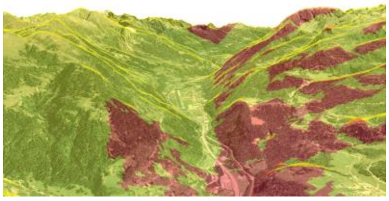
NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF RURAL AND SURVEYING ENGINEERING
POSTGRADUATE COURSE: *GEOINFORMATICS*

MOUNTAINOUS LANDSCAPE EXPLORATION VISUALIZING VIEWSHED CHANGES IN ANIMATED MAPS



Loukas-Moysis Misthos

Postgraduate Thesis submitted to the School of Rural and Surveying Engineering, National Technical University of Athens in partial fulfilment of the requirements for the degree of Master of Science in *'Geoinformatics'*

Athens, March 2014

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Athens, March 2014

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To those who use technology to provide knowledge and insight for society

"The claim of a realist ontology of science is that the only way of explaining why the models of science function so successfully in the overcoming of anomalies is that they approximate in some way the structure of the object."

Ernan McMullin

"But the supreme paradox of the scientific revolution is the fact that […] things which would strike us as the ordinary natural way of looking at the universe, the obvious way of regarding the behaviour of felling bodies, for example, defeated the greatest intellects for centuries [...] when their minds were wrestling on the very frontiers of human thought with these very problems."

Herbert Butterfield

PROLOGUE

We live in a world in which whatever we are experiencing constantly changes. No matter how a monist's metaphysical interpretation would entail that reality is unity and that the sensory evidence of change in our casual, ordinary experience is deceptive, the investigation and detection of change rather constitute the sole means of empirically apprehending the passage of time; and time passage holds dynamism. Nowadays, dynamic multi-sensory informational-overloaded representations of reality are further advancing in digital, virtual environments. A widespread rumour prescribes that the more the interactive, multi-temporal, high quantity and quality (e.g. high definition graphics) multi-sensory data/ information a visualization affords to a user, the more upgraded the knowledge and the wisdom gained. But, is this the case? Do we really become wiser – or even do we receive more meaningful information (i.e. knowledge) – by merely being bombarded by a vast amount of aesthetically appealing dynamically changing sensory stimuli? Or, at the antipodal, could it be that the only reason of existence of this kind of visualizations is sometimes due to their being 'fancy', 'cool', 'trendy', or even 'sexy'? Thence, a more generic question naturally ensuing is: are we to manipulate technology stretching its advancements to the extremities simply because we are capable of or because of an – admittedly – mounting audience seeking *panem et circenses*?

To me, this question is a rather rhetoric one, especially in the context of my immediate academic environment. This work refers to my postgraduate (master's) thesis conducted at the Cartography Lab of the School of Rural and Surveying Engineering, National Technical University of Athens, where mapping is the core of the matter; as a consequence, change and motion should definitely be included, but with a degree of abstraction and generalization, thus harnessing the amount and kinds of technical/ technological innovations (e.g. Geographical Information Systems, animation techniques, interactivity etc.) that can aid a *meaningful* visualization contributing to the interpretation of anything *spatial* (concrete or abstract) that changes with *time* or *motion*. So, provided that this thesis – titled as *'Mountainous Landscape Exploration Visualizing Viewshed Changes in Animated Maps'* – treats with the dynamic investigation of the visual properties of a landscape via the:

- re-conceptualization of the landscape's changing views from a *spatial representation*, (terrain and cartographic) *analytical* and *geovisualization* perspective, and
- spatial data/ information pre-processing, manipulation, analysis and visualization-interpretation,

it comprises a most legitimate venture in the realm of *Geoinformatics*, satisfying the interdisciplinary character of this program of postgraduate studies. The examination of the dynamic visual landscape, in the guise of several animated cartographic visualizations can prompt us delve into the substance of the landscape's topographic and visual structure and enrich our understanding in a manner that a novel and incredibly sophisticated 3-d visualization alone could not.

Acknowledgements

First of all, I could not be but grateful for being given the opportunity to attend and accomplish this postgraduate course. However, the completion of this postgraduate thesis would not have been achieved if it were not for some people to whom I am indebted to. So, I would like to express my wholehearted gratitude to my supervisor, Mr. B. Nakos, Professor, for his undivided attention and his invaluable assistance, aiding me to put order to my thoughts and aims, and to materialize elusive conceptualizations, meticulously commenting my text, constantly encouraging me to accomplish my task while managing to guide me within the medley of interesting scientific issues through pertinent, meaningful and attainable 'scientific tracks' – without steering the scientific research objectives of this thesis to his own research interests. I also want to acknowledge Mr. M. Kavouras, Professor and Director of the Postgraduate Program, who honoured me with his acceptance of being a member of the Board and because the rationale of this thesis was significantly affected by one of our conversations related to the selection of the subject of an assignment in one of the modules he was in charge. The contribution of the Assistant Professor Mrs. M. Menegaki, as a member of the Board, was highly beneficial, helping me to integrate technical aspects from a landscape analysis perspective – and I thank her very much. Special thanks go to Mrs. V. Filippakopoulou, Professor, for her invaluable teaching work towards my substantial acquaintance with the research paradigms in the history of cartography and for her useful remarks with regard to the generation of the visualization. Moreover, the assistance I received form the two PhD students V. Mitropoulos and V. Krassanakis was of extraordinaire significance and had a catalyst effect on the progress of my thesis with reference to technical issues in particular, while my support in wider technical facilities in the Laboratory of Cartography was achieved due to the efforts of Dr. N. Tzelepis; so, I am bound to these people for their assistance. In addition, I would like to thank Ch. Livas, PhD student in University of Piraeus and good friend for his essential help with statistical analysis tasks. Lastly, I want to thank my family for their indispensable caring support, which, along with the encouragement from my wider social environment, granted me the psychological and emotional backing, crucial for the accomplishment of this thesis.

ABSTRACT

Visual perception has had a profound effect on humankind thriving, since the latter has been deriving meaning from its surroundings; in other words, for us, humans 'to see is to understand and prosper'. Living in the natural environment, though, entails active visual landscape experience which is an inherently dynamic process and by which we apprehend and understand the most of our surroundings. Information about points of the landscape that are mutually visible or parts of a region which are visible from one or more points of observation is valuable for several reasons and applications. Yet, such information neither is synthesized by itself to a perceivable and meaningful context, nor it involves the active visual experience.

Maps are abstracted representations of (geographic) reality; so, in their generic form they are to represent and depict this reality in a means perceivable from a multitude of map readers/ users. Moreover, geographic reality includes phenomena which, similarly to visual landscape experience, are dynamic in nature. Although conventional mapping neatly corresponds to the static picture of the Earth, recent advancements in Cartography and Geographic Information Science have significantly shifted the scientific *Paradigm* from static mapping. The emerging Paradigm of *Geo-visualization* (or *Cartographic Visualization*) involves animation and interaction with an aim to representing and portraying dynamic geographic phenomena and processes with dynamic graphical media. However, cartographic visualization (and animation, in particular) is not only destined to communicate geo-spatial information; instead, it can also serve as a medium to creatively explore this kind of information.

This thesis treats with the problem of *visibility* but with an aim to integrate it in a context where geo-spatial digital data/ information handling and analysis result in perceivable and meaningful, non-static cartographic outputs. As such, it aims at rendering the evolution of what is visible – i.e. the *viewsheds* – for some defined topographically prominent tracks (or routes) by cartographically exploring viewsheds.

