites in agricultural areas have proven to be agriculturally related. “The present-day ecological footprint, therefore, is the cumulative legacy of historical land uses, spatially imprinted on the modern biophysical landscape”, (Etter et al, 2008) where “Spatial patterns of remnants are the result of previous human land-use decisions, and interactions with the biophysical environment”, (Lunt
and Spooner, 2005) thus as a consequence often originating material legacy in the land use.

3.5.3.2.5. Hydrographical Data

The usage of rivers by the Romans has long been discussed, and, therefore this data became an important variable for the creation of our predictive model. The data was downloaded from the Sistema Nacional de Informação Geográfica and was created by the Instituto do Ambiente – Atlas Digital do Ambiente in September 2003 with Map Projection of Transverse Mercator and Horizontal Geodetic Datum of Lisbon Hayford-Gauss.

Usually, “hydrologic modelling and GIS has to confront many complexities, including the need to integrate time-varying information on water movement through the landscape with static information about the character of the landscape” (Longley et al, 2006). In our case, the modelling of the complexities of hydrologic models will be discarded, as we’re not interested in the dynamic behaviour of the river circuit, but exclusively, on their location and the generated correlation to site distance. The figure below shows the methodology to arrive at this result: the overall river area is adapted to the area of study while creating Euclidean distance buffers of 50 meters. The factor for each is calculated accordingly and weighted to allow the generation of a propensity layer (Figure 13).
3.6. Logistic Regression Archaeological Predictive Model

Logistic Regression Models (LRM) are the most usual types in Archaeological Predictive Models (APM). Their usage is a clear statement to simple processualist Archaeology in which the question of understanding the past recognizes quantitative aspects of stochastic methodologies. Processualism in Archaeology has begun in the 60’s and seems to emerge in a time of large examination of exact sciences in different human sciences.

While the later discussed Multi-Criteria Evaluation (MCE) in predictive modelling are quite new it has proven great usage in urban and regional context (Voogd, 1983) and as Archaeology, those areas deal necessary with human action thus methodologies and tools could be shared and find a common ground.

Still, the novelty of this and the fact that no consensus regarding a single methodology for APM exists establishes the intrinsic need to generate the APM cautiously. As LRM have a high support from the Archaeological community the decision to generate such model and compare its result to the MCE model was important as these two models compared, clearly stand for a clarification about the
advantages and disadvantages of both methodologies contributing for further investigation concerning the most adequate methodology for APM. Datasets inventories as well as generated coverage from primary datasets are exactly the same in both models. It is the statistical analysis where also Archaeologists don’t seem to find a common ground that varies. While the MCE-APM (Multi-Criteria Evaluation Archaeological Predictive Model) was based on a Chi-squared test to measure the weight of each variable, LR-APM (Logistic Regression Archaeological Predictive Model) was done using Kolmogorov-Smirnov\textsuperscript{11} Goodness-of-Fit-Test (Kvamme, 1990). Table 2 shows the results of the relation of independent and dependent variables obtained by Kolmogorov-Smirnov:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dmax</th>
<th>D K-S</th>
<th>Dmax-D K-S</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
<td>0.153240</td>
<td>0.0785</td>
<td>0.074720</td>
<td>Not Random</td>
</tr>
<tr>
<td>Elevation</td>
<td>0.000001</td>
<td>0.0785</td>
<td>-0.078519</td>
<td>Random</td>
</tr>
<tr>
<td>Hillshade</td>
<td>0.074830</td>
<td>0.0785</td>
<td>-0.003690</td>
<td>Random</td>
</tr>
<tr>
<td>Land use</td>
<td>0.005124</td>
<td>0.0785</td>
<td>-0.073395</td>
<td>Random</td>
</tr>
<tr>
<td>Slope</td>
<td>0.848868</td>
<td>0.0785</td>
<td>0.770348</td>
<td>Not Random</td>
</tr>
<tr>
<td>Soil</td>
<td>0.194056</td>
<td>0.0785</td>
<td>0.115536</td>
<td>Not Random</td>
</tr>
<tr>
<td>River Distance</td>
<td>0.973333</td>
<td>0.0785</td>
<td>0.894814</td>
<td>Not Random</td>
</tr>
</tbody>
</table>

Table 2 - Results of Kolmogorov Smirnov

The Logistic Regression was calculated based on the weights of each independent variable class as mentioned earlier. Therefore, the final map is a result of the different sums of weight for the given area of study.

From our initial equation of:

\[
\text{Logistic Regression APM} = f([\text{Elevation}] + [\text{Riverdistance}] + [\text{Landuse}] + [\text{Soil}] + [\text{Aspect}] + [\text{Hillshade}] + [\text{Slope}])
\]

We obtained a more assertive relationship where Random variables were excluded, leading us to the following:

\[
\text{Logistic Regression APM} = f([\text{Riverdistance}] + [\text{Soil}] + [\text{Aspect}] + [\text{Slope}])
\]

\textsuperscript{11} Kolmogorov-Smirnov analyses the relationship between dependent and independent variables, calculating the largest difference in the accumulated percentages for each variable and comparing this result to a pre-determined value given by: \(D_{KS} = 1.36 / \sqrt{300}\). Further results can be assessed in Annex 1.
The resulting map creates a unique weight per cell where each cell has a 20m spatial resolution showing the potentiality of finding roman sites in the region (Figure 14).

![Logistic Regression Archaeological Predictive Model](image)

**Figure 14 - Logistic Regression Archaeological Predictive Model**

It is clear that the coastal area shows a larger potential than the interior of the Algarve. This conclusion enlarges furthermore our understanding that urban growth may endanger cultural heritage due to development of known urban areas or agricultural soils. This model has also shown that the potential for finding roman cultural heritage seems to be higher in the already existent urban centres this relationship exists due to historic re-usage of city centres among different civilizations explaining the large concentration of historico-urban patrimony. In the city of Faro this dichotomy is clearly stated in the report “Gestão Arqueológica em Faro – Que futuro?” (Paulo and Beja, 2007) where a large quantity of historico-cultural patrimony is endangered by urban growth. It would be quite interesting to perceive whether this result is related to a larger amount of excavations done in urban areas, or results from a real tendency of residual historic occupation in urban areas, that is, if settling patterns remain the same over time reused by diverse civilizations.
3.6.1. Logistic Regression Model Accuracy

Although no agreement regarding the best practice for assessment of accuracy of Archaeological Predictive Models exists, ground truth of site prediction is of chief importance as to validate the constructed model and to understand the accuracy of prediction. To achieve this, a set of random sites was left out which will serve as a jack-knife sample (Kvamme, 1988) measuring the models accuracy. The jack-knife sample consists of 70 random roman sites, which were unsystematically selected from our study area.

<table>
<thead>
<tr>
<th>Site Potential</th>
<th>Pixels per Class</th>
<th>Class Weight</th>
<th>Inverse Weight</th>
<th>Sites</th>
<th>Site Weight</th>
<th>Weight Rank</th>
<th>Final Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-20%</td>
<td>615470</td>
<td>0.050806</td>
<td>19.682816</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20-30%</td>
<td>2919199</td>
<td>0.240974</td>
<td>4.149831</td>
<td>4</td>
<td>0.06</td>
<td>0.24</td>
<td>0.011</td>
</tr>
<tr>
<td>30-40%</td>
<td>3967063</td>
<td>0.327473</td>
<td>3.053691</td>
<td>23</td>
<td>0.33</td>
<td>1.00</td>
<td>0.047</td>
</tr>
<tr>
<td>40-50%</td>
<td>1886949</td>
<td>0.155764</td>
<td>6.419984</td>
<td>18</td>
<td>0.26</td>
<td>1.65</td>
<td>0.078</td>
</tr>
<tr>
<td>50-60%</td>
<td>1219298</td>
<td>0.100650</td>
<td>9.935375</td>
<td>12</td>
<td>0.17</td>
<td>1.70</td>
<td>0.08</td>
</tr>
<tr>
<td>60-70%</td>
<td>1219738</td>
<td>0.100687</td>
<td>9.931791</td>
<td>9</td>
<td>0.13</td>
<td>1.28</td>
<td>0.060</td>
</tr>
<tr>
<td>70-80%</td>
<td>268498</td>
<td>0.022164</td>
<td>45.118336</td>
<td>3</td>
<td>0.04</td>
<td>1.93</td>
<td>0.091</td>
</tr>
<tr>
<td>80-90%</td>
<td>12890</td>
<td>0.001064</td>
<td>939.812490</td>
<td>1</td>
<td>0.01</td>
<td>13.43</td>
<td>0.632</td>
</tr>
<tr>
<td>90-100%</td>
<td>5078</td>
<td>0.000419</td>
<td>2385.620914</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>12114183</td>
<td></td>
<td></td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 – Weight Factor and Accuracy

Table 3 shows the accuracy of the Archaeological Predictive Model. A quick glimpse proves that most sites are located at a 30-40% accuracy interval. Nevertheless, this result is not adequate, as spatial dimension of each class potential is different. Thus our accuracy test was generated on the assumption that the existing 70 sites had a specific weight for each of the class, but also that each of the 10 classes would necessarily have an inverse weight, that is, should a class be larger than another, the larger class would have a larger propensity to have more sites, thus the class weight must be less than the previous class. Hence, pixels per class were crucial to size the weight factors of each independent class in the site weight context. The final result
esteemed an 80-90% of accuracy for the Logistic Regression Model as can be seen on the weight rank of the table. The following steps were considered:

a) Establishing the true weight for each class. As potential classes may have different spatial dimensions, it is important to establish a comparative weight for each class. Inverse values were considered.

\[
\text{Inverse Relative Weight of Class} = \frac{1}{\text{[(Pixels per Class / Total Pixels)]}}
\]

b) Establishing a relative weight for sites in each class.

\[
\text{Site weight per Class} = \frac{\text{Sites per Class}}{\text{Total Sites}}
\]

c) Creating the Relative weight of each class by multiplying site weight per class by the established class weight potential

\[
\text{Weight Rank} = \text{Site weight per Class} \times \text{Inverse Relative Weight of Class}
\]

d) Recording the true relative potential of all classes is thus, the result of the total weighted ranks. Value with highest ratio will correspond to accuracy of model

\[
\text{Final Ratio} = \frac{\text{Weights Rank}}{\text{Total Weights Rank}}
\]

3.7. Multi-Criteria Evaluation and APM – Innovating in uncertainty

Multi-Criteria Evaluation (MCE) “describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCE, desirable objectives are specified and corresponding attributes or indicators are identified.” (Smith, 1999). Its capacity to combine different datasets critically and obtain a common conclusion, make MCE adequate for GIS analysis where factors and constraints exist that influence the propensity of occurrence in a given area that may be of both, qualitative and quantitative significance. While factors are generally continuous and as such, easy to assess in a grid format, constraints are Boolean and serve mainly to limit areas of occurrence of the different calculated factors. This information may be merged in a common GIS system, as to form a single map which is a result of the visualization possibilities and the GIS interface itself, representing the general propensity of
occurrence in which each independent variable may be sub-categorized in factors or weights leading us to a propensity or suitability map.

