Chapter 15
The Role of Visualisation in Spatial Planning: A GIS-Based Approach

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Abstract Developments in Geographical Information Systems (GIS) have significantly empowered the role of visualisation in spatial planning. Visualisation mobilises 'visual thinking' contributing thus to the development of 'visual communication skills' through graphical representation, exploration and better understanding of spatial data and spatial relations. Furthermore, GIS support processing and analysis of spatial data as well as the investigation of spatial patterns and future visioning. In their capacity as integrated Spatial Decision Support Systems, GIS offer a critical comparative advantage to the formulation of robust decisions, concerning the future development of complex spatial systems, by enabling the visualisation of the involved elements and the efficient management of geo-referenced data. By refining the integration of Multiple Criteria Decision Analysis (MCDA) into GIS, further advancements can be achieved in spatial decision support processes. The present chapter focuses on the added value that visualisation may provide in spatial planning by integrating GIS technology into the planning process. Firstly, the concept of visualisation under the framework of GIS is analysed. Then, the potential of MCDA in visualisation for spatial analysis is illustrated and finally emphasis is placed on the role such developments may offer in participatory planning and scenario analysis.

Keywords Visualisation · Geo-visualisation · Spatial planning · GIS · MCDA · Scenario planning · Participatory planning

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15.1 Introduction

'A picture is worth a thousand words'. This famous and extensively used expression was born in the early twentieth century in the USA and has been attributed to Frederick Barnard. It is a variant of the Chinese proverb 'One picture is worth ten thousand words' and emphasises the force of optical means in conveying and communicating complex meanings and ideas. Its conceptual framework is based on the fact that sometimes graphical representations have the ability to transfer knowledge and thoughts more effectively than verbal expressions. Pictures are inherently linked to the mental capabilities of human perception and enhance consciousness through visioning. They constitute simple representations of reality while, in their more artistic form, they may also reflect thoughts and emotions.

The importance of visualisation for transferring knowledge and increasing awareness has been broadly acknowledged by a significant number of scientific disciplines and visualisation technologies were developed in order to serve several scientific purposes. Especially in the case of engineering and spatial planning, the visual representation of geographic reality, spatial entities and spatial relations is of utmost importance in order to deeply explore and understand the structure of complex physical systems and man-made environment. The term 'spatial planning' refers to a wide range of systematic activities designed to ensure that desired spatial goals are achieved in the future (Van den Brink et al. 2007). When it comes to the design and implementation of spatial interventions, visualisation/geo-visualisation is an inseparable component of the planning process and spatial decision making as it facilitates the investigation of existing problems, the elicitation of possible alternatives and the screening of their effects.

Before the advent of modern ICT, printed material such as maps, photographs, tabular data and graphs were used in order to better analyse the problem under study and seek for solutions. Nevertheless, such means offered limited capabilities for data elaboration and spatial analysis. Thus, in most cases they served as supplementary material that could simply support decision processes, however, missing the potential to 'produce' new and innovative information.

The evolvement of computer science and the advent of modern GIS technology inaugurated a new era for environmental and engineering sciences. They offered advanced visualisation and spatial analysis capabilities and contributed to the development of integrated Spatial Decision Support Systems (SDSSs) that enable storage and update of spatial data and information, data processing, structure of decision rules, argumentation mapping, production of decision maps and analysis of spatial patterns. Spatial planning takes advantage of all the above-mentioned competences and exploits visualisation technologies and GIS in order more robust, informative, efficient and concrete spatial decisions to be designed.

More specifically, the adoption of GIS and visualisation tools has been rapidly proliferated in cases where scenario analysis, participatory planning and GIS-based MCDA are performed, aiming at the future sustainable development of spatial systems and the efficient management of available resources. Mixed approaches such as participatory GIS-based MCDA and participatory scenario analysis have also capitalised on the comparative advantages that such technologies may bring to the planning process. The literature is replete of relevant applications exploiting the additive value of visualisation and spatial analysis under a spatial decision making framework. The majority of them concern the allocation of land uses, the assessment of site suitability for the establishment of activities, the protection of forest land and natural ecosystems, the improvement of transportation services, the allocation of landfills and waste management, the assessment of flood risks and the protection of coastal areas.

The starting point for the development of such applications was the evolvement of modern GIS software that integrate visualisation capabilities and algorithms supporting spatial analysis and management of spatial data (Goodchild 1992, 2004; Malczewski and Rinner 2015). Spatial analysis represents a distinguished characteristic of modern GIS technologies, underlining the key difference of GIS from software allowing simple map production (Maguire 1991; Goodchild 1988), and setting the ground for the detailed investigation of complexities and peculiarities characterising contemporary spatial systems. In this context, modern GIS represent integrated SDSSs assisting planners in producing 'new' knowledge that supports spatial decision making. GIS-produced dynamic and interactive maps are a vigorous visualisation tool in the hands of planners wishing to disseminate and better communicate the planning process (Lami et al. 2011; Xu and Coors 2012; Dunkel 2015; Fiorini et al. 2016; Wissen Hayek et al. 2016; Büttner et al. 2018).

The integration of MCDA methods with visualisation technologies and GIS can be met in various approaches and their implementation in spatial planning applications is found in a plethora of research articles, analysing their benefits and assessing their effectiveness. Most applications build on the potential that GIS bring into spatial decision making by offering the possibility for spatial analysis and production of decision maps (Goodchild et al. 1999; Malczewski 1999, 2006, 2010; Greene et al. 2010; Malczewski and Rinner 2015). This is the rationale upon which GIS-based MCDA was based and allowed for the representation and exploration of geo-referenced alternatives and criteria. The spatial variability of alternatives' scores and criteria weights has become more comprehensible and the specific framework of spatial MCDA has been scrutinised.

Participatory planning and stakeholder evaluation have also benefited from visualisation and GIS technology. Visualisation enhances visual thinking, comprehension ability and perception of the problem under study. GIS and web-GIS technology strengthen knowledge sharing, argumentation mapping, interactivity with dynamic maps and active participation in decision making processes. Participatory GIS/Public Participatory GIS (PGIS/PPGIS) technologies is a representative example of participatory initiatives promoting community planning and collaborative spatial decision aid (Hansen and Prosperi 2005; Ganapati 2011; Papadopoulou and Giaoutzi 2014; Brown and Fagerholm 2015; Wolf et al. 2015; Babelon et al. 2016).