Therefore, it is the *hidden-surface-removal problem* consideration – explained as 'which portions of a Digital Terrain Model (DTM) are seen from a viewpoint on this DTM' (i.e. the viewsheds) – that has reduced the approach and the approximation of the real active visual experience to a digital-technical framework. This framework consists chiefly of a Geographical Information System (GIS), an Image Manipulation Software and a Statistical Analysis Software so as to handle and analyze the respective spatial data in a semi-automated procedure, and eventually, visualize and evaluate the derived simulated processes. Nevertheless, all these technical means and tools successfully interact and yield outputs with semantic and cognitive utility only because they are: governed by an intended rationale ruled by a rigorous methodology and founded on predefined conceptualizations. And it is owing to these deliberate mental activities and

organization that some significant concerns are raised, pertaining to factors, parameters and limitations affecting the successful effectuation of this thesis.

So, the digital and generalized aspect of the visual landscape (visualscape) is to be visually explored. The theoretic considerations suggesting that a static landscape apprehension is merely an instantiation – a pause in locomotion – of the more generic conceptualization of active observation in motion have provided the background for dynamically probing such a (mountainous) landscape. Under this perspective, only ‘moving vistas’ can approximate the actual experience of visual sensory perception – that is observation along tracks/ routes. Yet, at first, the concern regarding the selection of such observation routes (view-routes) arises: could a random line engraving be sufficient, or a more mindful route election is required?

Although the exploration ‘doctrine’ dictates that one should proceed in an entirely data-driven approach (without a very concrete intent of the spectrum of what results to expect), we cannot defy the fact that some linear features (e.g. ridge-lines, course-lines) are topographically/ geomorphologically ‘endowed’ with special characteristics. So, the act of placing viewpoints along such different prominent features may entail equivalently varying properties with respect to their visibility spatial patterns. But a unified rendering of vistas along each route implies the (cartographic) visualization of both viewpoints movement and visibility spatial patterns propagation. Under this perspective, insight can be gained from pre-ordered animated sequences of such raster spatial data (i.e. viewsheds) which include their respective points of reference, i.e. the observation point corresponding to each viewshed. Besides, such spatially-changing data is at the same time a ‘facilitating visualization scheme’: the viewpoint spatial displacement is accompanied by a different configuration of visible cells of a landscape (raster surface), recalling the case of 3-d fly-overs; also, meaning derivation exploring this scheme/ data both enables the emerging evolving patterns themselves and entails the conscious decision of utilizing prominent linear topographic features for viewpoint selection.

In this thesis, this explorative task is indeed a procedure of reconciling proper approximation of the propagation of the changing raster surfaces, effective apprehension of this process, and mitigation of data volume/ computation load-time requirements. Nevertheless, for this enterprise to carry a pragmatical potential, it is also crucial to automate the procedure for the handling/ manipulation and identification of the relevant data/ information, using computational efficient methods via the aid of GIS. Thence, under these presuppositions, we investigate: i) the capability of certain cartographic visualizations to approximate the evolution of visualscapes in an explorative – but also in an automated – manner, ii) the differences and the varying requirements for visualizing viewshed changes in different topographic linear features (routes) and for spatially differing viewpoint placement, and iii) the effect of the moving viewpoint’s elevation variation upon the dynamic transition of the visual landscape.

The pertinent analysis and discussion gives prominence to the overall benefits stemming from cartographic visualization, while it focuses on the strategies dedicated to afford an effective dynamic 2-d visual landscape exploration. So, this explorative task reveals the significant variation of visibility spatial pattern trends in correspondence with different linear topographic features; in addition, the empirical experimentation with floating spatial viewpoint arrays along these linear features provides evidence that the geo-visualization/ animated map requirements both in terms of the processes (viewsheds evolution) approximation and rendering and in terms of their (processes') apprehension potential depend on the topographic feature each time investigated. Besides, (the difference with respect to) elevation as well as (with respect to) other terrain derivatives – namely slope and curvature – are found to affect viewshed transition, but not in a manner that this impact to diverge from a 'regulating spectrum' adumbrated by each viewroute-linear topographic feature. By expanding such findings and remarks, several other relevant emerging issues are touched with the perspective of further research.

Keywords: Dynamic viewsheds/ visualscapes; linear topographic features; terrain visualization; visual landscape exploration; animated maps.

ΠΕΡΙΛΗΨΗ

Η οπτική αισθητηριακή αντίληψη έχει αποτελέσει μείζονος σημασίας παράγοντα για την ανθρώπινη ευημερία, καθότι η τελευταία έχει ποριστεί νοήματος από τα στοιχεία που την περιβάλλουν· επεξηγηματικά, για μας τους ανθρώπους, «το να βλέπουμε ισοδυναμεί με το να κατανοούμε και να ευημερούμε». Η διαβίωση στο φυσικό περιβάλλον, εντούτοις, εμπεριέχει ενεργό/ή οπτική εμπειρία στο τοπίο, η οποία είναι μια εγγενώς δυναμική διαδικασία και δια της οποίας συλλαμβάνουμε και κατανοούμε εν γένει το περιβάλλον μας. Οι δε πληροφορίες περί σημείων του τοπίου τα οποία είναι αμοιβαίως ορατά, ή περί τμημάτων μιας περιοχής τα οποία είναι ορατά από ένα ή περισσότερα σημεία θέασης (παρατήρησης) είναι πολύτιμες για διάφορους λόγους και εφαρμογές. Όμως, τέτοιου είδους πληροφορίες ούτε μπορούν να αναχθούν, ούτε να συντεθούν από μόνες τους σε ένα αντιληπτό και πλήρες νοήματος πλαίσιο, αλλά ούτε και ενέχουν την ενεργό/ή οπτική εμπειρία.

Οι χάρτες είναι αφηρημένες/ αφαιρετικές αναπαραστάσεις της (γεωγραφικής) πραγματικότητας· ως εκ τούτου, στη γενική μορφή τους συνεπάγονται αναπαράσταση και απεικόνιση αυτής της πραγματικότητας κατά τρόπο εύληπτο από ένα ευρύ κοινό χρηστών χαρτών. Επιπροσθέτως, στη γεωγραφική πραγματικότητα συμπεριλαμβάνονται φαινόμενα τα οποία, όμοια με την οπτική εμπειρία στο τοπίο, είναι δυναμικά. Παρότι η συμβατική χαρτογραφική απεικόνιση ανταποκρίνεται «καταλλήλως» στη στατική εικόνα της Γης, οι πρόσφατες εξελίξεις στη Χαρτογραφία και στα Γεωγραφικά Πληροφοριακά Συστήματα έχουν μετατοπίσει το επιστημονικό *Παράδειγμα* από την στατική χαρτογραφική απεικόνιση. Το αναδυόμενο Παράδειγμα της Γεω-οπτικοποίησης (ή της Χαρτογραφικής Οπτικοποίησης) εμπλέκει την απεικόνιση με κινούμενες εικόνες (animation) και τη διάδραση προκειμένου να αναπαραστήσει και να αποδώσει δυναμικά γεωγραφικά φαινόμενα και διαδικασίες με δυναμικά γραφικά μέσα. Ωστόσο, η χαρτογραφική οπτικοποίηση (και το animation, ιδιαιτέρως) δεν προορίζεται μόνο να «επικοινωνεί» (μεταδίδει) γεω-χωρικές πληροφορίες· αντίθετα, μπορεί να χρησιμεύσει και ως μέσο δημιουργικής εξερεύνησης/ διερεύνησης τέτοιου τύπου πληροφοριών.

Αυτή η διπλωματική εργασία αντιμετωπίζει το πρόβλημα της ορατότητας με σκοπό να το εντάξει σε ένα συγκείμενο όπου τα γεω-χωρικά ψηφιακά δεδομένα/ πληροφορίες αποβαίνουν σε εύληπτα και πλήρη νοήματος, μη-στατικά χαρτογραφικά παραγόμενα. Ως τέτοια, αποσκοπεί στο να αποδώσει τη δυναμική εξέλιξη του τι είναι ορατό – τουτέστιν το πεδίο ορατότητας (viewsheds) – από κάποιες τοπογραφικά «προεξέχουσες» (ιδιάζουσες) διαδρομές, εξερευνώντας τα πεδία ορατότητας χαρτογραφικά.