In Archaeological Predictive Modelling where independent variables may very well represent factors and constraints of occurrence of sites, Multi-Criteria Evaluation is a sound process for site prediction (Verhagen, 2007). The problem in Archaeological Predictive Models which occurs with the Multi-Criteria Evaluation or with any methodology of prediction other than logistic regression, is, the distribution of the weights per factor. This obstacle underlies the lack of information regarding the impact of the independent variable on the dependent variable. That is, we may know that for instance, land use, may have a direct impact on site location given bibliographical research, but, are we able to quantify precisely the weight that each of the classes represents in the land-use dataset? Nevertheless, this methodology lends us an elegant degree of flexibility, which allows us to innovating on the form in which we calculate (and how we calculate) the factors weights.

This paradigm has brought in a series of discussions regarding the nature of Archaeological Predictive Modelling and is related fundamentally to the centre of discussion concerning the usage of inductive and deductive models. Following the debate originated in the 90’s, inductive models rely too much on environmental variables, not having in mind the past behaviour of cultures and the economic performance which is not that much related to environmental variables by itself, but rather a more casuistic and rather intangible human choice of action (Leusen, 2002).

It is also understood that there is not such a gap between the divergences of inductive and deductive models on a practical basis (Whitley, 2006). In fact, our choice of variables for a correlative inductive model, in which we formalize the choice of agricultural soil as a factor, is related to a previous knowledge of the trend e.g., we know, based on bibliographical research, that Romans preferred proximity to rivers and agricultural soils for residence. Our model becomes further accurate depending on bibliographical specificity of environmental variables that is, the kind of agricultural soils preferred by Roman settlements.

Thus, the choice of independent variables is in its nature based on a deductive approach (Sebastian and Judge, 1988), while the quantification and practical exercise of the model, relies on quantifiable methodologies that allow us to interpret and
create an as accurate spatial model as possible. Hence, the underlying approach of
deductive and inductive models is not a question per se, as both theories are
significant for the creation of the model underpinning cultural systems as well as
ecosystems variables (Kamermans and Rensink, 1998).

Deductive Models may give a preliminary choice of the variables to be analyzed and,
imductive models, to analyze stochastically the variables and to truly arrive to a clear
and crisp quantification of the predicted phenomena in the form of a propensity map.

Once arrived to this conclusion, it is reasonable to say that inductive models, with
support of independent environmental variables, will be able to project a given
scenario of possibility of occurrence. The question that occurs next is the following:
Having chosen the independent variables based on a deductive context of site
location and bibliographical research, how can we understand the weights (tradeoffs)
of each of these variables in a quantitative context instead of a qualitative survey? It
may be clear that for instance, slope and land use are important factors, but, given
those to independent variables for site prediction, which one is more important and
as consequence, how is the weight distribution between both of those stochastic
generated variables?

Looking back on each independent environmental variable we knew a priori that a
relation of dependent and independent variables existed:

\[ S = w_1A + w_2B + w_3C \]

Where, S is the Site propensity, W1 and W2 weight of independent variables and A,
B and C the independent variables.

This relationship obliges us to calculate \( w \) for each variable, where \( w \) represents the
tradeoffs of each independent variable for the propensity of the dependent sites (S)
variable.

In this model, we will try to understand the weight of \( w \) based on the distribution of
the existing dispersion.

Dispersion can be understood as the factor which allows more or less agglomeration.
Thus, our conclusion leads us to the notion that, if there should be less dispersion of
an independent variable, this variable must have higher tradeoffs and represent a
higher weight factor. This conclusion is reached based on the notion that agglomeration is a consequence of a voluntary choice in which the random context is diminished establishing a pattern that may be quantitatively analyzed using standard deviation.

The best way to measure effectively different weight factors as we have seen is the Multi-Criteria Evaluation (Figure 15) as it gives us a free choice of weight factors and, different from logistic regression, allows us to have a non-linear approach.

Figure 15 - Multi-Criteria Evaluation Model

3.7.1. Chi-Square Test

No consensus does exist regarding MCE as for the weighting method of the different factors (Conolly and Lake, 2006). This is necessarily a consequence of aggregating individual preferences into collective preferences (Voogd, 1983), result of MCE of factors and chosen weighting factors.

This problem does exist also in Archaeology as there seems to be no quantitative approach for ranking factors. The methodologies commonly chosen: Ranking Methods, Rating Methods and Pair wise Comparison Method. (Verhagen, 2007)

Although simple of usage, some doubts about coherent quantitative rules do appear in those methodologies. All three methodologies are rather of qualitative nature and aprioristic assortment then quantitative accurate inspection.
The Ranking Method is defined by:

\[ w_j = \frac{n - r_j + 1}{\sum (n - r_k + 1)} \]

Where, \( w \) is the weight for criterion \( j \), \( n \) the number of criteria under consideration and \( r \) the rank position of the criterion. As rank position is somewhat arbitrary, this criterion necessarily will not express confident set of rules for stochastic approach. Rating Method which is most widely applied in APM (Verhagen, 2007) allows the decision maker to estimate weights from 1-100 scale.

The qualitative nature of the weight criterion biased and uncertain an accurate quantitative methodology does not exist. Nevertheless, in Archaeology the problem of creating a Weight for factors may be of stochastic nature, and hence have a solution which may create quantifiable weights.

In our study we will try to answer this question with the chi-squared test. The chi-squared test is an excellent starting point for a situation when it is necessary to test the significance of observations made at nominal scales of measurement.

As non-parametric test of significance, it allows the comparison among different types of areas of an archaeological site (Conolly and Lake, 2006). It is formula is given by:

\[ \chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \]

Where \( \chi^2 \) is the chi-squared vale, \( k \) is the number of categories and \( O_i \) and \( E_i \) are the observed and expected number of classes in each category.

This will allow a correlation of expected and occurred values that may be compared by the total number of classes if:

\[ W = \frac{\chi^2}{\sum \chi^2} \]
Where W is the weight of $X_2$ per existing class over the total of $X_2$ results over the studied universe.

### 3.7.2. Testing Results for MCE - APM

No specific methodology for accuracy assessment of APM does exist. Therefore, we adopted a proven Methodology (Santos, 2006) in which assessment is based on a jack-knife sample as largely documented (Kvamme, 1990) and the Archaeological Predictive Model is reclassified in ten classes of potentiality 10% per class.

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Roman Sites</th>
<th>% Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-80%</td>
<td>17</td>
<td>24,29</td>
</tr>
<tr>
<td>50-60%</td>
<td>16</td>
<td>22,86</td>
</tr>
<tr>
<td>40-50%</td>
<td>11</td>
<td>15,71</td>
</tr>
<tr>
<td>80-90%</td>
<td>8</td>
<td>11,42</td>
</tr>
<tr>
<td>60-70%</td>
<td>6</td>
<td>8,57</td>
</tr>
<tr>
<td>0-10%</td>
<td>5</td>
<td>7,14</td>
</tr>
<tr>
<td>30-40%</td>
<td>4</td>
<td>5,71</td>
</tr>
<tr>
<td>10-20%</td>
<td>1</td>
<td>1,43</td>
</tr>
<tr>
<td>20-30%</td>
<td>1</td>
<td>1,43</td>
</tr>
<tr>
<td>90-100%</td>
<td>1</td>
<td>1,43</td>
</tr>
</tbody>
</table>

**Table 4 - Accuracy of MCE model**

As we could see, the MCE Predictive Model allowed a very nice result for site location. Not only is location propensity of jack-knife sampling in a 70-80% class, that is, there is a 70-80% accuracy of finding a site within the created APM, but also, the minimum results are constituted by single sites, of which 5 sites at 0-10%, which means that are located very near river areas and thus, tend to fall quite easily in the 90-100% rank as it is only a question of river proximity. This methodology has proven thus to be very accurate and adequate for assessing roman sites in the Algarve area. Furthermore, the following conclusions were obtained:
We can see clearly the tendency to find Roman near coastal areas. This is quite an important conclusion for further study, as this area is the one suffering significantly from urban growth and sprawl originated from the Tourist Industry as we may see in the next chapter.

There seem to be specific areas which create cluster region for site propensity. Analyzing those with the Geographic information of known Roman cities, we may see clearly the cities of Porto Hannibalis (Portimão) and Balsa (Tavira) with much higher site propensity. This conclusion also helps to reinforce the theory of the location of the city of Ossonoba as under the actual city centre of Faro (Gamito, 1997).

Furthermore, certain paths between high elevation with lower slopes appear in the interior of the Algarve, those areas seem to suggest the most adequate location for pathways among the Roman Algarve which may share some information on the location of the still undiscovered Roman Road circuits.

### 3.7.3. Goodness of Fit tests

Weighting the independent variables is an important step which justifies the significance that each of the variables has in the context of the studied environment. The environmental variables of this model have been chosen based on bibliographical and anthropological information (Sebastian and Judge, 1988; Ebert, 2004; Bona, 2000). Yet, the relationship that might exist between them can not be neglected as overall relations among dependent variables may differ. The *calculus* that decides relevant variables are equated by a quality of fit test, which is an important procedure to establish and test the weights of each of the environmental factors.

Several statistical methodologies exist, and it is in this context that non-parametric tests of significance like chi-squared ($\chi^2$) and Kolmogorov-Smirnov (K-S) are used. In our Logistic Regression methodology, we will try to use both, K-S and $\chi^2$ while in the second proposed methodology with Multi-Criteria a completely different approach will be discussed.
While $\chi^2$ is pointed out to be an excellent starting point for those situations when it is necessary to test the significance of observations made at nominal scales of measurement as well as of common practice, K-S has been largely used in the Archaeological context (Kvamme, 1990; Santos, 2006). Kolmogorov-Smirnov can effectively be used to assess distributional differences of any kind (Kvamme, 1988), still it may be problematic due to positive spatial auto-correlation, which invalidates any possible independence among variables (Kvamme, 1988; Altschul et al, 1988).

### 3.7.3.1. Kolmogorov-Smirnov Goodness of Fit test

Applying the Kolmogorov-Smirnov (K-S) test for the seven independent variables has proved that distribution of roman sites regarding the independent variables for each set isn’t random. This concludes our Goodness of Fit test and allows us to use all studied independent variables for our logistic regression expression.

The K-S test was done as follows:

1. Calculi of the Cumulative Percentage Class Area as a result of Zonal Statistics in ArcView with interchange with Microsoft Excel for creating tables and weights.
2. Sites observed per each defined class.
3. Percentage of sites per class as a result of the following equation:
   a. $\% = \frac{n}{\sum n}$, where $\%$ is the percentage of sites per each class and $n$ the existing sites.
   b. Cumulative site percentage presence was calculated as consequence of (a)
4. Sites expected was calculated as a result of the following:
   a. $E = (\sum n) \times \%$, where $E$ is the expected site value in real positive integer and $n$ the existing sites.
5. $D_{max}$ for comparison with DK-S was calculated based on the difference of Cumulative Percentage DK-S with Cumulative Percentage Sites. Should $D_{max}$ be higher than DK-S Hypothesis 1 is valid, that is, variable is not
random and should be used. Should the opposite occur, variable could be discarded. The tables and results of this can be seen in Annex 1.