Finally, the visualisation and assessment of scenarios by adopting GIS, photorealistic and 3D representations are is a very common practice, employed during scenario analysis and impact assessment. Scenarios are built in order to explore possible future conditions and propose likely policy packages. Visualisation means increase legibility, especially when spatial dimension is involved. Moreover, GIS-based MCDA supports scenario assessment by enabling the visualisation of impacts on a decision map. Relevant applications can be found in the works of Tress and Tress (2003), Sheppard and Meitner (2005), Sheppard et al. (2011), Kehl and de Haan (2013), Krolik-Root et al. (2015), etc.

This chapter reflects on the role that visualisation tools and technologies may play when addressing spatial problems in order to reach spatial decisions. The comparative advantages and additive value of such a potential are investigated under the framework of GIS technology. In this context, the concept of visualisation under the framework of spatial planning and GIS is explored; the potential of MCDA for visualisation in spatial analysis is presented; the role of visualisation and GIS-based MCDA in participatory planning and scenario analysis is delineated and finally a conclusive discussion is presented.

15.2 The Concept of Visualisation in the Context of Geographic Information Systems and Spatial Planning

The representation of geographical space, spatial phenomena and spatial relations requires the development of spatial models, supporting the visualisation of geographic reality. Through the potential that spatial models offer, geographic reality becomes more obvious and tangible. Visualisation mobilises the so-called visual thinking that enhances the intuitive approach of a research discipline. The scope of visualisation differs according to the purpose it serves; thus, it could vary from the artistic expression and visual communication of information to data visualisation for the development of interactive applications, etc. This explains the broad range of definitions for the term 'visualisation'.

Some indicative and popular definitions of 'visualisation', adopted by several disciplines, are:

- Visualisation is a tool that serves the comprehension/understanding of data acquired either through simulation processes or through physical measurements, by exploiting computer imaging technologies (Haber and McNabb 1990).
- Visualisation of information is the communication/transmission of abstract data through the exploitation of interactive visual interfaces (Keim et al. 2006).
- Visualisation of information exploits computer graphics and interaction in order to support problem solving (Purchase et al. 2008).
- Visualisation is a process through which patterns and relations among data become visible (Manovich 2011).
- Visualisation refers to representations of data after applying transformations, filters and visual encodings (Mclnerny et al. 2014).

- Visualisation concerns the representation and presentation of data to facilitate understanding (Kirk 2016).
- Visualisation supports data representation in order to be easily tangible by the viewer without the need for additional statistical details (Shen et al. 2019).

It is obvious that the majority of definitions place emphasis on data representation through the exploitation of interactive means in order to communicate information and make it more comprehensible. This is the primary scope of visualisation methods and a common element of all frequently used definitions. Among the available techniques supporting visualisation purposes are (Keim et al. 2005):

- *2D Visualisation*: Data are defined in 2 dimensions and represented in the Euclidian plane. Visualisation is based on geometric axioms and relations such as the distance among objects. In the case of spatial data, coordinates and spatial relations are taken into consideration.
- *3D Visualisation*: Data are defined in 3 dimensions. Except for the Euclidean space, the third dimension (height, depth, etc.) is exploited so that 3D representations to be produced.
- *Geometrically transformed display*: In this case, multi-dimensional transformations for data sets of specific interest are explored. Statistical techniques and geometrical representations of k-dimensional spaces in 2D space are exploited.
- *Stacked display*: It is used for the representation of hierarchically arranged data. In case of multi-dimensional data, the dimensions of data are used for data classification and structure of the hierarchy.

In the context of Geographic Information Science (GIScience) and spatial planning, visualisation concerns the representation of spatial data/information and aims at their processing, the implementation of spatial analysis procedures and the production of maps. According to the definition given by ESRI (2020), visualisation is the representation of data through a viewable medium or format. Its ultimate goal is the organisation of spatial data and information in a number of layers that can be analysed or represented as maps, 3D representations, charts, tables, etc. Buttenfield and Mackaness (1991) define visualisation as an important element for the comprehension, analysis or interpretation of the distribution of several phenomena on earth’s surface, while the level of importance is increased with the accumulation of spatial data and the need for their effective management. Processes like spatial data modelling, analysis of trends and patterns, elicitation of conclusions and Decision Support Systems (DSSs) exploit the advantages of visualisation towards the production of ‘new’ knowledge and information (Buttenfield and Mackaness 1991). Data analysis, exploration and validation of geographical information enhance ‘visual thinking’ while visual communication is attained through synthesis and production of ‘new’ geographical information.

At this point it should be mentioned that the visualisation of spatial data and information is usually referred to as ‘geo-visualisation’. Geo-visualisation belongs to the variety of communicative methods that exist to support social learning. Geo-visualisations are two-dimensional or three-dimensional visual representations of data having a geographic reference. They can be used to exchange spatial information in spatial planning processes (Van den Brink et al. 2007). Generally, the term ‘geo-visualisation’ concerns a set of methods, techniques and practices aiming at the visualisation of data, information and phenomena related to the earth’s surface and geographical space (geo-referenced data and information). Geo-visualisation exploits graphics for analysing data, the location of which is used as a necessary and essential part of the analysis while it may be perceived as the intersection of cartography and scientific visualisation through computer graphics (Unwin 2008). More definitions about geo-visualisation are:

- Geo-visualisation is a scientific tool focusing on the visual investigation, analysis, synthesis and representation of geographical data and information by combining different approaches derived from GIScience, cartography and image analysis (Dykes et al. 2005).
- Geo-visualisation aims at the exploration, analysis, synthesis and representation of geo-referenced data and information (Nöllenburg 2007).
- Geo-visualisation constitutes an abbreviation of geographical visualisation referring to a set of tools and techniques that support geo-spatial communication and processing, and information analysis through the exploitation of interactive maps (Jobst et al. 2010).
- Geo-visualisation supports the representation of real or simulated 2D or 3D geographical information by enabling interaction and exploiting the experience of users (Diehl and Delrieux 2012).
- Geo-visualisation supports representation of spatial data by using more sophisticated formats like maps, info-graphics, 3D globes, pie and fever charts, etc. (Harbola and Coors 2018).