Επομένως, είναι η εξέταση του *πρόβληματος-της-απομάκρυνσης-της-κρυπτόμενης-επιφάνειας* – ερμηνευόμενο ως «ποια τμήματα του Ψηφιακού Μοντέλου Εδάφους (ΨΜΕ) είναι θεατά από ένα σημείο παρατήρησης επί του

ΨΜΕ» – που έχει ανάγει την προσέγγιση της πραγματικής ενεργού οπτικής εμπειρίας σε ένα ψηφιακό-τεχνικό πλαίσιο. Αυτό το πλαίσιο αποτελείται κυρίως από ένα Λογισμικό Γεωγραφικών Πληροφοριακών Συστημάτων (ΓΠΣ), ένα Λογισμικό Επεξεργασίας Εικόνας και ένα Λογισμικό Στατιστικής Ανάλυσης προκειμένου να είναι δυνατή η διαχείριση, οπτικοποίηση και αξιολόγηση των εξαγόμενων εξομοιούμενων διαδικασιών. Παρόλα αυτά, όλα τα τεχνικά μέσα και εργαλεία αλληλεπιδρούν επιτυχώς και αποφέρουν παραγόμενα με σημασιολογική και γνωσιακή χρησιμότητα μόνον επειδή: ιθύνονται από μια στοχευμένη συλλογιστική διεπόμενη από μια αυστηρή μεθοδολογία και θεμελιώνονται σε προκαθορισμένες εννοιολογήσεις. Και είναι λόγω αυτών των ενσυνείδητων διανοητικών διεργασιών και της σχετικής οργάνωσης που κάποια ουσιώδη μελήματα εγείρονται, σε σχέση με παράγοντες, παραμέτρους και περιορισμούς που επιδρούν στην επιτυχημένη πραγμάτωση αυτής της εργασίας.

Έτσι λοιπόν, η ψηφιακή και γενικευμένη εκδοχή του οπτικού τοπίου (οπτικο-τοπίο/ visualscape) τίθεται προς οπτική εξερεύνηση. Οι θεωρητικοί προβληματισμοί που πρεσβεύουν ότι μια στατική σύλληψη του τοπίου είναι απλώς ένα στιγμιότυπο – μια παύση στη μετακίνηση – της γενικότερης εννοιολόγησης της ενεργού, εν κινήσει παρατήρησης έχουν παράσχει το υπόβαθρο για τη δυναμική διερεύνηση ενός τέτοιου (ορεινού) τοπίου. Υπό αυτή την προοπτική, μόνο «κινούμενες θεάσεις» δύνανται να προσεγγίσουν την πραγματική βιωματική εμπειρία της οπτικής αισθητηριακής αντίληψης – ήτοι παρατήρηση κατά μήκος «πορειών»/ διαδρομών. Εντούτοις, εγείρεται, κατ' αρχάς, το μέλημα σχετικά με την επιλογή τέτοιων διαδρομών παρατήρησης (διαδρομές θέασης): θα ήταν επαρκές να χαραχθεί μια τυχαία γραμμή, ή θα απαιτούνταν μια πιο ενσυνείδητη επιλογή διαδρομής;

Μολονότι το «δόγμα» της εξερεύνησης υπαγορεύει την υιοθέτηση μιας εξ' ολοκλήρου βασισμένης στα (οδηγούμενης από τα) δεδομένα προσέγγισης (δίχως μια προϋποτιθέμενη επιδίωξη ενός φάσματος αναμενόμενων αποτελεσμάτων), δεν είναι δυνατό να αψηφήσει κανείς το γεγονός ότι ορισμένα γραμμικά χαρακτηριστικά-οντότητες (λ.χ. κορυφογραμμές, κοιλάδες) είναι τοπογραφικά/ γεωμορφολογικά «προικισμένες» με ιδιαίτερα γνωρίσματα-ιδιότητες. Έτσι, το διάβημα «τοποθέτησης» σημείων θέασης κατά μήκος τέτοιων διαφορετικών ιδιαζουσών («προεξεχουσών») οντοτήτων ενδέχεται να ενέχει ισοδύναμα κυμαινόμενες ιδιότητες αναφορικά με τα χωρικά πρότυπα (δηλ. κατανομές) ορατότητάς τους. Αλλά μια ενοποιημένη απόδοση των θεάσεων κατά μήκος κάθε διαδρομής υποδηλώνει την (χαρτογραφική) οπτικοποίηση τόσο της μετακίνησης των σημείων παρατήρησης, όσο και της εξάπλωσης των χωρικών προτύπων ορατότητας. Υπό αυτή την οπτική, βαθύτερη κατανόηση μπορεί να αποκτηθεί από προ-διατεταγμένες ακολουθίες/ αλληλουχίες κινούμενης εικόνας τέτοιων ψηφιδωτού τύπου χωρικών δεδομένων (δηλ. ψηφιακών πεδίων ορατότητας) οι οποίες εμπεριέχουν και τα αντίστοιχα σημεία αναφοράς τους, ήτοι τα σημεία παρατήρησης που αντιστοιχούν σε κάθε πεδίο ορατότητας.

Άλλωστε, αυτού του είδους τα χωρικά-μεταβαλλόμενα δεδομένα συνιστούν ταυτόχρονα και ένα «διευκολυντικό/ επιτρεπτικό σχήμα οπτικοποίησης»: η χωρική μετατόπιση του σημείου θέασης συνοδεύεται από μια διαφορετική κατανομή των ορατών κελιών επί ενός τοπίου (επιφάνεια ψηφιδωτού (raster)), ανακαλώντας την περίπτωση των 3-δ εικονικών πτήσεων· η δε εκμαίευση νοήματος από την εξερεύνηση αυτού του σχήματος/ αυτών των δεδομένων, ταυτόχρονα καθιστά εφικτή την ανάδειξη των ίδιων των εξελισσόμενων προτύπων αλλά και συνεπιφέρει τη συνειδητή απόφαση της αξιοποίησης ιδιαζουσών γραμμικών τοπογραφικών οντοτήτων για την εκλογή σημείων παρατήρησης.

Σε αυτή τη διπλωματική εργασία, αυτό το εξερευνητικό έργο είναι στην πραγματικότητα μια διαδικασία συνταιριάσματος/ εναρμόνισης: κατάλληλης προσέγγισης εξάπλωσης των μεταβαλλόμενων ψηφιδωτών επιφανειών, αποτελεσματικής πρόσληψης/ σύλληψης αυτής της διαδικασίας, και μετριασμού των απαιτήσεων όγκου δεδομένων/ υπολογιστικού χρόνου. Ωστόσο, για να εμφορείται αυτό το εγχείρημα από μια πραγματιστική προοπτική, είναι ομοίως ζωτικής σημασίας να αυτοματοποιηθούν οι διεργασίες για τη διαχείριση και την ταυτοποίηση/ προσδιορισμό των σχετικών δεδομένων/ πληροφοριών με τη βοήθεια των ΓΠΣ. Επομένως, υπό αυτές τις προϋποθέσεις, εξετάζουμε: i) τη δυνατότητα ορισμένων χαρτογραφικών οπτικοποιήσεων να προσεγγίσουν την εξέλιξη της μεταβολής των οπτικο-τοπίων υπό έναν εξερευνητικό – αλλά επίσης αυτοματοποιημένο – τρόπο, ii) τις διαφορές και τις κυμαινόμενες απαιτήσεις για την οπτικοποίηση των μεταβολών των ορατών πεδίων σε διαφορετικές τοπογραφικές γραμμικές οντότητες (διαδρομές) και για χωρικά διαφοροποιούμενες διατάξεις σημείων θέασης, και iii) τον αντίκτυπο της διακύμανσης του υψομέτρου του κινούμενου σημείου θέασης επί της δυναμικής μετάβασης/ μεταμόρφωσης του ορατού τοπίου.