3.7.4. Weights of Independent Variables

While weights of each class of independent variables may be simply calculated by the estimated sites per class related to the sites found by the total area of existing class (see Annex 1), the issue concerning the calculus of generic weights is quite difficult as results may vary largely accordingly to different weights which are attributed.

As a consequence, no clear methodology for weighting those variables exists (Verhagen, 2007; Sebastian and Judge, 1988; Ebert, 2004) and thus, different approaches may be consistent based on varying statistical methods.

As a new methodology is proposed to create weights using Multi-Criteria Analysis having in mind concepts of dispersion, we will relax the hypothesis of creating statistical unique weights for each of the independent variables in our logistic regression model, but will introduce the notion that each variable has equal weight. This hypothesis is a result of our model being an exclusively inductive environmental variables related model for Cultural heritage Management and thus, creating weights by common average calculation of quantities of areas and types could lead to undesired patterns which would misrepresent our Archaeological Predictive Model. On the other hand, as weights were calculated per class of each independent variable regarding site expectancy, the weights will be anyhow intrinsically conditioned by their trade-offs accordingly, thus weighting an already weighted result seems to be unnecessary.

3.8. Comparing Generated Archaeological Predictive Models

Classifying accuracy among LRM and MCE Archaeological Predictive Models may help to understand more rigorously the differences between both maps. The figure
below (Figure 16) shows the low to high propensity of finding sites in both generated predictive models for the Algarve region.

Figure 16 - LRM and MCE Comparison

Though accuracy regarding site prediction has been tested previously, interpretation between both generated maps has not yet been established quantitatively. Using an error matrix, it can be possible to analyze on a category-by-category basis, the relationship between known reference data (ground truth) and the corresponding result of an automated classification (Lillesand et al, 2004). Such methodology for accuracy assessment is often used in Image Processing related to remote sensing generated land use maps but can similarly be used for other test comparison.

The choice of which of the Models should represent ground truth is not an obvious one, as both models are predictive in nature and therefore, error assumption and unknown circumstances may easily fuzzy the validity and truth in any of the generated models. Albeit this apparent controversy generated by the most natural perception of unknown a and inevitable circumstances in the essence of Model
building and their validity (which on the other hand has become proved by some extend by the jack-knife sample analysis to test the accuracy of both models), it is our feeling, that ground truth in this case should be based on the model which shows more robust bibliographical and scientific research and whose validation is a question of several decades of intensive scientific debates and works. As such, the logistic regression model appears to be a more cautious solution than the Multi-Criteria Evaluation model.

By reclassifying both models into low, average and high propensity, we were able to create a comparison matrix where Logistic Regression Model and Multi-Criteria Evaluation were compared. The results (Table 5) showed little consensus and only similarities of 15.26% for the Low; 12.25% for Medium and 0.88% for the High propensity classes were found. This results show the difference between both modelling realities.

<table>
<thead>
<tr>
<th>MCE Model</th>
<th>Logistic Regression Model</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>15.26</td>
<td>2.56</td>
<td>0.02</td>
<td>17.84</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>35.39</td>
<td>12.25</td>
<td>0.43</td>
<td>48.06</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>15.27</td>
<td>17.94</td>
<td>0.88</td>
<td>34.10</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>65.92</td>
<td>32.75</td>
<td>1.33</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 - Comparison Matrix for LRM and MCE

The disparity of both models may help to understand the different applications in site prospecting that LRE and MCE tend to have. Medium propensity appears to be higher in MCE while much less in LRM, middle classes indicate some possibility of site existence suggesting some care for stakeholders. Logistic-Regression Models indicate on the other hand higher results on low propensity, which suggest that they may be adequate for deducing non-site areas. As quantities of high propensity in LRM also appear to be much more local, these models prompt for an adequate usage for construction of local models for historico-cultural reconstruction instead of
regional cultural heritage planning purposes, as site location for historical studies should be specific to indicate exact location of sites.

MCE Predictive Models seem to be more adequate for regional purposes as more areas were evaluated with medium and high propensity for the general study area informing stakeholders easier where they should proceed with caution while building.

Notwithstanding the similar model accuracy for both studied models, that is jackknife samples prompting for similar accuracy results in both models. The fact that two different analytical methods prompt similar accuracy and remain different regarding spatial distribution of propensity, is a result of the different primary goals of the models which in the case of Logistic Regression Models are adequate for local historical reconstruction and in the other a call for regional planning and policy support. As no consensus on theoretical background for Predictive Models exist, we have to conclude, that the difference in predictive models is related to the objectives which are traced for the models purpose, thus, the ongoing debate regarding Archaeological Predictive Models will only end, if a common ground between reinforcing historic and planning models is found and analytical tools to cope with statistical divergences are created.

3.9. Conclusions: Comparing both Archaeological Predictive Models

Two completely distinct methodologies were used to assess possible site location in the Algarve region. Although similar regarding for finding sites, Logistic Regression and Multi-Criteria differ largely concerning the resulting information of spatial knowledge of archaeological heritage propensity.

This is mainly result of different methodological approaches, while Logistic Regression presents a more stochastic with quantifiable and finite values, Multi-Criteria are more flexible regarding the interchange and prospecting of different weight factors per used independent variable, permitting a more bendable interchange between the environmental and stakeholders necessities and allowing the producer to choose variables which intuitively seem more elegant.

Thus, although Logistic Regression presented a slightly higher accuracy targeting of high propensity areas of roman site occupation suggest usage for historic
interpretation, as results brought by those models should be assessed also by bibliographic research on areas with high propensity.

It has become clear that Archaeological Predictive Models are a solution for Historical and Regional understanding and knowledge diffusion of past civilizations (Miri and Varshosaz, 2005). The usage of integrated information technologies with modelling capabilities do allow to comprise past realities and shed new lights on future directions for planning. Albeit the existence of different methodological approaches which lead to some present conflict regarding which models are more adequate, the venture of Archaeological Predictive Modelling is a step towards future cultural sustainability.
4. URBAN GROWTH SIMULATION IN THE ALGARVE AREA

4.1. Introduction

While in chapter 3 our attention focused in understanding patterns of the past, chapter 4 discusses future land-use and land cover change (LULCC). To measure our objectives of cultural heritage management, future land development is a key aspect of our thesis. As such, this chapter abridges the following topics: (1) accurate modelling of future urban growth in the Algarve, while (2) understanding the changes of urban environment using CORINE Land Cover and (3) validating their potential.

Using CORINE Land Cover datasets, we will start by analyzing the growth that the Algarve has faced in the last decades while gathering social and environmental data which seems important to assess social factors of urban growth. The consequence of our choice of variables will lead us to a suitability map which encompasses the most likely growth characteristics in the next decades. Urban growth is assessed using transition rules for cellular automata, modelling the concise future urban growth in the Algarve. Manipulation of such models relies on the power of the generated empirical model thus, validation process is extremely important and done by on terrain surveying of non-urban and urban areas which latter are crossed with the generated model to testing the accuracy of the projected scenario.

Albeit some limitations in the usage of CORINE Land Cover for urban growth modelling related to the minimum mapping unit (MMU) we will try to defend our position regarding the usefulness of such datasets comparing CORINE Land Cover to spatial data inventories with smaller MMU.

4.2. Urban Growth Models

Urban Growth Models (UGM) may usually be seen as cell based models that allow projection of land cover of urban land use changes as to understand their dynamics and impacts (Oguz et al, 2007). The importance of such models is intrinsically
related to the need to monitor sustainable urbanization, key asset for global sustainable development (Camhis, 2006).

Urban growth models (UGM) are no novelty (Wilson, 1974) and have been applied to several regions in the world. In our case, we want to understand change using the south European region of the Algarve in Portugal using Cellular Automata. The reason of this choice relates to the topographic and cultural characteristics of the area, which offer a series of assets of important historico-cultural significance, studied in the previous chapters, as well as the possibility to analyze an area where urban growth is of rapid expansion in the last decades.

Spatial dimension of urban growth gives the possibility to generate models easily in a GIS environment, where environmental datasets with their factors and constraints for urbanity allow the creation of a suitability map which shares information on adequacy for urban growth. Urban areas can, in fact, “(...) only grow in four directions, in, up, down and out, likely to follow the last of these paths overwhelmingly, particularly in advanced countries endowed with abundant usable territory.” (Nivola, 1999). Projecting the future albeit apparent quantifiable rules is not an easy task as often the choices of used environmental variables are not always quite clear. The uncertainty and unpredictability regarding future urban growth due to social, economic and ecological reasons, justify the variety of models available and the various research centres involved in the existing research activities.

Nevertheless, based on a set of rules and using adequate toolboxes, it may be possible to shed at least some knowledge towards the propensity of occurrence of urban growth for areas which lack such studies. Understanding of spatial dynamic models and urban growth scenarios are important and have been studied widely (Meaille and Wald, 1990; Alkheder and Shan, 2005). One of the most frequent methods to generate Urban Growth Models are CA (Cellular Automata) which, due to their technological characteristics, become very suitable for such purpose and can be easily implemented in a GIS. Thus, “the challenge to find an acceptable level and pattern of development which is compatible with the maintenance or even enhancement of the environment” (Goodall and Stabler, 1992)
4.3. Importance of an Urban Growth Model for the Algarve

As discussed, the Algarve is the most southbound region of Portugal and it has a very heterogeneous morphology. This heterogeneity, made it not only in ancient times a diverse and interesting region for the Romans, but also, makes the Algarve still today a region of unrivalled ecological beauty with interesting eco and cultural tourism opportunities which allow economic prosperity.

Urban growth in the Algarve started suddenly in the 1960s with the exploration of Tourist industry in this region. The Algarve expanded and its littoral cities became major foci of mass-tourism, especially during the summer season, due to its temperate climate and beach areas. The demand generated an increasing economical prosperity in the Algarve and are four decades later naturally taking its course. The Algarve has prospered due to this active industry and the coast line of the Algarve is in fact, one of the most expensive areas of Portugal for habitation and many large and expensive investments may be found.

Population of the Algarve in winter is a tenth of the population in the summer season. One of the problems of the Hostel Industry in the Algarve has been to cope with the seasonality of the Tourist Industry which has much less activity during the winter time.

Tourism, as such, has shown for the Algarve both, a symbiotic and antagonistic relationship. Striving for harmonious development of both economy and ecology (Archibugi, 1988) should be a key aspect in which the criteria of sustainability should be the distinction factor (Buhalis and Fletcher, 1995) between symbiotic or antagonistic relations in tourism.

Symbiotic factors also present in the Algarve related to the attempt of establishing environmental consciousness eased by the unique and heterogeneous morphology as well as large cultural patrimony from which this region benefits. Environment, therefore, is a key factor for sustainability in an area where tourism may be a beneficial as long as there are sustainable and environmentally cognisant policies. Nowadays, we realize the benefits of a healthy environment and stakeholders possess knowledge to avoid the antagonistic relation of Tourist industry and do take an active as well as a more participative role. This becomes a result of the increasing
awareness of interrelationships between the economic, social and environmental dimensions of development which may be described in three distinct dimensions: (Camhis, 2006)

- **Acceleration**: We have been experiencing changes at a pace that was unimaginable in other periods in history: the information society, the population explosion, rapid urbanization, and climate change are the most characteristic examples.