Geo-visualisation is usually categorised into *static geo-visualisation* and *dynamic geo-visualisation*. Static geo-visualisation is used to represent geographical space and phenomena with the support of 2D maps, charts, etc.; dynamic geo-visualisation, on the other hand, involves the time dimension and enables the dynamic representation of geographical reality and processes by exploiting computer graphics, 2D and 3D animations, interactive maps, virtual reality, etc. (Fabrikant and Goldsberry 2005).

Some indicative geo-visualisation techniques are (Nöllenburg 2007):

- *2D Geo-visualisation*: It constitutes the most frequent method supporting the visualisation of spatial data and is commonly referred to as ‘2D cartographic visualisation’. The area of interest is depicted on a map. The representation of the several map components is based on their coordinates and on available statistical or classified data (e.g. choropleth maps).
- *3D Geo-visualisation*: The evolvement of graphics technology enabled the production of 3D realistic images and 3D virtual environments. In spite of the simple 3D representations, it is now possible to create Cave Automatic Virtual Environments (CAVEs) and Power Walls, allowing for a stereoscopic vision of the

several phenomena. 3D representations approach better the human perception of space while the third dimension may represent height, depth, time, etc.

- *Visual data mining tools*: This method supports visual analysis of data and the enrichment of existing knowledge stock through the production of 'new' knowledge. It allows for the representation of multi-variable data (spatial and non-spatial attributes) in order relations and patterns to be easily understood by the user. Such kind of representations may be geometric visualisations, pixel-based visualisations, graph-based visualisations, etc.
- *Animation*: It is a dynamic geo-visualisation technique that incorporates the dimension of time as a third dimension in the relevant representations. In this case, the temporal change of the represented elements becomes visible.
- *Spatio-temporal visualisation*: It supports the visualisation of temporal evolution of spatial properties, thematic properties, etc. (e.g. population changes, climate change). The two dimensions represent geographical space and the third one represents the dimension of time.

Visualisation/Geo-visualisation constitutes one of the key features of Geographical Information Systems (GIS). The original development of GIS was based on the fundamental concepts of visualisation, processing, analysis and interpretation of spatial data and spatial information. Nowadays they have evolved into integrated SDSSs with the main advantage of allowing for the simultaneous management of spatial and attribute (non-spatial) data. Moreover, they support the connection of such attribute data with the respective spatial entities.

GIS build on the principles of GIScience which focuses on the exploration of the nature of geographical information and geographical phenomena and constitutes the theoretical background of GIS and technologies serving the visualisation and management of geographical data and information (Goodchild 1992, 2004; Malczewski and Rinner 2015). Consequently, a Geographical Information System enables collection, storage, communication, management, analysis, indexing and representation/visualisation of spatial data and geo-referenced information aiming at the production of information/'new' knowledge and the support of decision making processes (Goodchild et al. 1999; Malczewski and Rinner 2015). Emphasis is placed on addressing/performing spatial analysis (Maguire 1991); that in many cases determines a GIS and differentiates it from systems that simply produce maps (Goodchild 1988).

GIS support the visualisation of the shape, size, position and orientation of spatial entities. This is achieved through the exploitation of two basic spatial models: the *field-based model*, representing continuous phenomena (e.g. temperature), and the *object-based model*, representing geographical space through distinct spatial entities (e.g. buildings). The field-based model is implemented by the raster data structure (canvas), while the object-based model is implemented by the vector data structure (lines, points, polygons or complex geometries).

Particularly in the case of spatial planning, geo-visualisation supports the exploration and analysis of interventions aiming at meeting future 'spatial goals'. These planning processes deal with complex planning issues involving multiple urban functions that compete for land, such as housing, employment and infrastructure (Van den Brink et al. 2007). Accordingly, geo-visualisation allows for the investigation of possible problems, the definition of relevant goals and objectives, the exploration of current situation and future trends, the analysis of future scenarios and their evaluation, as well as the definition of future policy options. A significant number of visualisations, like maps, satellite images, charts, tables, pies, etc., put an additive value to the whole spatial planning process by enabling the visual representation of all elements involved in the planning process. Moreover, visual means facilitate collaborative decision making, management of trade-offs and elimination of possible conflicts by making data and information more comprehensible, perceivable and tangible.

Andrienko et al. (2007) introduced the concept of *'Geo-Visual Analytics for Spatial Decision Support'* in order to determine an interdisciplinary scientific area, focusing on the development of computational methods, techniques and tools that deal with spatial problems through reinforcing human capabilities to analyse, envision, reason and deliberate. The complex structure of modern GIS and the multiple factors, criteria and knowledge involved in spatial decisions constitute the main characteristics differentiating 'Geo-Visual Analytics for Spatial Decision Support' from the general discipline of 'Visual Analytics'.

Geo-information technologies, embodying several bottom-up processes (e.g. PGIS, PPGIS), enhance also participatory planning (McCall and Dunn 2012). Such technologies offer the possibility for the development of applications enabling the implementation of (online) discussions onto map backgrounds or other visualisation means, the formulation of comments and suggestions, the design of sketches and symbols on maps, etc. The development of PGIS/PPGIS technologies has been strengthened by the evolvement of web-GIS and web-mapping technologies. Among the advantages of such technologies are the possibility for broad and asynchronous public participation, the extensive dissemination of spatial decisions and the better understanding of spatial problems.