Η σχετική ανάλυση και συζήτηση προάγει τα συνολικά οφέλη που απορρέουν από τη χαρτογραφική οπτικοποίηση, ενώ ταυτόχρονα εστιάζει στις στρατηγικές που έχουν ως αποκλειστικό σκοπό να παράσχουν τα μέσα για να καταστεί δυνατή μια αποτελεσματική 2-δ εξερεύνηση του οπτικού τοπίου. Ώστε, αυτό το εξερευνητικό έργο αποκαλύπτει σημαντική διακύμανση των τάσεων των χωρικών προτύπων ορατότητας σε σχέση με (ή ως απόκριση σε) διαφορετικές γραμμικές τοπογραφικές οντότητες· επιπλέον, ο εμπειρικός πειραματισμός με μεταβαλλόμενες χωρικές διατάξεις/ αλληλουχίες σημείων θέασης κατά μήκος τέτοιων γραμμικών οντοτήτων καταμαρτυρεί ότι οι απαιτήσεις της γεω-οπτικοποίησης, δηλαδή του χάρτη κινούμενης εικόνας, τόσο σε όρους προσέγγισης και απόδοσης των διαδικασιών (δυναμικής εξέλιξης πεδίων ορατότητας), όσο και σε όρους δυνατότητας σύλληψής και κατανόησής τους (των διαδικασιών) εξαρτώνται από την τοπογραφική οντότητα που εξετάζεται κάθε φορά. Εξ' άλλου, (η διαφορά ως προς) το υψόμετρο, αλλά και (ως προς) άλλα παράγωγα του αναγλύφου – ήτοι η κλίση και η καμπυλότητα – διαπιστώνεται πως επηρεάζουν τις μεταβολή του πεδίου ορατότητας, αλλά όχι κατά τρόπο που αυτή η επίδραση να αποκλίνει από ένα «κανονιστικό φάσμα» που οριοθετείται από την εκάστοτε διαδρομή θέασης-γραμμική τοπογραφική οντότητα. Επεκτείνοντας τέτοια ευρήματα και σχόλια, διάφορα άλλα σχετικά

αναδυόμενα ζητήματα θίγονται υπό την προοπτική περαιτέρω έρευνας-διερεύνησης.

Λέξεις-κλειδιά: Δυναμικά πεδία ορατότητας/ ορατο-τοπία· γραμμικές τοπογραφικές οντότητες· οπτικοποίηση αναγλύφου· οπτική εξερεύνηση τοπίου· χάρτες κινούμενης εικόνας.

MOUNTAINOUS LANDSCAPE EXPLORATION VISUALIZING VIEWSHED CHANGES IN ANIMATED MAPS

1. INTRODUCTION

[If a picture is worth a thousand words, then a succession of spatio-temporally linked pictures is worth a billion words, a whole story; so, what if the constituents, if the events of this story referred – self-consciously – only to the observable sections of its 'plot', what would this story tell us?]

Unknown

1.1. MOTIVATION AND PROBLEM STATEMENT

Imagine that you visit a place for which there are widespread rumors of panoramic, majestic vistas of the surrounding landscape. Suppose, moreover, that within the wider area there is a variety of alternative routes or paths, not all of them as much picturesque or 'revealing'. Only some (or some segments) of these routes entail such properties, while some others, in contrast, may 'hide' considerably large or 'valuable' sub-regions of this area (the relief itself obstructs its observation), or expose the less attractive ones. Motivated both by everyday experience argumentation, as well as by the core of an existing theoretical background pertaining to human perception and preference, it could be inferred that most of us would rather opt (to move along) a route with a wide viewing horizon where elements of visual 'amenity' are maximized (e.g. lakes, parklands) and annoying or disturbing vistas are minimized (e.g. an open pit or a landfill) rather than a road with a limited horizon implicating monotonous, dull patterns and landscapes. Of course, this is not always the case: military operations may seek, in contrast, paths that are least visible (most hidden) from the rest of the landscape, irrespectively of the scenic beauty of the vistas these paths entail.

Nonetheless, the prevailing 'research tradition' concerning landscape probes into the significance of the landscape perception and cognizance; in this context, landscape has been given prominence and reviewed by delving in the 'history' of human evolution (e.g. Appleton, 1975; Kaplan and Kaplan, 1989) or by approaching it from the standpoint of visual perception (ambient optic array, optic flow) and affordances (Gibson, 1979; 1986). On the other hand, the high, even therapeutic value of certain elements or pattern combinations (structure) of landscape has opened another discussion and promoted research for both structural and qualitative aspects of landscape characterization and evaluation (scoring) (e.g. Ulrich, 1981; Purcell et al. 1994; Coeterier, 1996 Parris, 2002; Swanwick, 2002; Tveit et al., 2006; Ode et al., 2008; Sevenant and Antrop, 2009; Cassatella, 2011). Moving to a more geographic perspective, a large amount of research attempts has been directed towards landscape classification, analysis and evaluation by using GIS/ cartographic methods (e.g. Brabyn, 1996; Council of

Europe, 2000; Turner et al., 2001b; Germino et al., 2001; Dramstad et al., 2006; Ode et al., 2008; Brabyn, 2009; Brabyn and Mark, 2011; Cassatella, 2011).

To some extent, the potential of gaining amenity or taking delight in landscape regions emanates from (at least) a 'visual contact' with them – the case where an observer and the target of observation (regions) are mutually visible. The delineation of such regions on a vertical projection (i.e. planimetric 2-d perspective), and more specifically on a cartographic product can be attained via suitable means, procedures and data: a GIS, an algorithm and a Digital Terrain Model (DTM). Visibility or viewshed maps are the main cartographic products – showing which parts of a geographic area are visible and which are invisible from one or more observation points irrespective of viewing direction or field of view (i.e. 360-degree field of view) – of a typical GIS terrain analytical/ computational function, while they are based on the implementation of proper algorithms conducted on pertinent digital data structures, that is DTMs. The literature teems with research papers and reviews dealing with terrain visibility and viewshed concepts and computation (e.g. Yoeli, 1985; De Floriani et al., 1986; Goodchild and Lee, 1989; Lee, 1991; Fisher, 1993; Nagy, 1994; De Floriani, 1994; De Berg, 1997; De Floriani and Magillo, 1997; 1999; 2003), while others approach the matter from a landscape perspective, identifying/ specifying its visual properties and structure (Tandy, 1967; Benedikt, 1979; O'Sullivan and Turner, 2001; Turner et al., 2001a; Turner, 2003; Llobera, 2003).