- **Human impact**: Up to now, nature’s absorbing or carrying capacity could withstand the impact of human activities. Today they affect global cycles and systems.

- **Internationalization**: The economy is global. Environmental problems do not recognize borders. What happens in one place has adverse effects somewhere else, ranging from trans-boundary to global impacts. The sum of individual actions can have different global results, in qualitative terms, from its components.

Some of the poorly designed hotels however, resulting from the initial mass-tourism industry in the Algarve and resulting meagre urbanization prospects as well as lack of environmental information have lead to a successive destruction of fauna and flora showing clear antagonistic effects.

Mass-tourism is not the only factor of urban sprawl and growth in the Algarve, as other areas in Portugal have been victims of urban sprawl (Cabral, 2006). The consequence of increasing world population, have been defined as “ville éclatée”, “ville éparpillée” and “ubiquitous city” which allow future expansion or urban areas into larger (and often unorganized) urban areas (Capello, 2001) may be seen as factors that directly contribute to urbanity. Nevertheless, the Algarve has specific fauna, flora and cultural characteristics, that make this region worthwhile of alternative for tourism opportunities that generate more symbiotic effects rather than the already existing antagonistic ones. The main problem lies in the re-qualification of existing urban tissue and the capacity to cope with a further landscape adequate urbanization of those areas. Also, new urban areas support the aggregation of previously existent urban tissues, leading to a continuous artificial land cover highly endangering the natural landscapes as well as the existent ecosystem. As
consequence of this, small towns such as Olhão have become cities, where proximity to the districts capital Faro, transformed Olhão into a dormitory city. The consequence of this agglomeration generated a continuous urban area of circa 5 km reaching from Faro to Olhão. This continuous urban area, due to the proximity to the Natural Reserve and the existence of important cultural heritage resources, has in fact endangered valued patrimony. Monitoring and creation of prospective future scenarios is an important task to avoid similar future situations. Currently, ongoing regional policies, such as Programa Regional de Ocupação do Território do Algarve (PROTAL) protect some aspects of growth in the region. Still, it is important to understand urban growth in this region, as it has been modestly studied and if assessed correctly may help future environmental collapse by direct impact on strategic planning or sensitizing and creating social awareness.

Although our study consists mainly on the cultural heritage endangerment aspects due to urban growth, as to foment preservation and sustainability, cultural heritage is but one of many facets in which unsustainable urban growth may have negative consequences. An example of natural heritage endangerment in coastal Algarve area is the Ria Formosa. Tidings, as well as existent water depth make of this area an ideal ecosystem for diverse forms of live: crustaceous species, birds and fish. With circa 20000 to 30000 mud living species many aviary species pass through this region for migration between Africa and Europe.

The protected area of Ria Formosa was founded in 1987 and encompasses a total area of 60 km of the Algarve coast between Ancão (Loulé) to Manta Rota (Vila Real de Santo António) with a total of 18400 hectares it covers partially the municipalities of Loulé, Faro, Olhão, Tavira and Vila Real de Santo António. Alas, these municipalities have registered significant urban growth which may be a potential hazard for the existing and fragile ecosystem. This phenomena has been assessed by stakeholders and is available in the Instituto da Conservação da Natureza e da Biodiversidade (ICNB) plan for the time span of 2007 - 2013, in which the agenda with a total budget of 7.575.000 € appointed in November 2006 considered most of the budget related to sustainability issues, re-conversion and maintenance of the area. This conveys the utmost need for monitoring of urban growth in the mentioned municipalities in which urban growth models for the region may help to understand
the environmental impacts and accurately assess the actions taken by decision-makers as a decision making and support tool.

4.3.1. Cellular Automata

Cell based models, due to their similarity to urban growth behaviours are an optimal choice for tracking change (Batty, 2005). As such, these models may have an important role for the decision making process regarding future urban growth and regional planning strategies (Piyathamrongchais and Batty, 2007). One way to generate cell based models is by using Cellular Automata (CA). Theoretically, CA gained an importance since the 50’s, with von Neumann and Ulam attempting to provide information on logical self-replication in computerized systems. Intrinsically, a CA can be seen as a form of Artificial Intelligence given a set of states of a rule-set to which the CA reacts. It is about 20 years later that CA are regarded for geographic purposes also due to Waldo Tobler’s vision of relating spatial distance to agglomeration factors. Programming a Cellular Automata is not an easy task and, the programming skills to do such require time and technical knowledge where a good proficiency with programming languages is assumed. The construction of such syntax and later on, validation of the algorithms that were generated, takes important time. Although that the creation of such a programmed model would allow a more personalized vision of Urban Growth, as all the program would have been done to answer a specific scenario. Dynamic processes differ from one another, urban growth patterns and interfering variables may change from area to area. Thus, toolboxes with standardized CA are a useful solution. One of the software is IDRISI with its CA_Markov module, which in comparison to other cellular automata (GeoMod, CA_Advanced) did offer the fairest results for the Lisbon - Sintra urban growth area (Cabral, 2006). As the morphology is quite similar (proximity a districts capital, existence of natural reservoir, land cover types and urban sprawl tendencies), we decided to use this cellular automaton tool for our study.
4.3.2. Markov chains in Urban Growth

The usage of Markov chains to measure change in land use and land cover is well documented and constitutes one of the most common methods of predicting change among various classes. Their capacity to stochastically approach a large number of variables make them useful resources for analyzing complex phenomena such as urban growth. Due to their capacity to create a transition matrix based on conditional probabilities, land use change probabilities may be assessed underpinned by multi-temporal land use covers. Thus, a resulting matrix will necessarily evoke the changes occurring within a defined time-span. The mechanisms of change between t and t+1 are thus detected and repeated as to allow an accurate perception of the moment t+2 (Cabral, 2006) in which every pixel changes based on a transition rule as function of the neighbouring pixels as to form the t+2 moment expressed as a land use map.

IDRISI uses the Markov module to analyze a pair of land cover images and returns a transition probability matrix, transition areas matrix, and a set of conditional probability images. The transition probability matrix is a text file that records the probability that each land cover category will change to every other category. The transition areas matrix is a text file that records the number of pixels that are expected to change from each land cover type to another land cover type over the specified number of time units. In both of these files, the rows represent the older land cover categories and the columns represent the newer categories. This algorithm is of extreme importance for cellular automata, as it measures the given probability of change in a land-use map. The software package IDRISI gives a tool that implies Markov probability chains and CA. This tool gives the name of CA_Markov and proposes a series of advantages which give depth for accurate urban and land use change analysis.

The choice of CA_Markov is a result of the possibilities of calibrating within the land use complexity. By this we mean the unique possibility of Markovian Cellular Automata to have undermined to our Change Matrix a set of suitability maps which allow an important aspect of environmental planning and a more intuitive modelling based on analysis of the decision making process. We have discarded the usage of the model Geomod for our study, as it predicts only changes among one class and
does not allow assessing simultaneous gain or loss (Pontius and Malanson, 2005). As valid as this may seem for certain studies (for instance deforestation), it removes the complexity of dealing with a set of different existent classes that are important for stochastic analysis of urban growth.

4.4. Land Cover Map Adequacy for Studying Urban Algarve

A land use / land cover map allows us to “assemble far more knowledge about the Earth than is possible on our own” (Longley et al, 2006). This characteristic in our days leads us to a large quantity of information which can be represented as a spatial data infrastructure, supporting spatial, temporal and thematic datasets which are the types of phenomena of the real world (NCGIA, 2000).

The choice and adequacy of the data we use, will inherently depend on the results we want to obtain, and therefore, must be a question of important reflection as many different types of datasets do exist which allow to represent our study area e.g. the urban areas of the Algarve. Our choice must be adequate to the following criteria:

- **Thematic**: Represent with accuracy urban areas in the Algarve region with less error as possible as well as analyze different types of land use for the region.

- **Spatial**: The area represented should be similar to the Archaeological Predictive Models as to allow a comparison which doesn’t bias the model but rather is an asset for an as extended as possible information for region planning. Thus, preferably contains the entire Algarve.

- **Temporal**: Answers not only to one static temporal moment, but rather, several subsequent series do exist that allow the existence of at least two points in time (preferably three for validation) permitting the implementation of a dynamic model.

Combining these factors is not easy, as land use maps are always used for different purposes and no prêt-a-porter situation exists. Thus, three land use databases available for the Algarve region were analyzed, as to assessing which has most adequate characteristics to study urban growth. Knowing that up-to-date and accurate data at regular intervals of time on the changing urban sprawl, urban land use, urban resources and urban environment are needed are key aspects (Maktav et al, 2005). As
the fourth option would be the conception of land use maps based on satellite imagery, we must realize that this would be as much time consuming as expensive, largely surpassing our work and its objectives.

The creation of land use maps has been largely documented and is in the areas such as remote sensing a very important and widely studied area. Own creation of land use maps nevertheless, besides having a very long duration and financial expenditure, would not alter to significantly the results. This is mainly due to the size of our area of study, in which spatial accuracy is not as much prompted as is the overall notion of changing patterns. Thus instead of technical accuracy, regional adequacy of chosen variables as well as accurate notions of current development are important aspects. This can be concluded from the notion that sustainability will depend upon a continuous flow of decision making process and not merely on exact site location in a very specific area. This argument was also taken *a priori* to justify the choice of Archaeological Predictive Models in its inductive relying merely upon environmental variables.

The three land use inventories we shall consider and compare have both, advantages and disadvantages. We will study for the Algarve region are Carta de Ocupação de Solos 90 (COS’90) knowing that the choice of assessing the accuracy of COS’90 is merely for informative reasons, as no other temporal frame of this spatial data inventory exists that would allow land change assessment, MURBANDY – Algarve Region and CORINE Land Cover (CLC).

CORINE Land Cover (CLC) project started on the 27th June 1985, as a program that would address the following issues: State of individual environments, Geographical distribution and state of natural areas, Geographical distribution and abundance of wild fauna and flora, Quality and abundance of water resources, Land cover structure and the state of the soil, Quantities of toxic substances discharged into environments and List Natural Hazards (EEA, 1995). In this sense, CLC can be seen as an *'an experimental project for gathering, coordinating and ensuring the consistency of information on the state of the environment and natural resources in the Community'* (85/338/EEC, Council Decision 27/6/1985).

The primary source of information for the CLC is satellite imagery which is represented into a 1:100000 scale with a 25 ha minimum mapping unit. The
consequences of this minimum mapping unit make that smaller features than 25 ha or 100 m (hedgerows, etc.) are generalized in the CLC inventory (Paínho and Caetano, 2006). But these elements represent important structural elements of certain landscapes, essential in ecological terms and an inherent integrated part of physiognomy and the visual perception. In this “(... sense the results present give only a broad picture of the countryside.” (European Community, 2000). The minimum mapping unit (MMU) is a key aspect to be chosen when undertaking the creation of land use topography. The question is whether CLC with a MMU of 25 ha may be accurate enough for urban growth analysis in the Algarve region. After all, existing urban areas with a lesser dimension than 25 ha may be unrepresented and this could lead to misleading and inaccurate representation of the urban growth phenomena. One of the solution would be the usage of a different inventory which would have different temporal moments as well as a smaller MMU or, building a land use map with a smaller MMU that assessed more accurately urban areas.