In the literature, there is a significant number of indicative examples where visualisation applications have been used for supporting spatial planning and spatial decisions. In the region of Ruhr (Germany) dynamic maps were built in order to represent/visualise territorial transformations related to the possible implementation of three alternative scenarios for improving the rail line; Analytic Network Process (ANP) was combined with geo-visualisation tools in order results of the ANP (subnets and scenarios) to be shown and support users to better understand the parameters and effects of each scenario (Lami et al. 2011). For a better management of issues related to Maritime Spatial Planning (MSP) (e.g. management of traffic volumes, reduction of ship emissions, etc.) and the spatio-temporal distribution of human activities in marine areas, worldwide route density maps were created by exploiting Automatic Identification System (AIS) records, providing vessel positions, in order to process ship routes (Fiorini et al. 2016). In the Canton of Zurich, Switzerland, a web-based visualisation platform, incorporating ecosystem services indicators, was developed in order to support municipal authorities to identify watercourse corridors based on the revised Swiss Waters Protection Act (Wissen Hayek et al. 2016).

Other indicative examples originate from: Carsjens and Ligtenberg (2007), dealing with the STEPP tool that allows for the assessment of land use environmental impacts and the design of new spatial arrangements through the analysis of human activities, on the basis of land use data, and the visualisation of relevant environmental impacts in order zones of influence to be identified and 'environmental impact' and 'environmental quality' maps to be produced; Xu and Coors (2012), addressing the assessment of urban residential development through the exploration of trends of sustainability indicators and the visualisation of results in 2D density maps (ArcGIS) and 3D representations (CityEngine); Dunkel (2015), focusing on the contribution of crowdsourced data (photos) from Flickr to the visualisation of landscape perception and evaluation of scenarios supporting the development of landscape and urban planning; Büttner et al. (2018), presenting the development of the Technical University of Munich (TUM) accessibility Atlas for the metropolitan region of Munich in order to explore accessibility issues (e.g. accessibility by the public and private transport, future trends in mobility costs, etc.) as part of the integrated land use and transport planning of the area, through the adoption of a GIS toolbox supporting map production and visualisation of spatial and socioeconomic disparities; Bouattou et al. (2018), dealing with the issue of producing real-time visual summaries of spatio-temporal patterns through the adoption of a multi-agent system approach; Ma et al. (2020), concerning the development of a virtual reality tool that enables the visualisation of spatial systems dynamics and supports the management of urban infrastructure ecosystem.

In the above context, visualisation supports a variety of spatial procedures by enabling the integration of multiple factors affecting spatial planning, facilitating the assessment of alternative future scenarios, enhancing participatory initiatives, reinforcing the analysis of geo-referenced data and strengthening visual thinking and reasoning. In the following sections, such issues are analytically presented in an attempt to deeply investigate the added value that visualisation may bring into GIS-based MCDA, scenario analysis and participatory planning.

15.3 The Potential of MCDA in Visualisation for Spatial Planning

The adoption of interdisciplinary approaches for managing spatial problems is a very popular practice supporting the integration of methods, techniques and tools in the spatial planning process. Towards this end, the integration of MCDA with GIS and the resulting geo-visualisation capabilities have determined a new 'era' in the field of spatial decision making and the development of SDSSs. The outcome of all the steps of a MCDA process namely definition of alternatives, criteria and weights may be visualised and analysed with the support of GIS technology, where the spatial dimension of the several components involved in a MCDA process can be considered.

GIS-based MCDA is defined as a process that: a) allows the transformation of geographical data and their combination with assessments and b) supports decision making through the generation of robust and integrated knowledge (Malczewski 2006, 2010). Moreover, the integration of MCDA methods in GIS tools and software may support participatory evaluation, enabling convergence of possible conflicts, comprehension of spatial interactions and communication among the participants involved in a decision making process. Ideally, an integrated MCDA-GIS system combines the advantages of multi-criteria assessment and spatial analysis. The user has the possibility to interact with the system, explore the consequences of several alternatives and produce decision maps by overlaying layers that represent evaluation criteria.

Spatial decision support focuses on the management of problems with particular characteristics. The final decision on the most suitable solution is based on two main questions: (1) *what* should be done? (Action) and (2) *where* it should be implemented (Location)? (Malczewski 1999; Chakhar and Mousseau 2008; Malczewski and Rinner 2015). The first question refers to the decision making process per se, while the second concerns the 'receptor' of the final decision, namely, the most suitable location for the development of a specific activity. Accordingly, in the cases where GIS-based MCDA is applied, emphasis is placed on the spatial variability of alternatives' scores and criteria weights. Thus, parameters of spatial homogeneity and heterogeneity are taken into consideration when defining and standardising criteria weights.

The most popular MCDA methods, incorporated in GIS software include the Weighted Sum Method, the TOPSIS method, the Analytic Hierarchical Hierarchy Process (AHP), the Analytic Network Process and a number of hierarchical methods (Malczewski and Rinner 2015). Indicative GIS software/routines, employing GIS-based MCDA methods are: the IDRISI (Multi-criteria Evaluation Model) package, the ArcGIS Overlay Toolset and the MCDA4ArcMap. Such computational tools allow for the management and spatial analysis of either vector or raster data by exploiting map algebra and MCDA algorithms (Rinner and Voss 2013; Malczewski and Rinner 2015).

In general, MCDA involves assessments regarding the performance of alternatives with respect to a number of evaluation criteria and judgments concerning the importance of criteria (criteria weights) with respect to the main goal of the problem (Nijkamp and van Delft 1977; Roy and Vincke 1981; Nijkamp et al. 1990; Beinat and Nijkamp 1998; Montibeller and Franco 2010; Cinelli et al. 2014; Roy 2016). Spatial analysis focuses on the profound exploration of spatial relations, the examination of spatial attributes and the assessment of several spatial procedures through the exploitation of spatial methods, spatial models and algorithms (Rogerson and Fotheringham 1994; Goodchild and Longley 1999; Longley and Batty 2003; Steinberg and Steinberg 2015).

Under a GIS context, spatial analysis and visualisation are inseparable. Visualisation allows for the visual representation of spatial analysis procedures such as data processing, investigation of spatial correlations, analysis of spatial relations and spatial patterns, production and mapping of innovative spatial information. Moreover, visualisation supports the elaboration of various types of data such as text content, statistical and tabular data and topographic/geodetic data on map backgrounds, establishing an integrated framework for a robust analysis of the problem under study, the consideration of all parameters involved and the generation of novel outcomes.