Beyond the more intuitive application of viewsheds in landscape apprehension and evaluation (i.e. preferences in routes), an overall description of the landscape in terms of its more abstracted, underlying topography (terrain) may be effectuated via the combination of proper 'sampling' schemes and viewshed analyses. Since terrain visibility has been rated as a standard topographic derivative in digital terrain modeling to calculate, analyze, interpret and visualize the terrain, the proper scaling and sampling aspects in geomorphometric and visualization terms existing in literature, reveal some essential dimensions to (even fully) describe a landscape without prior knowledge of its visual properties or structure (e.g. Warnz, 1966; Peucker and Douglas, 1975; Pfalz, 1976; Li, 1991; Lee, 1994; Zhang and Montgomery, 1994; Goodchild and Quattrochi, 1997; Lee and Stucky, 1998; Hutchinson and Gallant, 2000; O'Sullivan and Turner, 2001; Rana, 2003; Kienzle, 2004; Kim et al., 2004; Fisher, 2004; MacMillan et al., 2004; Li et al., 2005; Shary et al., 2005; Hengl, 2006; Deng et al., 2007; Riggs and Dean, 2007; Lu et al., 2008; Zhilin, 2008; Hengl and Evans, 2009; MacMillan and Shary, 2009; Olaya, 2009; Wang et al., 2010; Evans, 2012; Wilson, 2012). In a sense, these visual properties could be infused to conventional static maps displaying the degree of radial observation capacity (including the typical viewshed maps depicting the viewing points and their respective vistas/ panoramas points – pertaining to the aggregate of vistas resulting from a full rotation of an observer's head) or to the road (route) segments from which picturesque vistas occur. Yet, for these outputs – referring to a static perspective of the landscape visualization or/ and of the terrain description – to acquire the potential to facilitate dynamic and interactive viewshed visualization for (every single location of prominence within) a linear feature or a route require a 'special management'. This management can emerge by the consideration of conceptual and implementation folds referring to visual landscapes, viewshed computation and digital terrain modeling, within the overarching framework imposed by cartographic visualization (geovisualization).

So, imagine now that you are able to know in advance – i.e. before physically visiting an area – the potential of these alternative routes in panoramic scenic vistas. Imagine, also, that you are even able to extract interactive information about "what is visible" along each route by dynamically probing both the changing patterns of these vistas-regions along a track, and the amount of other latent and unforeseen information (e.g. the ratio of visible/ non-visible regions). But, this capability entails the shifting from visually enhanced/ augmented virtual environments, towards more abstracted or generalized views, positing, in a sense, acts and procedures pertaining both to the mitigation of serious constraints stemming from 3-d 'egocentric' oblique perspective 'fly-overs' and to the raise of symbolization and spatial inference/ awareness through 2-d 'exocentric' planimetric animated scene sequences.

As a consequence, this means that the venture of visually exploring the terrain/ landscape is based on the assumption that dynamic, animated viewsheds – operating at a certain level of abstraction – can link thematic relevant features to perceptual salient ones, involving symbolized changing patterns (i.e. dynamic variables) in their visualization. Relevant literature demonstrates the usefulness of generalized 2-d perspective views for several reasons such as tackling disorientation or information overload/ irrelevance (e.g. Fukatsu, 1998; Fuhrmann and MacEachren, 2001; Hornbaek et al., 2002; Fuhrmann, 2003; Fabrikant and Goldsberry, 2005; Harrower and Sheesley, 2005; Harrower and Sheesley, 2007; Fabrikant et al., 2010; Krassanakis et al., 2013a; 2013b). Within the vast literature 'inaugurating' and continuing to 'instigate' the research paradigm/ tradition of geovisualization (e.g. DiBiase, 1990; DiBiase et al., 1992; MacEachren et al., 1992; MacEachren, 1994a; 1994b; Fairbairn et al., 2001; MacEachren and Kraak, 2001; Dykes et al., 2005; Cartwright and Peterson, 2006; Slocum et al., 2009; Kraak and Ormeling, 2010), our venture concentrates in harnessing the explorative (animated and interactive portrayal for private use) 'corner' of geovisualization (e.g. DiBiase et al., 1992; Koussoulakou and Kraak, 1992; Taylor, 1994; Slocum et al., 2001; Adrienko et al., 2003; Harrower, 2003; Slocum et al., 2004; Blok, 2005a; 2005b; Kraak and van de Vlag, 2007; Harrower and Fabrikant, 2008; Goldsberry and Battersby, 2009; Battersby and Goldsberry, 2010) for landscape/ terrain interpretation and description, even though for the cognitive limits and potentialities of animated displays such as maps to be unraveled (Chandler and Sweller, 1991; Edsall et al., 1997; Sweller et al., 1998; Betrancourt and Tversky, 2000; Morrisson et al., 2000; Simons, 2000; Mayer, 2002; Tversky et al., 2002; Rensink, 2002; Mayer and Moreno, 2003; Harrower, 2003; Hegarty et al., 2003; Ayers, 2005; Fabrikant and Goldsberry, 2005; Griffin et al., 2006; Harrower, 2007a; Fabrikant et al., 2010), considerable amounts of further empirical research grounded on a coherent framework of consistent theoretical principles is demanded.

Consequently, the affordance offered to a map reader/ user from such a dynamic visual exploration can be determined both by the user's scientific (or not) background or relevance with the domain, and the map-use (e.g. presentation *vs.* exploration), even though the issue has not been already settled (e.g. DiBiase, et al., 1992; Fabrikant and Goldsberry, 2005; Goldsberry and Buttersby, 2009; Harrower, 2007a; Fabrikant et al., 2010). Furthermore, two other factors can determine this affordance: the proper overall geovisualization design (level of generalization, symbols, dynamic variables, static map display design) (DiBiase et al., 1992; Goldsberry, 2005; Harrower, 2007a; 2007b; Goldsberry and Buttersby, 2009; Fabrikant et al., 2010), and the faithful approximation of the real phenomenon/ process under study (Adrienko et al., 2003; Rana and Dykes, 2003; Blok, 2005b). While all of these factors are equally significant, in this thesis we abide by the principles and rules pertaining to the two first factors, but we do not empirically and explicitly evaluate them.

Our efforts, instead, focus on the third factor, and, by acknowledging such rules and principles and by creatively adopting them to our scope, we deal with the means that this exploration can provide insight about the viewshed transition as an operation stemming both from the act of locomotion or/ and from the inherent landscape (terrain) configuration. And, since there is no actual 'ground truth' with which to compare the outputs resulting from an animation, we compare several differently sampled series of static viewshed map displays to an 'ideally' sampled visualization. Yet, the assimilation of some principles and rules imply that it is not about a sheer data-driven exploration (it could tend towards *confirmation* – see DiBiase, 1990): in essence, we explore visibility data in a meaningful but inherent to the landscape (i.e. topographically consistent) manner through locomotion over linear topographic features. So, the properties of each feature could have some distinct effects: Regarding animation suitability (the sequence of viewshed frames that are the most coherent for animation), these differing properties might call for different requirements in animation sequence; beyond investigating the most suitable series of viewsheds, the behavior of viewsheds can be studied by the impact of terrain's elevation and change in a intrinsically existing continuum (i.e. regardless of our subjective, extrinsic demarcation) – that is linear topographic features.

Imagine, this time, to be capable of apprehending the ('radial') visibility of a landscape by a 2-d fly-over: by visually comparing different topographically consistent routes ('viewroutes') and the explicit role of elevation of the moving viewpoint in such routes. We must admit that this potential deviates to a certain degree from what has been presented in the beginning: While in the beginning the quintessence of the visualization was directed to the communicative end of dynamic visibility maps and their strength to present routes that are elected among others depending on their vistas (assessed in quantitative and qualitative terms), now the crux of visualization entails the more profound inquiry of the different ways of 'sampling' the viewshed frames for the proper animation, along with the comparison of the dynamic viewshed sequential occurrence, yet by accentuating the topographic factor (different features/ elevation changes).