A significant venture was done by the MURBANDY (Monitoring Urban Dynamics) project and as the project covers a large enough period of time, becomes feasible to know how cities have grown in the past (Maktav et al, 2005). Thus, we decided to validate our choice regarding CLC defined urban areas by comparing with a data inventory with a smaller MMU, which was the case of COS'90 that has a 1 ha MMU. Hence, we hoped it would indicate us for this specific choice of area the adequacy of CORINE Land Cover (explained in Chapter 4.5).

For the Algarve area, MURBANDY has three land use inventories: 1972, 1986 and 1998. Albeit the classification and size of 1 ha areas for artificial areas, this project abridged the coastal area from the Algarve only in a 10 km buffer along the shoreline from Albufeira to Vila Real de Santo António. As this project is a reflection upon population increase in the Algarve varying from 20 to 60% and thus of extreme concern (Caetano et al, 1999). Nevertheless, as suitable as the choice of MURBANDY does appear for our study, if we want to compare past with present and future, we have to take in account the changes of human patterns and thus, attractiveness which may have led to higher population density in present may not be the case in the Roman days. This has become clear after evaluating the APM for the entire Algarve region, where it has become comprehensible that site distribution are
not necessarily higher in the shoreline between Albufeira and Vila Real de Santo António, but rather, result in a distribution which show higher concentration towards interior and west coast Algarve areas. Such phenomenon has made us consider MURBANDY as an extremely interesting inventory should it have considered the entire Algarve region.

COS’90 seems to satisfy both paradigms inherent to MURBANDY and CLC, not only does it have a more accurate MMU (1 ha) but also, it does cover similarly to the CLC, the entire region of Portugal, and thus, the Algarve is well represented. Unfortunately, as far as the temporal issue is concerned, COS’90 with all its virtues does only represent a static moment in time, as no subsequent inventory was yet created. This would lead us again with the choice of narrowing the area and creating a land use map based on COS’90 criteria or discarding COS’90.

4.4.1. Comparing CORINE Land Cover with COS’90

The conclusion for the Algarve regarding urban growth by comparison of CLC land use maps may be assessed by using another standardized land use map and comparing the similarity from one land use inventory with the other. To achieve this, we decided to use the Portuguese COS’90 (Carta de Ocupação de Solo) which has a Minimum mapping unit of 1 ha (Nunes and Caetano, 2006) and therefore may shed some light towards the accuracy of assessing urban areas in the Algarve with CORINE Land Cover 90.

<table>
<thead>
<tr>
<th>AREA</th>
<th>URBAN</th>
<th>NON URBAN</th>
<th>SIMILARITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>611</td>
<td>CLC90</td>
<td>21152</td>
<td>378848</td>
</tr>
<tr>
<td>611</td>
<td>COS90</td>
<td>31293</td>
<td>368707</td>
</tr>
</tbody>
</table>

Table 6 - Similarity between CLC90 and COS90

Analyzing the 611 Cartographic Area which comprises the Faro and Olhão urban areas, we have reached the conclusion that, taking in account the artificial areas classified in the COS’90, more urban, that is, artificial areas are registered compared to the CORINE Land Cover areas. This result is a consequence of the MMU paradigm initially suggested. Nevertheless, after further analysis, we reach the
conclusion that the main artificial areas which exceed are small urban areas which are located outside the cities periphery which do not impact regional planning. A total similarity of 68% exists (Table 6), which is a fairly good result and allows us to opt for the usage of CLC. Albeit some limitations in similarity (after all 68% is sufficient, but not a grand result) with the mapping of CLC2000, besides the already manifold usage of CLC, we have the advantage of assessing two distinct moments in time and thus, change evaluation in landscape and land use can be obtained by the analysis of multi-temporal images (Prol-Ledesma et al, 2002) which otherwise would not be possible. Besides the advantage of having from CLC usable standardized datasets, the fact of comprising similar time intervals allow a GIS to handle this data (Aspinall, 2000) and have a time frame towards the scope of change, leading us to a dynamic models. The comparison of urban areas in the Algarve concerning the CLC 90 to the CLC 2000 series is hence, the best option to measure change accurately.

CORINE Land Cover has a general nomenclature which was generalized into five distinct classes, namely: Urban, Agriculture, Forest, Wetlands and Waterbodies. All of these five types appeared in the Algarve area.

4.4.2. Comparing Urban Areas in the Algarve in CLC90 and CLC2000

Using ArcGIS ®, both CORINE Land Covers were converted into Raster formats with a 20 pixels cell dimension. The objective of this conversion was the assessment regarding the changes from CLC90 to CLC2000 regarding the main classes as shown in Table 7.

<table>
<thead>
<tr>
<th>From:</th>
<th>Urban</th>
<th>Agricultural</th>
<th>Forest</th>
<th>Wetlands</th>
<th>Waterbodies</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1.94%</td>
<td>0.82%</td>
<td>0.24%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>3.00%</td>
</tr>
<tr>
<td>Agricultural</td>
<td>0.00%</td>
<td>41.95%</td>
<td>0.24%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>42.18%</td>
</tr>
<tr>
<td>Forest</td>
<td>0.00%</td>
<td>1.61%</td>
<td>49.94%</td>
<td>0.00%</td>
<td>0.01%</td>
<td>51.56%</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0.00%</td>
<td>0.01%</td>
<td>0.01%</td>
<td>2.15%</td>
<td>0.00%</td>
<td>2.17%</td>
</tr>
<tr>
<td>Waterbodies</td>
<td>0.00%</td>
<td>0.17%</td>
<td>0.08%</td>
<td>0.00%</td>
<td>0.83%</td>
<td>1.08%</td>
</tr>
<tr>
<td>Total</td>
<td>1.94%</td>
<td>44.55%</td>
<td>50.51%</td>
<td>2.15%</td>
<td>0.84%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Table 7 - Global changes in land use
Both of these changes reflect directly human impact on ecosystem as agricultural areas have reduced in size due to abandonment or from conversion from agricultural areas to urban. What is most shocking, is the urban sprawl within a time frame of 10 years, as the positive variation of 1.94% in urban growth corresponds to a total increase of 62.5% of new urban areas.

Using the comparison matrix (Table 7), we could compare CORINE Land Cover 90 and CORINE Land Cover 2000 at a glance and understand the possible changes within a decade timeframe. This was possible using the methodology shown in Figure 17. With this comparison we assessed the following conclusions:

1. Most of the agricultural areas changed to forest and urban areas.
2. A lesser quantity of Forest areas have changed to urban areas
3. Some Forest areas have changed to agriculture Areas.
4. Little agriculture areas have changed to Forest
(5) Agricultural areas transformed into waterbodies

4.5. Urban Growth Model for the Algarve Area

CORINE Land Cover 90 and 2000 will be used to assess urban growth for the estimated time period of 2007. The results occurred as projection of our model, have to be assessed in territory as no third time period does exist. The validation will be done on GPS assessing a large enough amount of location which allows identifying the accuracy of the generated 2007 map, as can be seen in the figure below (Figure 18, adapted from Cabral, 2006).

![Figure 18 - Accuracy Assessment](link)

The validation of the estimated Urban Growth for 2007 will be done directly in terrain. To achieve this result, GPS points will be randomly collected within the area of study as to allow assessing similarity of actual borders and simulated results. This part is of extreme importance, as it may allow if the results are not as expected a calibration of the model as to allow accurate results. After comparison and relevant accuracy, the 2050 estimate will be projected based on the generated data.
4.5.1. Suitability Map

A suitability map (Figure 19) comprises the complex aspect of social and environmental data and is a map which reflects the adequacy for occurrence of a given phenomena. As we have seen, suitability maps were used in the context of APM to define the locations with higher probability of site occurrence. Regarding urban growth, the paradigm is similar, as it conveys equally in human choice for urban growth adequacy based on a set of rules.

Nevertheless, contrary to the APM in which we had a static model in which we could stochastically understand the propensity of occurrence and therefore use tools such as logistic regression, urban growth is not as much a prediction as it is a projection of the future. This temporal dynamics of Urban Growth models bring us to the uncertainty of urban sprawl and don’t always allow us a clear quantitative approach for modelling urban growth.

Thus, albeit the possibility of using logistic regression to understand urban growth, we have preferred the usage of Multi-Criteria Evaluation as our different datasets may be calibrated at will and adjusted later on as to form the most adequate suitability which projects the as accurate as possible scenario regarding the reality of our analyzed borderline locations.

Hence, a suitability map will be a map in which we have a total weight of different factors that are favourable for urban growth. The factors we have chosen are as follows: Distance from main Roads, Distance from existing Urban Centres, Proximity to coastal area, Slope and variation of population density within municipalities.

In this context, to understand better the dynamics of change, building a Suitability map is very important. A suitability map can be defined as a map which allows a consistent choice of ideal areas and “is significant for land use planning to exploit potential capacity of land, to increase food production and income with effective use and sustainable development of land.” (Zhou et al, 2005)

In the context of sustainable development, urban growth is of course, a major key player and as such, the variables that interfere with urban sprawl should be assessed accurately using a suitability map. Urban growth has been largely documented and is
quite well studied in the GIS context as explained in the Introduction. In our suitability map we will use the criteria which have already been defined in other works (Clarke and Hoppen 1997; Syphard et al, 2004; Alkheder and Shan 2005) and can be consistently explained as follows: “slope, urban extent, transportation, and portions of the landscape that are excluded from development.” (Syphard et al, 2004). In case of the Algarve we will use the dataset of CORINE Land Covers urban extend, slope, main roads and the Natural Reserve Ria Formosa as excluded area from development. Urban extended and its proximity as well as the proximity to the EN 125 are conglomerating factors, while the Natural Reserve and the sea area are constrain factors.

Figure 19 - Suitability Map for urban growth for the Algarve region

Depending on the used spatial resolution, one of the limitations of usage of Cellular Automata may be the area size, as the processor is often unable to process areas with a certain extent. This is a technological handicap which can be forfeited by creating several smaller areas of study interest between the total suitability map thus, calculating areas separately.