MCDA, on the other hand, provides a comparative advantage on spatial analysis, as it sets the ground for the assessment of geo-referenced alternatives on the basis of geo-referenced evaluation criteria. This comes through the visualisation potential that modern visualisation tools and technologies offer. The visual representation of alternatives and criteria and the execution of MCDA algorithms—implementing relevant MCDA methods—on a map background contribute to a better formulation of spatial decision problems, the deep comprehension of the components involved in a MCDA process, the enhancement of visual thinking during the spatial decision making processes, the elicitation of more realistic conclusions and the design of effective interventions.

GIS-based MCDA comprises a number of distinct steps through which a spatial problem is analysed and possible alternatives are assessed. Such steps include (Fig. 15.1): (a) the explicit definition of the problem under study, (b) the de-composition of the problem into several sub-models in order to reduce complexity, (c) the determination of evaluation criteria and their transformation into map layers, (d) the reclassification of values referring to different numbering systems in order layers to be comparable (standardisation), (e) the assignment of weights to the relevant criteria-layers, (f) the aggregation of all map layers and the production of a decision map and g) the analysis of outcomes.

The implementation of the aforementioned procedure allows for the visualisation and experimentation with geo-referenced alternatives and criteria, the contemporaneous analysis of both spatial and non-spatial data, the production of new visualised information, the visual interaction of all elements and dimensions of the problem under study and the visual representation and interpretation of the respective results. The spatial variability of all involved factors is considered and figured out with the support of relevant map backgrounds and spatial models. In this context, the specific characteristics of each location are considered.

Common applications of GIS-based MCDA include evaluation of site suitability, assessment of land use changes, appraisal of natural disasters, risk assessment, allocation of several activities, etc. Evaluation criteria, represented as map layers, incorporate concepts like 'accessibility' to transportation networks, 'proximity' to areas of interest (e.g. urban centres, markets), 'distance' from hydrographical network or protected areas, slope suitability, etc. Possible alternatives are included in such layers. The visualisation of all necessary data and information offers the potential for screening feasible alternatives by eliminating those which are totally unsuitable, inspecting one by one the evaluation criteria, making suggestions as to their importance and getting familiarised with the particular characteristics of the study area.

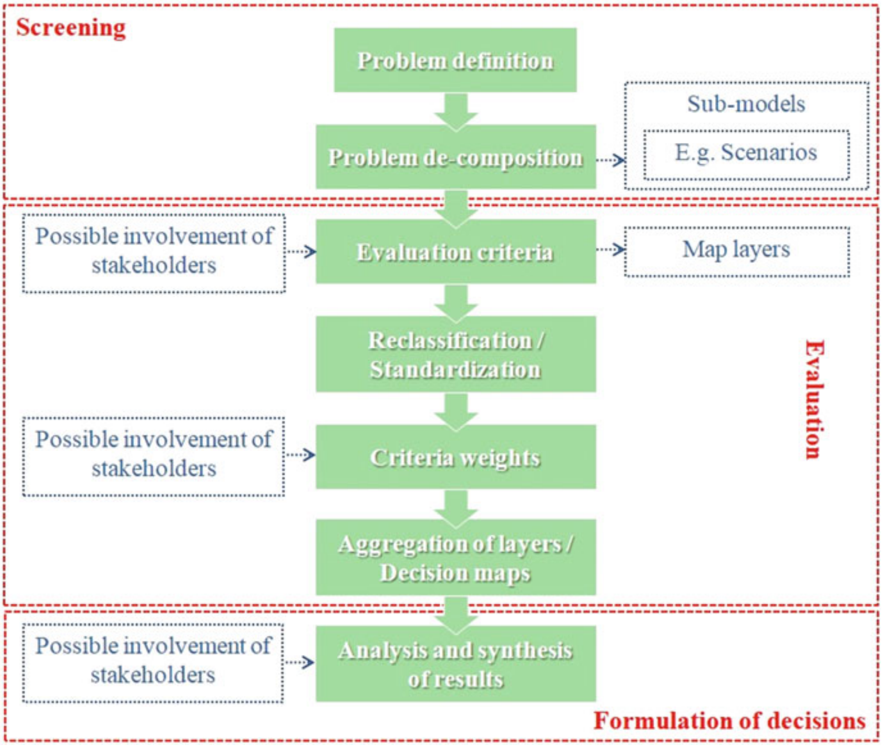

Fig. 15.1 GIS-based MCDA process (adapted from ESRI 2020)

The literature reports on a significant number of GIS-based MCDA applications referring to various spatial decision problems where the visualisation of MCDA components and the analysis of spatial entities are of utmost importance for the robust output of spatial decision processes. De Feo and De Gisi (2014) implemented a GIS-based MCDA for selecting the most suitable location for the establishment of a landfill; a land use map enabled the visualisation of possible locations and the initial exclusion of unsuitable areas. Meng et al. (2011) employed GIS-based AHP and 'Ordered Weighted Averaging' (OWA) for mapping accessibility patterns of housing development sites in Alberta. Papadopoulou and Hatzichristos (2019) applied Weighted Sum and Fuzzy Overlay Analysis in order to explore the most suitable location for the establishment of an agro-tourist infrastructure in Crete, Greece.

Other indicative examples include: the investigation of suitable sites for the location of a landfill in the urban area of Pondicherry (India) through the implementation of MCDA and overlay analysis in GIS where visualisation capabilities and spatial analysis allowed for the elimination of environmentally unsuitable areas (initial screening) and the assessment of possible suitable sites on the basis of a number of criteria, represented as map layers (Sumathi et al. 2008); the selection of the most appropriate site for industrial development in Vojvodina (Serbia) through site screening and site evaluation supported by GIS-based AHP and Weighted Linear Combination (Rikalovic et al. 2014); the exploitation of a GIS-based MCDA approach, involving fuzzy AHP and TOPSIS, for the development of a refugee camp in south-eastern Turkey (Çetinkaya et al. 2016); the production of landslide susceptibility maps by adopting GIS-based MCDA methods and their combination with logistic regression analysis and association rule mining in order to assess risks related to landslide hazards (Erener et al. 2016); the identification of proper areas for the establishment of healthcare facilities by employing GIS-based MCDA in order suitability maps to be produced (Dell'Ovo et al. 2018).