1.2. RESEARCH IDENTIFICATION

1.2.1. Research Goal/ Objectives

Thence, this thesis deals principally with the potentiality and appropriateness of harnessing an animated viewshed fly-over as a medium and facilitator to explore the dynamic visual landscape of different viewroutes (topographic features) by addressing the discreteness effect originating from the digitization of terrain and by inquiring the importance of abstraction in such a cartographic exploration. Towards accomplishing this generic **goal** or **scope**, several partial specific **objectives** are to be attained, namely:

- Examination of the 'nature' of viewsheds from a variety of perspectives – algorithms and data structures, landscape, representation, geomorphometry
- Investigation of the possibility for viewsheds to acquire a dynamic character in the geovisualization framework
- Decision of the congruent and consistent linear features/ routes at which the viewsheds should be visualized in an animated sequence
- Concern of conceptual, methodological and implementation aspects for approaching evolving viewsheds
- Election of the 'sampling viewpoints' along linear topographic features/ routes of different character
- Exploration/ Hypothesis Confirmation of animated viewshed analysis along different viewroutes and with varying viewpoint intervals with relation to their most appropriate (approximating an ideal standard) visualization
- Exploration of the influence of topography – linear feature and elevation – over the visualscape evolution.

1.2.2. Research Questions/ Hypotheses

Stemming both from 'what is available and effectible', and from 'what is demanded or desirable', this thesis addresses the issues being described in the previous. Bibliography and empirical studies inform us about the former, while the problem statement engraved on the goal and objectives motivate our interest and pursuit with reference to the latter. The overall/ aggregate resultant direction for the realization of this thesis is funneled through *research questions* and *hypotheses*. These questions and hypotheses posed below are closely interrelated; yet, they differ in that the second ones are much more specific, declaring a direction, and in that not each one of the questions is transubstantiated to a concrete hypothesis.

Research Questions

1. **In which ways can a landscape (visualscape) be 'fully' described via visual exploration?**
2. **Can a dynamic visualization of viewsheds approximate/ be equivalent to a landscape fly-over?**
3. **What are the cognitively (minimum) requirements to be met within an animated (fly-over) sequence?**
4. **What are the generic spatial (scale-interval) requirements in order to manipulate and harness scenes-frames for a sequence?**
5. **Are there differences in those requirements (question 4) between pre-ordered sequences on *different* routes (topographic features)?**
6. **How does elevation variation along different topographic features affect the changing visibility patterns (and how can this explorative task become integrated within a visualization)?**
7. **For the full description of a representative sampling route across all over the landscape, would a constant interval be satisfying?**

Research Hypotheses

Hypothesis 1: The 'deployment' of a set of points which are topographically 'enhanced' contribute to an improved strategy for the exploration of the landscape visibility.

A persistent research issue relates to the ideal way of sampling a region posing points of observation in order to fully or optimally describe this region in terms of visibility (see Turner et al., 2001a; O'Sullivan and Turner, 2001). Several approaches intended to satisfy the above issue promote points on prominent topographic features (see Lee, 1994; O'Sullivan and Turner, 2001; Rana, 2003; Kim et al., 2004). On the other hand, O'Sullivan and Turner (2001) have used *visibility graphs* to manipulate viewshed analyses in order to gain facilitated accessibility and 'explorability' of a landscape's visual properties potentially providing GIS users the capability for rapid access, retrieval and display of viewshed information.

Hypothesis 2: Animated viewshed sequences have the potential of substituting 3-d oblique perspective visualization (fly-overs).

3-d fly-overs involve a great deal of weakness when nothing is done to enhance their level of abstraction and generalization or to lift their visual occlusion/ immersion barriers (Harrower and Sheesley, 2005; Harrower and Sheesley, 2007). With regard to the immense information present causing visual saturation to the viewer and the absence of visual hierarchy or symbolization, Fairbairn et al. (2001: 22) suggest that "a more generalized display may be more effective for interpretive purposes than a highly detailed and complex virtual world", whereas the imposition of visual hierarchy and the entailment of other means of symbolization – increasing the levels of abstraction/ generalization – can associate thematic attributes of a visualization with salient features of each scene (Fabrikant and Goldsberry, 2005). On the other hand, the lack of spatial awareness/ orientation arising in the 3-d 'egocentric' perspective can be addressed by further contextualizing this oblique perspective with the prompt of a locator map showing its (relative) position within a complete view of the area of interest building a live-link between 3-d oblique and 2-d 'exocentric' planimetric perspectives (Fukatsu, 1998; Fuhrmann and MacEachren, 2001; Fuhrmann, 2003). Harrower and Sheesley (2005) have proposed the depiction "on the 2-d map all of the terrain currently visible in the 3-d map (i.e., viewshed analysis in GIS)" as a possible solution to the problem. Expanding the utilization of the visible portions from a predefined route/ path by consecutively computing them from a series of properly selected points of observation, it could constitute a generalized dynamic contextual (reference) map that can at the same fulfill much of the task of landscape visual exploration – since there is no immersion or visual occlusion.

Hypothesis 3: Denser viewpoint locations in more refined DTMs signify better approximation of the dynamic viewshed visualization and optimal insight gaining about the underlying process through cartographic exploration for every single viewroute through animation.

Common sense denotes that as the scale is refined and the sampling of viewpoint becomes denser, the visualization of the viewshed dynamic evolution across landscape routes approximates the inherent realistic conditions of the pertinent process, while the associated spatial data/ information exploration entails enhanced understanding and meaning. This premise exhibits a certainty that the 'optimization' of the behavior of the 'natural' viewshed dynamic process coincides with the optimization of its animated counterpart in cognitive terms as well. Yet, even if "*animations are believed to be useful for the representation of spatial dynamics because they can mimic real-world dynamics and show processes",* it is questionable "*whether they are also effective"* (Blok, 2005b: 71); therefore the critical question is: *"Are users able to extract useful information and acquire knowledge from them?"* (Blok, 2005b: 71). Thence, the major concern of the generic efficacy of animated maps towards map-users'/ readers' knowledge gaining and learning affordance in a readily and accurately perceived and comprehended manner giving prominence both to the *Congruence* and *Apprehension Principles* (Tversky et al., 2002; Griffin et al., 2006) is in particular extrapolated to the case of landscape dynamic visualization through viewshed animation.

Hypothesis 4: Elevation variation provides a useful and consistent indicant for the viewshed variation – but other factors impinge as well –, while the insert of a diagram portraying this elevation variation greatly pays off in a dynamic explorative task.

While a significant trend arises between elevations and the number of visible pixels, it is characterized by a weak positive correlation often accompanied by a very large standard deviation (Lee, 1994; Franklin and Ray, 1994). In addition to the motto "higher isn't necessarily better", several not explicitly understood factors, such as the specific cell that is tested, plus the topographic particularities of the neighboring pixels or of the totality of an area contribute to the investigation of visibility with respect to elevation and landscape relief (Franklin and Ray, 1994: 758). However, Lee (1994) has shown that peaks and ridges tend to dominate and not been dominated by other pixels, whereas the opposite applies for pits and ravines.

1.2.3. Research Methodology

For the goal and objectives of this research to be materialized in a rational and meaningful manner towards addressing the basic research questions and hypotheses, a coherent methodological configuration and flow is needed. The generic methodological framework of the thesis is presented below (Fig. 1). In essence, the multifarious literature review interacts with motivational, 'pre-empirical' knowledge shaping questions and hypotheses consistent to the research objectives. On the other hand, the bibliographic probation steered by these objectives leads us to the formulation of a dynamic cartographic visualization focused on viewsheds and animation. Controlled experiments with animated sequences yield certain dynamic outputs that are visually and statistically assessed. Eventually, several conclusions are drawn, which, intertwined with the initial research questions and hypotheses beget certain responses; 'follow-up' research is suggested in domains in which further endeavor is required or with respect to aspects that herein remain unresolved.