4.5.2. Choice of Areas
One of the obstacles yet to overcome regarding applications with cellular automata is the usage in a large enough area of study with high spatial resolution. In our case although it would make sense to use cellular automata for the entire Algarve region, the region is too large to be processed as a whole and as a consequence, it is for now technologically impossible to cope with the total area. As we are interested mainly on the impact of urban growth regarding cultural heritage propensity, a comparison matrix was constructed which allowing in forehand to see, which areas do share the most urban growth (using the generated propensity map) as well as have the largest propensity for site occurrence (using the calculated Multi-Criteria Predictive Model). The areas were compared based on following assumptions: (1) Urban growth propensity should be more than 75 % of occurrence per municipality, and (2) Archaeological Site propensity should be also higher than 75 % per municipality. These assumptions allowed us to apply zone statistics using the urban growth suitability map as well as the predictive archaeological propensity map. The results are shown in the table below (Table 8)

<table>
<thead>
<tr>
<th>Municipalities</th>
<th>Total Area</th>
<th>Propensity for Urban</th>
<th>% Urban</th>
<th>Normalized Urban</th>
<th>Propensity for Site</th>
<th>% Site</th>
<th>Normalized Sites</th>
<th>Risk of Heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagoa</td>
<td>209603</td>
<td>145643</td>
<td>0.69</td>
<td>100</td>
<td>95877</td>
<td>0.46</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>Olhão</td>
<td>304225</td>
<td>111671</td>
<td>0.37</td>
<td>53</td>
<td>160909</td>
<td>0.53</td>
<td>100</td>
<td>53</td>
</tr>
<tr>
<td>Albufeira</td>
<td>341659</td>
<td>171290</td>
<td>0.50</td>
<td>72</td>
<td>128854</td>
<td>0.38</td>
<td>71</td>
<td>51</td>
</tr>
<tr>
<td>VRSAG</td>
<td>116854</td>
<td>30337</td>
<td>0.26</td>
<td>37</td>
<td>46261</td>
<td>0.40</td>
<td>75</td>
<td>28</td>
</tr>
<tr>
<td>Faro</td>
<td>397280</td>
<td>104592</td>
<td>0.26</td>
<td>38</td>
<td>140269</td>
<td>0.35</td>
<td>67</td>
<td>25</td>
</tr>
<tr>
<td>Portimão</td>
<td>427525</td>
<td>125814</td>
<td>0.29</td>
<td>42</td>
<td>102826</td>
<td>0.24</td>
<td>45</td>
<td>19</td>
</tr>
<tr>
<td>Lagos</td>
<td>524705</td>
<td>129570</td>
<td>0.25</td>
<td>36</td>
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| Table 8 - Risk of Heritage Endangerment per Freguesia |
These values were calculated based on the concept that total area of a municipality has in fact, a certain predisposition of cell change into urban area. As a consequence of certain areas being more vulnerable to urban growth than others (propensity of growth has been explained in our suitability map), it becomes important to select which of the most probable urban sprawl municipalities have the highest propensity of having yet undiscovered archaeological heritage. Thus, higher propensity than 75 % for both urban and archaeological activity, have been taken in account knowing total spatial size per municipality. Risk of Heritage therefore is a consequence of higher urban growth probability related to higher archaeological site propensity in given spatial limitation area. The values were normalized based on the samples maximum values per relative percentage to allow the standardization of the so-called Risk of Heritage factor.

As can be seen, highest Risk of Heritage is found in Lagoa (86%), Olhão (53%), Albufeira (51%) (Figure 20).

The overall distribution shows that interior Algarve is less affected by Cultural heritage risk, while littoral areas show highest risk values. The objective to assess these areas becomes even further important, as the municipalities listed with highest values are among the areas with most tourism.

Figure 20 - Areas with higher Cultural Risk
4.5.3. Cellular Automata Urban Growth for Study Areas

Once the criterion for the areas of study choice was defined a cellular automata was build to test urban growth propensity based on the suitability map. The results for each area were constituted by a Markovian transition matrix based on the propensity of land use transformation from CLC 90 to CLC 2000. Having in mind a recommended marginal error of 15%, the Markovian matrix shows propensity of transformation. These sets of change are used for projecting a random choice of 5x5 cells on the latest temporal land cover (CORINE Land Cover 2000). The overall operation was based on CA_Markov on IDRISI which is recommended as a simple and useful methodology (Pontius and Malanson, 2005).

4.5.4. Validation of Study Areas

The forecasted municipalities of Lagoa, Olhão and Albufeira had to be validated for a known time frame. This process is of extreme importance, as it allows calibration of the forecasted model. Albeit the often usage of digital orthophotomaps for such process, we decided to conveniently collect via GPS, thirty random points per municipality, more GPS points per municipality could have helped our accuracy even further, but inaccessibility to certain locations salvaged this as the best option. The random points were strategically located in urban and non-urban areas (15 points of each type) and compared with the projected land-use for 2007. This comparison is done by a so called Confusion-Matrix where, urban and non-urban soil is countered with the random collected point and their correct / incorrect classification. This will give us an error-matrix which leads to a global exactitude (total well classified points in map) and overall statistical Kappa.

In this sense, two hypotheses were underpinned that would lead us further in our study:

\[ H_0: \text{Shall Global Exactitude be less than 80\%, suitability map and model shall be calibrated again for municipality and variables re-considered and re-thought.} \]
**H1:** Shall Global Exactitude be higher than 80% we may process urban growth for 2020.

A global exactitude higher than 80% was found in all three areas. That is, we could advance further in the calculation of the land-use changes for 2020 using the variables we considered and CA_Markov would seem as an interesting methodology. The overall results can be assessed as follows (Table 9).

<table>
<thead>
<tr>
<th></th>
<th>Lagoa</th>
<th>Olhão</th>
<th>Albufeira</th>
<th>Total</th>
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<tr>
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<td><strong>Kappa</strong></td>
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<td>80</td>
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<td>86.5</td>
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**Table 9 - Highest Heritage Endangered Municipalities**

A good Global Exactitude and Statistical Kappa were found. One of the limitations of this analysis is related to the amount of statistical points and their spatial locations. Although the assessed GPS points were located as much as possible in clear urban and non-urban areas, we must be clear that certain areas which could have had results on non-urban inference weren’t feasible to access due to limited assessments. We can’t be exactly sure that those areas are not wrongly classified, as no total points were taken.
4.6. Conclusions

The three areas studied registered a significant augmentation of urbanity in the two time frames existent in CORINE Land Cover (Figure 21). Using the suitability map, we were able to project urban growth for the year of 2007. The importance of this known time reference was that of validation to allow a future projection of urban growth for 2020. As we could see, coastal areas of the Algarve have shown the largest increase of urban growth in last decades and tend to grow even further becoming most probably continuous artificial areas. This tendency is a clear call for sustainability among urban growth areas as natural and cultural heritage landscape may be forever lost in just a little more than a decade.

Jeopardizing Cultural heritage in the Algarve coastal area is seems to be eminent, prompting stakeholders to act proactively. In the next chapter we will analyze the endangerment of cultural heritage phenomena in the studied areas and try to understand which measures may be taken to avoid future risk and to help preservation.

It is clear that urban sprawl can’t be avoided, but at least, there should be an attempt for stakeholders to correct the dire scenario that looms in predictive models. The 2020 scenario should be seen as merely one possibility of interpretation as if we do organize and create the necessary changes, such an eminent disaster can be changed avoided.

The direct impact on archaeological spoils and the projected future scenario is quite obvious: Measures must be taken quickly to avoid future destruction of the endangered cultural heritage.

Our main conclusion from this chapter is that in the next three years, ongoing municipal policies should have in mind the endangerment of the urban sprawl scenario for those areas and should also engage, as construction occurs, archaeological teams and cultural heritage managers to assess directly the construction areas in the next five years as otherwise the cultural heritage are at risk to be lost. In this sense, PROTAL should be assessed in the context of cultural heritage resources, which, although in 2006 reissued regarding sustainability wasn’t the case.
5. ASSESSING THE FUTURE

5.1. Urban Cultural Endangerment Model

The mentioned importance cultural assets, leads us to the construction of a model which compares urban growth in different times, as well as archaeological site propensity. Understanding the dynamics of change from one side, and allowing a comparison of archaeological predicted phenomena, can spatially represent a model of sustainable cultural heritage action.

Having compared urban growth against archaeological predictive models, we have arrived in the previous chapter to what we may define cultural endangerment areas due to urban growth. In this chapter we will try to develop a methodology which may give an accurate perception of spatial endangerment within the most affected municipalities (Lagoa, Albufeira and Olhão).

To achieve this comparison, each municipality represents a spatial aggregate with clearly defined boundaries. The boundaries comprise the articulation to each of the stakeholder’s local policy areas (municipios). The reason for such restricted boundaries relate to two reasons:

- Local policy makers may only act within a municipality and have independence of local decision making processes.
- The models capabilities to calculate a large enough area which would refer to the total extension of the Algarve is not technologically feasible yet, as one of the problems of IT still is, the capabilities and limitations to calculate large enough amount of data.

The calculi of each independent municipality will function in raster datasets, where the UGM and APM as a resulting overlay will shed new light over endangered areas. It is those endangered areas that may lead new clues to urban planning until 2020.

Some of the limitations we have to consider are related to the fact that urban growth is not a constant as well as the prediction of archaeological areas is not a certainty.

Though the existence of these obstacles, it would be possible to understand the change and as a result we would be able to take in the future proactive measures that are important.
The figure (Figure 22) below shows the ontology to achieve the desired results underpinned by the importance of spatial representation in GI Science (Agarwal, 2005): Firstly, Archaeological Predictive Models are calculated; secondly, a suitability map is generated. The spatial overlay of the studied area will allow us to have some perception of cultural heritage endangerment. If we further develop based on the generated suitability map for urban growth urban expansion (using cellular automata) our model may be calibrated and project future urban growth for the specific area. This result allows us to assess accurately which areas may be protected in a certain time frame of analysis.

Figure 22 - Example of Cultural Endangerment Methodology
5.2. Urban Cultural Endangerment Model for Lagoa

As was previously assessed, Lagoa presents the highest rate of Cultural Endangerment especially in the littoral area. Lagoa comprises a total of 6 freguesias (Praia do Carvoeiro, Estômbar, Ferragudo, Lagoa, Parchal and Porches) and the municipality was founded in 1773.

Surrounded by many attractive beaches (Praia de Benagil, Praia de Carvoeiro, Praia Grande, Praia do Molhe, Praia Nova, Praia da Senhora da Rocha, Praia do Pintadinho, Praia da Albandeira and Praia da Angrinha among others) it is a municipality of much tourist attraction and has a yearly festival of circa 800 showcases related to tourism, craftsmanship, agriculture and commerce activities called FATAcil.

Cultural heritage Endangerment appears to be a phenomenon happening around the area of Carvoeiro, between the Borderline of Portimão and the city of Lagoa, and in the proximity of the region of Porches. Unfortunately, very little archaeological investigation has been done in the area, thus, only a few archaeological sites are mentioned in the Carta Arqueologica Portuguesa: location of 200 roman tombstones in Estombar as well as a villa with roman mosaics which are clear indications of wealth and a hermitage in the municipality. This sites suggest a fairly high propensity for archaeological heritage albeit incomplete research.

This conclusion was assessed by calculating the difference between urban growth for 2007 and 2020 obtaining a buffer of the area of predictable growth. Overlaying this information with a higher occurrence then 80% for Archaeological Heritage, we could identify these urban areas that in the proximity tend in the next thirteen years to be endangered. The projection of this information onto Google Earth allowed us to visually assess the landscape endangerment (Figure 23).
Figure 23 - Cultural Endangerment in Lagoa
5.3. Urban Cultural Endangerment Model for Olhão

With 53% of Risk Endangerment the municipality of Olhão is also located in the litoral area. Founded in 1808, Olhão with a total of 5 freguesias (Fuseta, Moncarapacho, Olhão, Pechão, Quelfes), is recently becoming a suburb city of the capitals district Faro. This has influenced directly the urbanization patterns and growth of the cities trend in the last decade, expanding into a large dormitory along the National Road 125.

With much less tourist offer than the municipalities of Lagoa and Albufeira, the city of Olhão is par excellence the capital of the Fish industry in the Algarve. Counting in the beginning of the twentieth century with over 40 fish industries for fish processing, Olhão’s industrial area still today exports to the rest of Portugal certain fish products that have become much appreciated (e.g. sardine paste).