The successful implementation of such applications depends on both, the adoption of an appropriate MCDA method and the use of visualisation means and technologies in support of spatial analysis. Evaluation criteria are visualised and represented as thematic maps; constraint maps, enabling the identification of unsuitable areas, are created; screening of possible alternatives is carried out, and decision maps are generated through the aggregation of the relevant layers. This is the common place of all applications utilising MCDA in combination with GIS technology and targeting at addressing spatial decision problems.

15.4 The Role of Visualisation and GIS-Based MCDA in Participatory Planning

Participatory planning implies the engagement of stakeholders in decision making processes and constitutes a significant tool supporting the elicitation of valuable knowledge and expertise. In the case of spatial planning, the involvement of stakeholders and the exchange of information greatly influence the degree of mutual understanding, consensus and support for proposed changes.

According to Van Asselt and Rijkens-Klomp (2002), participatory planning allows participants to get involved in processes concerning the design of initiatives and decisions that are going to affect them. In this context, participatory planning is directly connected to the involvement of interested parties (e.g. citizens) in plan-making and problem solving procedures (Dietz 1995; Innes 1996) while it is strongly related to the concept of democracy (Woltjer 2002). Participatory planning contributes to the improvement of management decisions as it builds on the concepts of 'collaboration' and 'co-creation' and sets the ground for the undertaking of broadly accepted solutions (Kovács et al. 2017).

The role and influence of stakeholders in such processes vary according to the level of participation that is practised. The levels of participation differ, ranging from the 'simple provision of information' up to 'citizen control' (highest level of participation) (Arnstein 1969). In its highest level, participatory planning takes the form of 'co-design' and 'co-decide' as participants are invited to actively 'co-shape' their future by reporting existing problems, expressing their preferences, specifying their needs and discussing possible future perspectives. Thus, participatory planning represents a learning and retroactive process that feeds decision making with new and innovative knowledge which in turn, leads to the design of informative and robust decisions (Dalal-Clayton and Dent 1993; Rowe and Frewer 2000).

In recent times the shift from 'top-down' to 'bottom-up' approaches has gradually evolved and participatory initiatives have been dynamically incorporated in spatial decision making. The rationale behind such an approach is that spatial decisions affect people's daily life and standards of living as they set the ground for the development of several productive sectors. Moreover, people/citizens may offer into the planning process additive knowledge related to the specific characteristics, comparative advantages and peculiarities of 'their' own city/neighbourhood. As a result, participatory planning has evolved into a critical dimension of spatial planning, supporting among others the efficient management of environmental resources, social relations and economic assets.

The exponential proliferation of visualisation/geo-visualisation tools, GIS technology and GIS-based MCDA routines has empowered participatory planning initiatives as they enable the visualisation of parameters and variables involved in a study problem, the illustration of the area of interest on map backgrounds and the graphical representation of alternative solutions and evaluation criteria upon which decisions are based. The exploitation of such technologies allows participants to better understand the study problem through visual thinking and visual communication skills (Fig. 15.2). However, visualisation practices should satisfy certain prerequisites in order to be appropriate for public participation purposes (Warren-Kretzschmar and Von Haaren 2014), namely orientation capabilities, spatial understanding, ability to consider landscape changes and credibility (Warren-Kretzschmar 2011). Participants on the other hand should enhance their digital skills in order to be able to interact with the relevant technologies. 'Maps and graphics are active instruments in the end-users' "thinking process" and help them comprehend the study problem and its spatial dimensions' (MacEachren and Kraak 2001, p. 3).

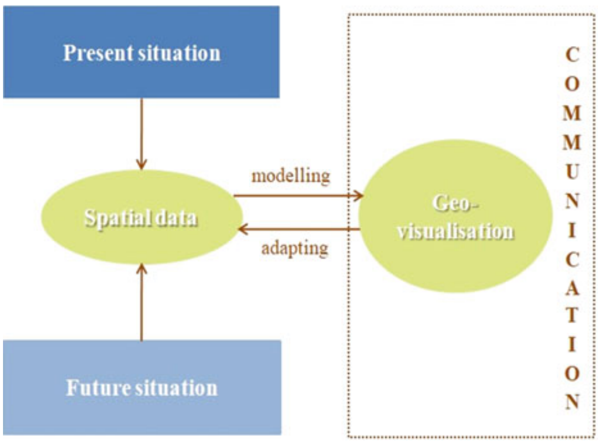

Fig. 15.2 Geo-visualisation and communication of spatial data (adapted from Van den Brink et al. 2007)

Among the most commonly used visualisation technologies in participatory spatial planning are PGIS and PPGIS. PGIS/PPGIS are applications that include published maps and real/dynamic GIS software, allowing users to interact with geographic information, suggest spatial interventions, make annotations and distribute/share spatial data and information (Papadopoulou and Giaoutzi 2014). They constitute popular tools enhancing the willingness of a community to take part in evaluation processes where spatial decisions are to be taken (Hansen and Prosperi 2005). Visualisation potential along with user-friendly interfaces facilitates public participation even for lay participants. PGIS/PPGIS enhance mutual understanding, support knowledge dissemination, promote the participatory dimension of spatial problems and reinforce co-decision making. The adoption rate of PGIS/PPGIS has been increased during the last decades in environmental studies, urban and regional planning, decision making, political and social science, etc. Some representative examples include: the exploitation of PPGIS in order to facilitate e-government procedures and evolution of debates (Ganapati 2011); the application of PPGIS/PGIS methods for the identification and mapping of ecosystem services (Brown and Fagerholm 2015); the adoption of a PPGIS in combination with GPS tracking for monitoring bikers, visiting national parks for tourism and recreation in Northern Sydney (Australia) (Wolf et al. 2015); the establishment of a web-based PPGIS serving municipal planning purposes through the assessment of urban densification (Babelon et al. 2016).