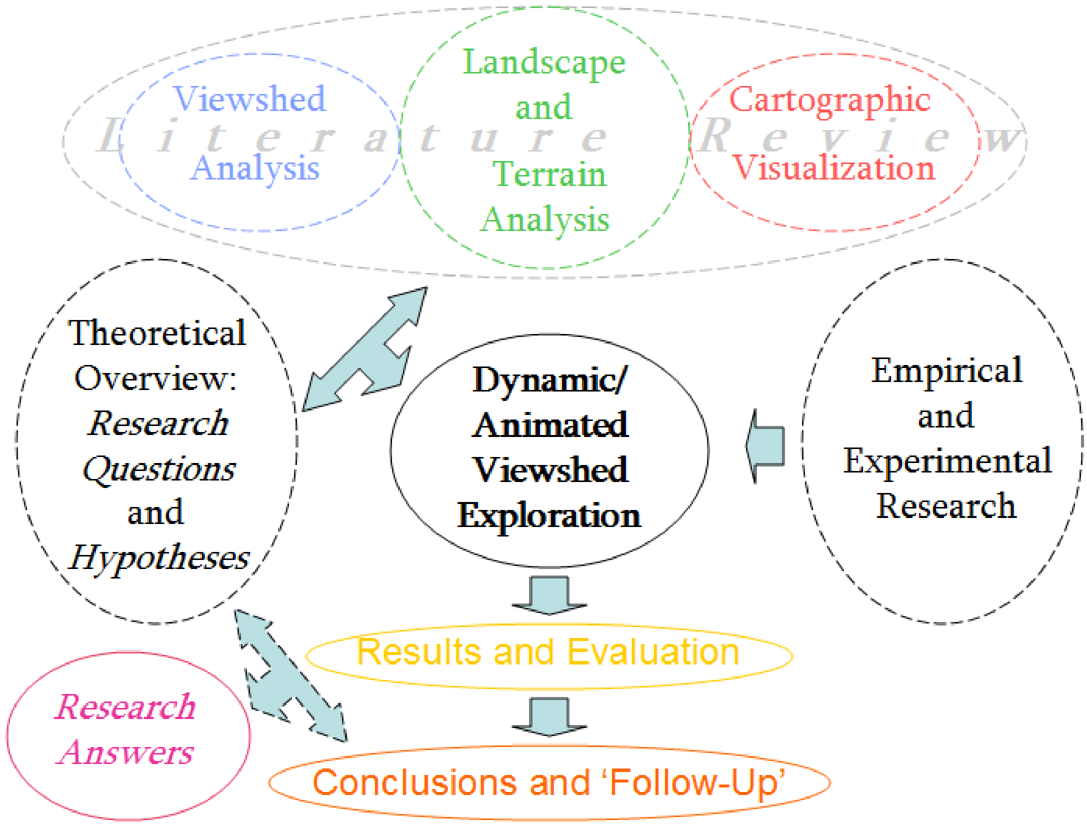

Figure 1: Generic methodology of the research.

1.3. THESIS OUTLINE

The structure of this thesis is formulated in a way that, after providing the present introductory chapter, the rationale is exposed through several chapters by introducing, analyzing and evaluating the most 'persistent' traditional fundamental theoretical concepts and practical aspects and the current trends by delving into the pertinent research literature. In addition, the overview of the literature is steered by the statement of the problem and the identification of this thesis. So, the three next chapters deal with the visibility/ viewshed matter from different perspectives, while the fifth one addresses another such perspective, while presenting the formation of the specific methodological framework. The sixth chapter is the 'mental output' resulting from the literature overview, where the general approach and methodology support and promote an experimental inquiry. The conclusions are presented in the last chapter. More specifically:

The following chapter intends to approach the nature of the problem of terrain visibility from a geographic/ spatial information handling and analysis perspective. As a consequence, it focuses on the required geographic data structures – that is models of terrain representation – and chiefly on the interwoven fundamental algorithmic processes dedicated to deal with the visibility problem for each model. So, the two predominant Digital Terrain Models (DTMs), and namely Triangulated Irregular Networks (TINs) and Regular Square Grids (RSGs) or gridded Digital

Terrain/ Elevation Models (DTMs/ DEMs) are introduced, in association with the fundamental underlying principles of the congruent visibility algorithms, their specification and their basic categorization. The description of these algorithms is environed by the basic processes yielding cartographic outputs of discrete viewsheds, while fuzzy viewsheds are mentioned as well. The chapter closes with a general assessment in terms of suitability and utility between the different representation data structures and the visibility/ viewshed algorithms.

The description of concepts referring to landscape's properties, qualities and classifications prompting the perception and understanding of the visual landscape comprise the focal points of the third chapter. Additionally, some structural aspects of vision and visualization with relation to the architectural and geographic space (isovists, viewsheds, visualscapes) are described so as to provide particular meaning to the inherent and perceptual configuration of the visual landscape. Moreover, the landscape's visual perception is further rated as an active-observation experience performed by moving observers – thus setting the agenda for locomotive visual landscape analysis in a dynamic context, introducing dynamic visual-scapes.

Next, the fourth chapter aims at demonstrating how maps can be manipulated or managed to comprehend time and change in their "fabric', and in which ways the new paradigm of cartographic visualization has shifted the paradigm of static map displays. But, beyond the aftermath of this shift in conceptual grounds, and the overview of overall principles, variables, classifications and particular techniques ensuing in the realm of cartographic visualization – that is means to create dynamic or interactive displays –, the ways in which such displays are capable of enabling adequately effective visualizations are investigated. Since motion and animated graphics are to increase the cognitive burden, there appear to be relevant limitations to the apprehension of animated/ interactive maps that should be surpassed or mitigated. Last, while managing the cognitive load, it is argued how an abstracted and 'objectified' (or 'exocentric') means of visualizing the locomotive visual landscape experience (i.e. visually exploring the landscape) with a planimetric view can and should serve as an effective abstracted 2-d fly-over (in opposition to 3-d fly-overs in virtual environments).

The fifth chapter deals with the representational and geomorphologic aspects for viewshed management, calculation, interpretation and visualization. So, from a representational standpoint the especial character of viewsheds is approximated by a fused object/ field perspective, while the core matter of time and change is once again considered. On the other hand, since viewsheds are derived by digital terrain analysis and they are often rated as 'non-local land surface parameters', several issues are raised regarding to the digital terrain modeling procedure as a whole, and to tasks such as data (i.e. DTMs/ elevation) scale (resolution and geographic extent), capture and sampling; plus, classification of digital land-surface derivatives and the more specific discrimination of land-surface parameters take place, according to which the uniqueness of viewshed is put forward with relation to its calculation and scale. Moreover, both the discreteness of digital models and the sampling potential of topographic features are more closely examined, in relation to the way viewsheds are analyzed and visualized so as to describe a landscape with reference to its visual properties/ configuration. Ultimately, the literature overview of all the abovementioned topics (second to fifth chapter) leads us to subordinate our rationale to our methodological framework, more exactly specified at this stage.

Theoretical, bibliographical and methodological components, all contribute to the materialization of our goal, enabling the implementation tasks pertaining to this thesis. These tasks are thoroughly described in the sixth chapter within a case study as stages within a procedure: from the identification of the study area, digital data acquisition and pre-processing, to the final animation generation. The further processing, interpretation and evaluation of the results through the visual exploration of the dynamic spatial data and their statistical analysis revealing important evidence pertaining to the fundamental research requirements of the thesis complete the composite picture of this chapter.

Within a context of summarization of the most important findings stemming from literature, theoretical deduction and empirical induction, answers to the research questions posed above emerge, in particular, in the final chapter of conclusions. Eventually, some considerations and suggestions regarding further development of our approach are presented, with an aim to exploring the track of future ‘research trajectories’.

2. VISIBILITY CONCEPT AND ALGORITHMS IN GEOINFORMATICS

[“A friend who is far away is sometimes much nearer than one who is at hand. Is not the mountain far more awe-inspiring and more clearly visible to one passing through the valley than to those who inhabit the mountain?”]