While Moncarapacho, Pechão and Quelfes are located in the interior, Fuseta and Olhão have a more litoral location making especially of Fuseta an interesting beach area in summer.

A clear tendency of continuous urban growth may be observed between Fuseta and the city of Olhão. Moncarapacho shows a large propensity for finding cultural heritage and is expected to grow rapidly in the next years.

Regarding Roman cultural Heritage in Olhão, Estácio da Veiga wrote “The monumental antiquities of the quinta de Marim belonging to Sr. João Lúcio are of utmost importance. This gentleman granted me the rights to examine and explore the vast vestiges of grand constructions that profile the quinta de Marim as a destroyed city which location between Balsa and Ossonoba correspond entirely to the Statio Sacra12 of the Anonimous of Ravenna” (Veiga, 2005). Figure 24 depicts a chapter from the VI / VII century found in the quinta de Marim. (Graen, 2007)

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12 Possible city station from the Roman Imperial period with uncertain location mentioned by an anonymous geographer from Ravenna in the VII century and believed to be located in the quinta de Marim.
The overall assessment of Olhão can be seen in Figure 25, visualization allows us to recognize a clear endangerment pattern around the northern city periphery as well as between the cities of Olhão and Fuseta, where Quelfes is located as well along the border of Moncarapacho.
Figure 25 - Cultural Endangerment in Olhão
5.4. Urban Cultural Endangerment Model for Albufeira

The municipality of Albufeira was founded in the year of 1504 and has been since the 1960s strongly affected by the mass tourism industry. As a result, the main attractions are tourist promotion of sun and beach products, which have brought in the last 40 years to the construction of many hotels along the shore lines of this municipality with a total of 5 freguesias (Albufeira, Ferreiras, Guia, Olhos de Água and Paderne).

The area of Guia seems seriously endangered. This may very well be due to the creation of the largest shopping facility of the Algarve in recent years. On the other hand, the peripheral areas of the main city of Albufeira seem to be enlarging rapidly while expanding along the coast (Figure 29).

Between 2007 and 2020 a new urban area seems to be appearing in the extreme north of the municipalities boundaries. Accessibilities may plain in this case a major role, the A2 as well as the National Road 270 are directing this new trend. If we use Google Earth to analyze closely this area, we seem to be in the limit of the creation of a new urbanization of villas.

Propensity of urban growth and propensity for cultural heritage endangerment share roughly the same values. This is concluded by Table 8 where the normalized urban propensity and cultural heritage are bound to be similar (72 and 71 percent respectively).

Contrary to Lagoa where urban growth is the key responsible for cultural heritage endangerment and Olhão, where cultural heritage endangerment results mainly due to a very high level of site propensity, Albufeira is a case of a synergic endangerment, where the existence of heritage and the existence of some extend of urban growth both together provoke the risk of heritage.

Natural resources available were used largely by the Romans in the present municipality of Albufeira where remains as aqueducts and bridges (like the case of Paderne and Guia shown in Figures 26, 27 and 28) still may be found. Archaeological heritage shows a great presence of Roman commerce and industry in the area (Nunes, I.; 1989).
Figure 26 - Roman Bridge in Paderne (Nunes, I.; 1989)

Figure 27 - Roman Bridge in Guia (Nunes, I.; 1989)

Figure 28 - Roman path in Paderne (Nunes, I.; 1989)
Figure 29 - Cultural Endangerment in Albufeira
5.5. Conclusions

It seems that, urban growth may be endangering phenomena for cultural heritage particularly if no measures are taken to protect the different types of vestiges that may exist. In the Algarve, certain areas which tend to show a larger propensity for urban growth as well as great potential for cultural heritage. Archaeological sites are seriously at stake over the next decade and a half.

The contingency of this risk takes us to the urgent need to handle future urban growth quickly and accurately. Although many Archaeological sites may very well be already lost, it is not too late for planning of urban growth to take specific actions with involved stakeholders, regarding the vestiges of the past.

If urban growth measures are taken with intervention of municipalities collecting and recording cultural heritage and archaeological sites before random planning, proactive thinking may help to understand even further the historic importance of areas useful for future generations keeping a historic legacy which is at stake if no action is to be taken, jeopardizing cultural landscape.

In this chapter it has become evident that urban growth is an eminent phenomena and that cultural heritage may become endangered. Spatial analysis in the form of predictive models (both archaeological and urban) may represent interesting tools for modern planning and monitoring of the dynamics of change as well as informing stakeholders in their regional and local decision making processes and responsibilities.
6. CONCLUSIONS

6.1. Context of Study

It has become quite clear that spatial analysis and Modelling are key methods to track change. In fact, living in a time of major environmental and technological changes, such methods developed this study, are a major asset for sustainable and harmonious planning.

Geographic Information Systems have been proved to be a wonderful tool to analyze urban growth. As accuracy of the models may be tested, their exactitude may be ripened to provide very important information for actors and for future development of areas. Indeed, it is with the technological advances of TI that stakeholders may in future apparently count on sound decision making processes.

The US, England and the Netherlands represent examples of usage of both: Dynamic Spatial Modelling for Urban Growth as well as Archaeological Predictive Modelling. The usage of such models, therefore, is a step towards modernity in the sense where urban growth is not anymore an unpredictable and chaotic process, but rather, a synthesized and studied domain in which actors give great attention in an attempt to preserve, whatever patrimony for future generations.

Unfortunately, predictive models (urban and archaeological) are not much used in Portugal, as data may become quite costly for urban growth models and digital archaeological information is very recent in the Archaeological panorama. This may also be explained due to the natural divergence existing between the human sciences and the technological sciences: Not often do archaeologists or people involved in similar areas have a technological or exact sciences background that may lead to the understanding of IT tools. Nor, with other questions such as the natural environment at hand do stakeholders worry as much about human made patrimony.

Anyhow, human made patrimony is a deep part of mans roots and culture, and should, as such be preserved as much as possible to allow future generations to assess the ways of life of our ancestors.

In this work, two different dimensions have been discussed. We have travelled from the past, in an attempt to spatially understand cultural heritage phenomena and location as
to prevent future damage upon those existing (or yet to be discovered) archaeological sites. Cultural heritage, in fact must necessary understand the facets of the future to preserve. Thus, our two dimensional approach of diving into the past and flying up to the future of urban growth, is an attempt to cope with both worlds in the hope to shed some light upon a new methodological approach which may help stakeholders in their decision making process.

The many questions raised by such venture are in the hope to allow stakeholders to reflect and work together in diverse areas for a better common future.

The choice of the Algarve for such endeavours relates to the summary that this area represents: For one, a strong cultural background due to geographical locations for the Roman Empire, second, the fast urban growth experienced since the 1960s, and finally, the trend of endangerment of natural habitat in the Algarve area and the paradigm on how this endangerment might affect also artificial historical patrimony.

The limitations were naturally a few and are mainly related to the common problem of prediction: The future is in itself completely uncertain. We only may work in a linear approach that models as well as we can what we already seem to know. Thus, as governance and policies as well as societies themselves may change or may have changed due to natural or human incidents our conclusions are necessarily tapped by uncertainty.

Still, our attempt is a methodological approach towards uncertainty, not having in mind an objective analysis of the exact location, as we know that this would be a frivolous attempt that would never reach its goal. Rather, the objective is to offer among uncertainty an idea of monitoring directions for Cultural Resource Managers and regional policies in which differential areas are clearly defined, and thus urban chaos on cultural heritage may be anticipated and necessary proactive measures to protect, as well as discovering while building may be taken.

6.2. Predictive Archaeological Modelling

It has been shown that Predictive Archaeological Models may be important to understand spatial dynamics of the past. Not only in a historical context could they make sense, but mostly, the capability to predict accurately the location of
Archaeological sites may help future technology to discover new findings as well as understanding behavioural patterns of past societies. There is much need for such work in an area such as Portugal where little of such work has been done although there is a vast historic and civilization background.

As no certainty exists which predictive models are more exact, we have created two different models using distinct methodologies. While the first model, Logistic Regression, obeyed to classic rules of Predictive Archaeology, the second model was used with a more expansive and creative methodological approach using Multi-Criteria Evaluation. As Multi-Criteria is commonly used for regional planning, we considered our data as a regional input, in which we used as a trend the clustering of sites in the hope to understand dispersion relations between sites. Such an attempt is quite new and perhaps a bit daring. Fortunately, our results were spatially similar to the ones calculated by the traditional methodology leading us to think that with future developing of Multi-Criteria Analysis for Archaeology interesting approaches could be suggested conciliating a common problem of deductive and inductive modelling strategies.

We may conclude generally, that the Romans in the Algarve had a similar preference to ours relating to spatial occupation, as the highest propensity of sites is in fact, in proximity to current urban areas. This characteristic concatenated to the fact of constant urban expansion and sprawl, justifies the need of the ongoing study.

6.3. Urban Growth in the Algarve

Urban growth has been a constant situation in the last decades. This is an eminent concern, and has been largely discussed in a European context. Regionally, the Algarve is suffering from this problem, and the continuous growth at the constant rate it has had in recent years, will quite quickly in the next 15 years endanger natural and artificial patrimony. One of the reasons which appear to be related to the urban growth areas in the Algarve is tourism. As urban areas with higher tourist activity are more rapidly expanding than others. As cultural heritage is a phenomena which may work as a tourist product by itself, it is up to stakeholders to allow a more sustainable development of further tourist growth having in mind cultural patrimony.
It is clear that urban growth can’t be hindered, and the tendency is for the creation of mega-cities. The question is then how can cosmopolitan areas be sustainable and conciliate fauna, flora and man made patrimony simultaneously? This is indeed a challenge for the short future and may be a decisive step for future generations.

Of our three studied municipalities we concluded that all three are victims of quickly spreading urban growth. The municipality with a highest rate of urban growth in the coming 12 years (2020) is the municipality of Lagoa, followed by Albufeira and Olhão. Figure 30 examines urban growth in the different studied time frames (CLC90, CLC00, 2007 and 2020) for each of the case-study municipalities.

![Figure 30 - Trend lines for urban growth in the studied areas](image)

### 6.4. Cultural heritage Endangerment

The crossing of both models, Archaeological Predictive Models and Urban Growth, has led us to a clearer understanding of cultural heritage and archaeological endangerment due to urban growth. Archaeological sites which have never been discovered yet as well as archaeological sites in the periphery of cities are in an eminent danger as cities continue to expand.

Monitoring in next years in the proposed areas may be a proactive approach for future preservation: As cities grow cultural heritage teams may become engaged as housing is planned, recovering archaeological sites and cataloguing this valuable patrimony considered to be “the most universally valued and most even distributed resource in the world”. (Box, 1999). Also, the decision making process on where to build may become
more accurate, as strategies such as the PROT (Plano Regional de Ordenamento do Território) exist.