Volunteered Geographic Information (VGI) is another participatory approach where crowdsourced geographic information is gathered through the mobilisation of volunteers. GPS, remote sensing, statistical and tabular data, and data provided by sensors may be visualised on map backgrounds and support participatory mapping, spatial planning, allocation of activities and resource management. VGI has been used among others for the assessment of natural hazards (De Longueville et al. 2010); the organisation of emergency response in case of earthquakes (Camponovo and Freundschuh 2014); the validation of land cover maps (Fonte et al. 2015); and the exploration of vehicles' mobility patterns on roads based on Global Navigation Satellite System (GNSS) traces (Mozas-Calvache 2016).

The evaluation process and the relevant GIS-based MCDA approaches have profited from the introduction of visualisation in participatory planning. As a result, a new concept, that of *participatory evaluation*, has been introduced for the development of a joint evaluation framework where a number of stakeholders cooperate in order alternatives to be assessed and evaluation criteria to be determined. In the spatial planning context, participatory evaluation offers the chance to enrich the existing knowledge stock, analyse the complex dimensions of spatial problems, indulge into the specific characteristics of each problem and reinforce the content of spatial decisions by exploiting special and locally oriented knowledge, gained experience and expertise emanating from stakeholders (see Cousins and Earl 1992; Garaway 1995; Fawcett et al. 2003; Daigneault and Jacobs 2009; Chouinard and Cousins 2015).

Participatory evaluation is strengthened by visualisation as it involves the use of maps, photographs, 3D representations, augmented reality and a variety of other visual means that enable the graphical/cartographic representation of a study problem. All the above enhance the inherent optical intuition and perception of human mind and empower comprehension capabilities. GIS-based MCDA constitutes an ideal tool for the analysis of spatial problems, in a participatory context, as it allows for the illustration of alternative solutions and criteria. These are depicted in map backgrounds and participants have the chance to 'inspect' and formulate assumptions as to their effectiveness. They can easier understand all the steps of the selection process of alternatives. They are offered the opportunity to perform an initial screening of the study area and a rough/generic assessment of all possible alternative solutions. Evaluation criteria may be collaboratively defined while they are translated into map layers in order to be further elaborated through the implementation of spatial analysis. The visualisation of evaluation criteria offers participants the opportunity to understand their relative importance but also their correlation with the objectives selected. But the most important advantage that visualisation could provide in participatory evaluation is that it makes explicitly clear the spatial variability of criteria, criteria weights and alternatives' scores.

A vast number of scientific publications report on the usability and advantages of GIS-based MCDA in community planning and decision support. Typical examples refer to: the management of land uses and urban control in urban regions of Iran through the development of a web-based SDSS, enabling argumentation mapping and participatory GIS-based MCDA processes in order suitability maps to be produced (Mansourian et al. 2011); the identification of protected/management zones in the Yunnan Province (China) through the creation of suitability maps by adopting GIS-based participatory MCDA (Zhang et al. 2013); the selection of appropriate parking sites in the city of Tehran by using a web-based group GIS-MCDA approach that gives the chance to interested stakeholders to get involved (Jelokhani-Niaraki and Malczewski 2015); the search for solutions for the renovation of Urban Blighted Areas in Tehran (UBAs) by involving owners, investors and urban managers through the adoption of PPGIS in combination with MCDA (Omidipoor et al. 2019); the allocation of residential areas in the island of Mykonos (Greece) where a GIS-based participatory evaluation took place in a living lab environment in order suitable areas for housing development to be explored (Papadopoulou and Hatzichristos 2020).

Such applications were developed on the basis of potentialities provided by visualisation means, which make MCDA data more comprehensible by the broad audience of participants, engaged in spatial decision making procedures. In this context intuition is enhanced and the several dimensions of spatial problems are clarified, while a more integrated assessment of possible solutions is achieved.

15.5 The Role of Visualisation and GIS-Based MCDA in Scenario Analysis

Spatial interventions constitute the main tool in the hands of planners for addressing spatial problems. A range of objectives such as sustainable management of natural resources, reinforcement of social cohesion and bettering of economic prosperity may correspond to the outcome of spatial planning processes and lead to policy packages aiming among others, at the management of conflicts and trade-offs, the establishment of synergies and the confrontation of discrepancies, towards the attainment of future goals.

In this context, integrated solutions, taking into account all possible factors that may affect future developments, should be explored. To this end, scenario analysis comprises an effective approach for structuring informative decisions that incorporate the likely prospects of a study system and suggest potential options for their efficient management.

Scenario planning requires the detailed analysis of elements shaping the unique profile of a study system and the key variables which may affect its future development. Moreover, it builds upon the investigation of complex direct and indirect interrelations existing among the components of the system; the exploration of relevant actors and their power relations; the analysis of forecasts concerning system's future trends, and the formulation of future assumptions. The process of structuring future scenarios represents a multifaceted and complicated process as a considerable number of factors should be taken into account and possible future risks should be assessed. Scenario planning has its foundations in strategic thinking and its main benefits include: the possibility to investigate an extensive number of alternative future options, the analysis of future trends and the assessment of uncertainties (Shoemaker 1995; Ringland 1998; Peterson et al. 2003; Lindgren and Bandhold 2009; Star et al. 2016). A considerable number of scenario planning techniques have been developed such as 'qualitative' and 'quantitative' ones, techniques based on 'backcasting' and 'forecasting' approaches, simplistic practices, etc. The selection of the most appropriate approach depends on the particular needs and characteristics of each problem.

Visualisation technologies have greatly contributed to scenario planning as they enable the graphical representation of proposed spatial interventions. Future scenarios may be presented on map backgrounds that support the investigation of possible changes, such as change of land use patterns, as well as the assessment of impacts resulting from the implementation of the respective scenarios. Thus, visualisation enhances the ability to foresee future conditions and deal with uncertainty as it supports future visioning and provides meaningful information for increasing awareness.