Until 2020, the urban landscape will change rapidly and cultural heritage may be jeopardized. The need for action is absolute and urgent to avoid future endangerment of the studied municipalities. Special care should be taken in the municipalities of Lagoa, Olhão and Albufeira that, due to a mix of existing archaeological vestiges and historico-cultural background as well as rapid growth seem to be mostly jeopardized. Olhão shows a very high propensity for cultural heritage and further excavations and ongoing research regarding this municipality should take place especially in the areas of imminent urban construction.

6.5. Future Directions

Much work can still be done regarding both studied dimensions. Regarding Archaeological Predictive Modelling, it has been shown that albeit divergences from the scientific community they are an important tool which may be used in a regional context. Thus, new methodologies that intertwine the doubts of the scientific community are of much importance. As APM become more accurate avoiding the problem of accuracy and consistency (Berman, 2006), urban growth models have to be better understood. Using GIS for UGM is a mandatory direction for future urban planning and predicting the scenarios in such a context is very important. Analyzing urban growth with CORINE Land Cover seems to be a sound direction, as it is the actual European spatial data inventory that shows the scenarios for an entire European tendency of growth. Still, the Minimum Mapping Unit of the CORINE Land Cover as we have seen is quite large, and as a result, it would be an interesting opportunity to in future study how accurate CORINE Land Cover may become or actually is in an urban growth study context.

The future is indeed a question of European and regional synergies in an attempt to inform as well as create knowledge. The Transversal areas called for in such venture, share a common ground in the usage of IT and GIS to shed directions of monitoring and sustainable planning. Above all, this work has made us realize, that the most important future step for sustainability is the need to work together and think together in the
attempt to grasp new processes and ideas which may create mainly more accuracy on proposed methodologies in the hope of sustainable preservation and growth.
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ANNEX
Annex 1. Kolmogorov-Smirnov Tests

1.1. Kolmogorov-Smirnov Test for Aspect Variable:

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<td>1</td>
<td>31</td>
<td>0.45</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Dmax = 0.1532 > 0.0785, Variable not Random

1.2. Kolmogorov-Smirnov Test for Elevation Variable:

<table>
<thead>
<tr>
<th>Elevation Level</th>
<th>Cumulative Percentage Class Area</th>
<th>Sites Observed</th>
<th>Cumulative Percentage Sites</th>
<th>Sites Expected</th>
<th>Class Weight</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>154</td>
<td>0.51</td>
<td>53</td>
<td>2.91</td>
<td>-0.3357</td>
</tr>
<tr>
<td>2</td>
<td>0.37</td>
<td>45</td>
<td>0.66</td>
<td>57</td>
<td>0.79</td>
<td>-0.2962</td>
</tr>
<tr>
<td>3</td>
<td>0.54</td>
<td>24</td>
<td>0.74</td>
<td>51</td>
<td>0.47</td>
<td>-0.2076</td>
</tr>
<tr>
<td>4</td>
<td>0.68</td>
<td>28</td>
<td>0.84</td>
<td>44</td>
<td>0.64</td>
<td>-0.1549</td>
</tr>
<tr>
<td>5</td>
<td>0.81</td>
<td>28</td>
<td>0.93</td>
<td>38</td>
<td>0.74</td>
<td>-0.1200</td>
</tr>
<tr>
<td>6</td>
<td>0.90</td>
<td>12</td>
<td>0.97</td>
<td>26</td>
<td>0.46</td>
<td>-0.0733</td>
</tr>
<tr>
<td>7</td>
<td>0.95</td>
<td>3</td>
<td>0.97</td>
<td>17</td>
<td>0.18</td>
<td>-0.0153</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>5</td>
<td>1.00</td>
<td>12</td>
<td>0.42</td>
<td>-0.0008</td>
</tr>
<tr>
<td>9</td>
<td>1.00</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
<td>1.00</td>
<td>0.0000(1)</td>
</tr>
</tbody>
</table>

Dmax = 0.0000(1) < 0.0785, Variable Random
1.3. Kolmogov-Smirnov Test for Hillshade variable:

<table>
<thead>
<tr>
<th>Hillshade Level</th>
<th>Cumulative Percentage Class Area</th>
<th>Sites Observed</th>
<th>Cumulative Percentage Sites</th>
<th>Sites Expected</th>
<th>Class Weight</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.04</td>
<td>3</td>
<td>0.01</td>
<td>12</td>
<td>0.25</td>
<td>0.0289</td>
</tr>
<tr>
<td>2</td>
<td>0.18</td>
<td>28</td>
<td>0.10</td>
<td>42</td>
<td>0.67</td>
<td>0.0748</td>
</tr>
<tr>
<td>3</td>
<td>0.55</td>
<td>155</td>
<td>0.62</td>
<td>112</td>
<td>1.38</td>
<td>-0.0683</td>
</tr>
<tr>
<td>4</td>
<td>0.89</td>
<td>108</td>
<td>0.98</td>
<td>101</td>
<td>1.07</td>
<td>-0.0905</td>
</tr>
<tr>
<td>5</td>
<td>1.00</td>
<td>6</td>
<td>1.00</td>
<td>33</td>
<td>0.18</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Dmax = 0.0748 < 0.0785, Variable Random

1.4. Kolmogov-Smirnov Test for Land use Variable:

<table>
<thead>
<tr>
<th>Land use Type</th>
<th>Cumulative Percentage Sites</th>
<th>Sites Observed</th>
<th>Cumulative Percentage Sites</th>
<th>Sites Expected</th>
<th>Class Weight</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>0.03</td>
<td>45</td>
<td>0.15</td>
<td>8</td>
<td>5.63</td>
<td>-0.1238</td>
</tr>
<tr>
<td>Agricultural</td>
<td>0.45</td>
<td>193</td>
<td>0.79</td>
<td>127</td>
<td>1.52</td>
<td>-0.3427</td>
</tr>
<tr>
<td>Forest</td>
<td>0.97</td>
<td>55</td>
<td>0.98</td>
<td>156</td>
<td>0.35</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0.99</td>
<td>3</td>
<td>0.99</td>
<td>6</td>
<td>0.50</td>
<td>0.0051</td>
</tr>
<tr>
<td>Waterbodies</td>
<td>1.00</td>
<td>4</td>
<td>1.00</td>
<td>2</td>
<td>2.00</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Dmax = 0.0051 < 0.0785, Variable Random

1.5. Kolmogov-Smirnov Test for Slope (Percentage Rise) Variable:

<table>
<thead>
<tr>
<th>Definition (Percentage Rise)</th>
<th>Cumulative Percentage Class Area</th>
<th>Sites Observed</th>
<th>Cumulative Percentage Sites</th>
<th>Sites Expected</th>
<th>Class Weight</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 9 %</td>
<td>0.51</td>
<td>230</td>
<td>0.77</td>
<td>117</td>
<td>1.97</td>
<td>-0.2593</td>
</tr>
<tr>
<td>9 - 17 %</td>
<td>0.79</td>
<td>46</td>
<td>0.15</td>
<td>13</td>
<td>3.54</td>
<td>0.6411</td>
</tr>
<tr>
<td>17 - 26 %</td>
<td>0.91</td>
<td>19</td>
<td>0.06</td>
<td>2</td>
<td>9.50</td>
<td>0.8489</td>
</tr>
<tr>
<td>26 - 34 %</td>
<td>0.97</td>
<td>5</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34 - 43 %</td>
<td>0.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>43 - 51 %</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51 - 60 %</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 - 68 %</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>68 - 77 %</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dmax = 0.8489 > 0.0785, Variable not Random
1.6. Kolmogov-Smirnov Test for Soil Variable:

<table>
<thead>
<tr>
<th>Definition (Soil Type)</th>
<th>Cumulative Percentage Sites Observed</th>
<th>Cumulative Percentage Sites Expected</th>
<th>Class Weight</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.01</td>
<td>3</td>
<td>2.00</td>
<td>-0.0092</td>
</tr>
<tr>
<td>Fluvisols</td>
<td>0.03</td>
<td>4</td>
<td>0.50</td>
<td>-0.0011</td>
</tr>
<tr>
<td>Regosols</td>
<td>0.03</td>
<td>0</td>
<td>0.00</td>
<td>0.0002</td>
</tr>
<tr>
<td>Lithosols</td>
<td>0.49</td>
<td>138</td>
<td>0.58</td>
<td>0.1941</td>
</tr>
<tr>
<td>Vertisols</td>
<td>0.50</td>
<td>2</td>
<td>4.50</td>
<td>0.1724</td>
</tr>
<tr>
<td>Solonchaks</td>
<td>0.53</td>
<td>10</td>
<td>3.10</td>
<td>0.1033</td>
</tr>
<tr>
<td>Cambisols</td>
<td>0.67</td>
<td>41</td>
<td>2.22</td>
<td>-0.0636</td>
</tr>
<tr>
<td>Luvisols</td>
<td>0.99</td>
<td>96</td>
<td>0.83</td>
<td>-0.0097</td>
</tr>
<tr>
<td>Podzois</td>
<td>1.00</td>
<td>4</td>
<td>0.25</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Dmax = 0.1941 > 0.0785, Variable not Random

1.7. Kolmogov-Smirnov Test for River distance Variable:

<table>
<thead>
<tr>
<th>Definition</th>
<th>Cumulative Percentage Class Area</th>
<th>Sites Observed</th>
<th>Cumulative Percentage Class Area</th>
<th>Sites Expected</th>
<th>Class Weight</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.20</td>
<td>8</td>
<td>0.03</td>
<td>60</td>
<td>0.13</td>
<td>0.1728</td>
</tr>
<tr>
<td>200</td>
<td>0.37</td>
<td>90</td>
<td>0.30</td>
<td>52</td>
<td>1.73</td>
<td>0.0722</td>
</tr>
<tr>
<td>400</td>
<td>0.52</td>
<td>41</td>
<td>0.14</td>
<td>45</td>
<td>0.91</td>
<td>0.3840</td>
</tr>
<tr>
<td>600</td>
<td>0.65</td>
<td>50</td>
<td>0.17</td>
<td>38</td>
<td>1.32</td>
<td>0.4796</td>
</tr>
<tr>
<td>800</td>
<td>0.75</td>
<td>33</td>
<td>0.11</td>
<td>31</td>
<td>1.06</td>
<td>0.6390</td>
</tr>
<tr>
<td>1000</td>
<td>0.83</td>
<td>27</td>
<td>0.09</td>
<td>24</td>
<td>1.13</td>
<td>0.7402</td>
</tr>
<tr>
<td>1200</td>
<td>0.89</td>
<td>20</td>
<td>0.07</td>
<td>19</td>
<td>1.05</td>
<td>0.8263</td>
</tr>
<tr>
<td>1400</td>
<td>0.94</td>
<td>14</td>
<td>0.05</td>
<td>14</td>
<td>1.00</td>
<td>0.8935</td>
</tr>
<tr>
<td>1600</td>
<td>0.98</td>
<td>5</td>
<td>0.02</td>
<td>11</td>
<td>0.45</td>
<td>0.9586</td>
</tr>
<tr>
<td>1800</td>
<td>1.00</td>
<td>8</td>
<td>0.03</td>
<td>7</td>
<td>1.14</td>
<td>0.9733</td>
</tr>
<tr>
<td>2000</td>
<td>1.00</td>
<td>4</td>
<td>0.01</td>
<td>0</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Dmax = 0.9733 > 0.0785, Variable not Random