In addition, GIS-based MCDA supports the assessment and prioritisation of alternative scenarios on the basis of geo-referenced evaluation criteria. After the application of a GIS-based MCDA, decision maps are produced, that may greatly support participatory scenario planning. In principle they constitute excellent tools for communication among politicians, technicians and stakeholders involved, as they support argumentation mapping, explicit representation of all suggested interventions and mutual understanding.

Scenario visualisation and GIS-based evaluation of scenarios have been applied for communicating future landscape changes in the Danish countryside by creating photorealistic landscape scenarios (Tress and Tress 2003); evaluating forest management scenarios in British Columbia (Canada) by adopting 3D visualisations and MCDA (Sheppard and Meitner 2005); assessing scenarios that concern the impacts of climate change at the local scale in British Columbia (Canada) (Sheppard et al. 2011); assessing flood risks through the simulation and visualisation of flood scenarios in the Netherlands (Kehl and De Haan 2013); creating visual representations of managed retreat scenarios concerning coastal planning in Southern UK through the exploitation of LiDAR data for landscape visualisation (Krolik-Root et al. 2015).

The above-mentioned cases are only indicative examples as literature provides a great variety of applications, having been implemented for the support of spatial decision making. Such applications enable the visual communication of suggested alternative scenarios, capture the attention of the interested parties, increase awareness on the issues being dealt in each case, enhance the comprehension and dissemination of the proposed spatial interventions and mobilise the undertaking of joint initiatives leading to the formulation of broadly accepted solutions.

15.6 Discussion

Visual representation and visual communication of spatial and non-spatial data and information are of great importance in spatial planning processes. Spatial planning is directly related to changes and transformations occurring in the geographical space which impact physical environment, social coherence and economic activities. These planning processes deal, among others, with complex planning issues involving multiple urban functions that compete for land, such as housing, employment and infrastructure, and enable decision makers to meet with scientific methods that set the framework for analysing key factors, and designing effective solutions (Van den Brink et al. 2007).

A common way of dealing with such complex issues is inviting citizens, pressure groups, public organisations and private enterprises to participate in the planning process. Spatial planners consider the expertise, involvement and support of participants to be essential for an effective planning procedure and successful realisation of spatial transformations. The engagement of stakeholders and the information exchange during the process greatly influence the degree of mutual understanding, consensus and support for proposed changes. The role and influence of stakeholders in such processes vary according to the level of participation that is practised (Arnstein 1969; Dalal-Clayton and Dent 1993; Rowe and Frewer 2000).

The power of visualisations to influence the perception and decisions of people, and therefore to influence participants in the planning process, is widely acknowledged (e.g. Lange and Bishop 2001; Appleton and Lovett 2005). In this context two-dimensional (2D) geo-visualisations have traditionally been used to exchange information about transformations in the spatial units. These visualisations were and still are difficult to be understood for a considerable number of stakeholders, who generally have little experience with interpreting maps that represent spatial information (Darken and Peterson 2002). Moreover, 2D geo-visualisations are limited to visualising differences between the current and future situation, presenting scenario studies and switching between scales and viewpoints. Therefore, more effective geo-visualisations had have to be used to communicate spatial information to all participants. Using such visualisations may help to avoid unfocused design discussions, unjustified expectations, and expensive and unchangeable planning decisions (Al-Kodmany 2002). The spatial information that is communicated via geo-visualisations needs to be adjusted to the planning context because the information exchange takes place in diverse combinations of stakeholders, planning phases and participation levels (Al-Kodmany 1999; Kingston et al. 2000; Al-Kodmany 2002).

Within this changing planning context, geo-visualisations must be able to meet the changing requirements for visual representations in terms of subject, level of detail, scale, interaction possibilities, etc. New methods and techniques that do meet these criteria for communication in spatial planning can be provided by 3D geo-visualisations. 3D geo-visualisations are three-dimensional visual representations of data that have a geographic reference and can be used to exchange spatial information in spatial planning.

Geo-referenced spatial data are involved in almost all cases where spatial planning initiatives take place and represent a substantive tool supporting the formulation of spatial decisions. In this respect, cartographic representations offer the possibility such data to be mapped and visually communicated to several interested parties, engaged in decision making processes. Except for spatial data, statistical, tabular and textual data can also be visualised and analysed with the support of modern GIS/web-GIS technology. Visualisation means mobilise visual thinking, enhance visual communication skills, and contribute to a better understanding of spatial patterns.

Visualisation and GIS together with MCDA and scenario planning constitute decision aid tools playing a fundamental role in participatory planning, as they allow for knowledge dissemination and sharing, assessment of alternative solutions, visualisation of evaluation criteria, scenario analysis and argumentation mapping. There seems to be a need for a conceptual framework to structure the use of geo-visualisations in participatory spatial decision making frameworks. Such issues were thoroughly analysed in this chapter through the exploration of relevant benefits and capabilities that visualisation and spatial analysis technologies provide in spatial decision making.

Literature review indicated that GIS-based MCDA, participatory scenario analysis, participatory GIS and mixed approaches are extensively adopted by researchers in order to design, communicate, analyse and assess the impacts of spatial interventions. The majority of applications address environmental problems, urban and regional planning issues where the effects of possible future options should be considered on the basis of a number of criteria. The widespread adoption of such approaches demonstrates their comparative advantages as to the management of complex problems and the design of effective decisions targeting at the sustainable development of urban centres, rural areas and natural ecosystems. Most researchers claim that such spatial planning practices entail multifaceted advantages in the planning process and planning outcomes as they integrate multiple tools and methods under a unique decision framework. In this context, knowledge stock is enriched, subjectivity is reduced, democratic procedures are strengthened and wide-accepted solutions are figured out.

Conclusively, technological advancements have prescribed the evolvement of traditional planning methods and techniques by bringing the potential of visualisation and spatial analysis of data involved in spatial decision making frameworks. They have enabled the simultaneous management and processing of spatial and attribute data, the development of interactive and dynamic maps supporting visual communication and cartographic analysis, the incorporation of MCDA methods in GIS software and the establishment of integrated SDSSs that produce innovative knowledge. Such a progress has led to the undertaking of more objective and efficient decisions while it has also stimulated the openness of planning processes to the public, the final 'receptor' of spatial decisions and interventions.

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