Khalil/ Kahlil Gibran

The world around us exposes only certain facets of its multicity each single time it is observed. And since it provides different vistas from different observation points (or viewpoints), it would be rather irrational and inconsistent for the “curious man” not wanting to know either which regions are observable, or, inversely, from which viewpoints given areas of observation are visible. Yet, the incentives for retrieving such a knowledge (information), are far from being merely “curiosity solving” or self-fulfilling. On the contrary, the demands of various applications are triggering and augmenting these motivations, rendering the geographic information about visibility problems indispensable: line-of-sight transmitters/ receivers or fire towers optimal location, identification of physiographic elements, orientation and navigation with reference to the horizon, landscape (scenic path) visibility and assessment, military activities decision-making comprise some aspects of the same problem. What is even more crucial nowadays lies in automating the procedure for the handling/ manipulation and identification of the relevant data/ information by applying using computational efficient methods and techniques in the context of Geographic Information Systems.

2.1. VIEWSHED ANALYSIS BASIC CONCEPTS

The conceptualization of the notion of visibility differs in real and in digital world. In everyday reality, earth surface (including the underlying topography and all the entities on it, i.e. vegetation, buildings, vehicles etc.) is the major factor determining the visibility from a viewpoint. In Geographic Information Systems, a *digital model* is required to represent the earth surface, or the *terrain*. Such models – *Digital Terrain/ Elevation Models* (*DTMs/ DEMs*)[1] – are abstract representations of the terrain emphasizing the topographic aspect (elevation), while the abstraction occurring by the interrelation between terrain elevation and visualization called *geometric visibility* is nothing but the intersection of the

[1] DTMs can be considered a generic class for computer/ digital representation of the terrain, including DEMs (Digital Elevation Models), DSMs (Digital Surface Models) and DBMs (Digital Building Models).

terrain with the *lines of sight* from each viewpoint (Nagy, 1994). Therefore, this fundamental operation in GISs both for visualizing the terrain (De Berg, 1997; De Floriani and Magillo, 1997) and for analyzing/ detecting properties of the terrain itself (De Floriani and Magillo, 1997) can be accomplished by *direct computation* instead of *inspection*, using geometric visibility (Nagy, 1994). An intermediate case pertains to the manual production of intervisibility maps based on the contours of a topographical map (Yoeli, 1985).

In essence, visibility operations arise primarily as responses to specific questions. Problems and queries related to visibility on terrains are in general referred to as *viewshed analyses*. De Berg (1997: 79) condenses the viewshed analysis problem through a simple question: "Which parts of the DTM are visible from a given view point"? De Floriani and Magillo (1997) further categorize such an analysis into *visibility queries*, whose purpose is to seek the segments from a query object that are visible from a viewpoint, and *viewshed computations*, which are dedicated in specifying the segments/ regions of the whole terrain that are visible (from a viewpoint).

To give answers to these spatial problems and queries, the *intervisibility* (*mutual visibility)* notion is introduced. More specifically, the mutual visibility requirement between a pair of points is satisfied if a straight line or line segment or line of sight (LOS) joins them without intersecting the terrain, and, more specifically without passing below its surface (Lee, 1991; Fisher, 1993; De Floriani et al., 1994; Nagy, 1994). Given that viewshed delineation is treated as a *two-and-a-half-dimensional* (2,5 D) problem (i.e. terrain elevation is a single valued function of x and y with reference to a horizontal datum) (Nagy, 1994), relevant algorithms require at least two inputs. According to Maloy and Dean (2001), the first one is the DTM, which functions as a means both to represent the relief (topography) and regionalize the area of interest later classified as visible or invisible, whereas the second one determines the 3D location of the viewpoint.

Visibility operations/ functions can occur among points, lines and surfaces (regions), although only point-to-point and point-to-region functions are useful. In practice, a N x N *symmetric matrix* or the equivalent *visibility graph* with N nodes and up to N^2 arcs is the data structure representing the point-to-point visibility among every pair of the data points; in point-to-region visibility functions, a two-dimensional choropleth map dividing (in a binary manner) visible and invisible map is the output (Nagy, 1994). Kim et al. (2004) note that the first function merely predicts whether mutual visibility occurs between two points and is referred to as *intervisibility analysis*, while the second one estimates which segments/ areas of a terrain are visible from a viewpoint, called *viewshed analysis*. It is inferred, thus, that viewshed analysis is a more comprehensive function (Kidner et al., 2001).

In its earliest form, viewshed visualization in cartographic terms has emerged by graphically creating topographic profiles (cross sections) emanating from a view point by harnessing contours on topographic maps, and then delineating continuous hidden areas by manually linking together (interpolating) adjacent hidden segments from the profiles previously produced (Yoeli, 1985). As unsophisticated a method as this may seems, it holds as the fundamental strategy for viewshed prediction and representation in various cases in digital environments. Nagy (1994) presented in *1-and-a-half* dimensional horizons the emerging subdivision of the terrain into visible regions and invisible regions or *blocking segments* and *shadow segments* respectively: Inducing a double projection – the orthogonal projection of the central projection from the viewpoint – of the terrain variation (along a horizon), the projected terrain edges at the transition from visible towards invisible regions are blocking edges (odd order horizons) while the opposite are shadow edges (even order horizons) (Fig. 2). Odd order horizons typically correspond to ridges or shoulder lines, whereas even order horizons imply the far sides of these ridges.

As previously mentioned, terrain visibility is an operation inextricably interlocked with visualization when the data processed is the elevation accounting for a terrain (De Berg, 1997), and the related query objects or observable regions are parts of the DTM itself. Under these circumstances visualization of the terrain in a DTM can yield visibility computations depending, nonetheless, on what computer representation of the terrain (DTM) is selected (De Berg, 1997; Nagy, 1994).

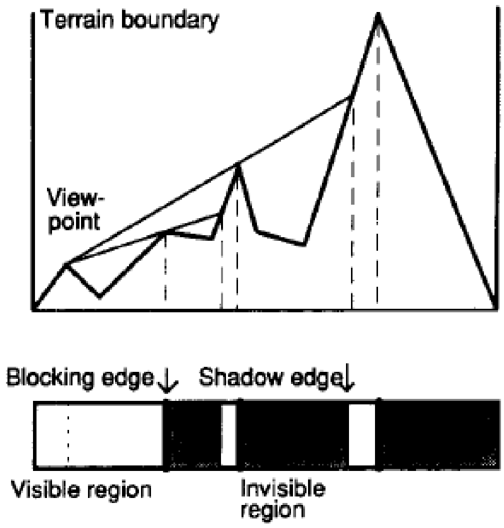

Figure 2: Horizons in 1-and-a-half D. There are three odd order (blocking edges) and three even order (shadow edges) horizons for the viewpoint. Terrain segments between odd and even horizons are invisible, while segments between even and odd horizons are visible from the viewpoint.
After Nagy, 1994.

2.2. TERRAIN REPRESENTATION (DTMs) AND VISIBILITY ALGORITHMS

The two models most usually utilized are the gridded DTM or *Regular Square Grid* (*RSG*) and the *Triangulated Irregular Network* (*TIN*). An important element of the adaptation of these models is that they both “discretize” the otherwise analog/ continuous terrain in order to be stored and handled in a digital form[2]: While elevation models are mathematically continuous functions in two variables, digital elevation models are finite representation of the former (van Kreveld, 1997). Nevertheless, no matter how this modeling deviates from mathematical models and from human way of relief perception and visualization in cartographic terms (isoline maps – contour maps), this kind of representation is innate to the computer substance, providing direct implementation of several operations and computation.

From relevant literature review, several authors have manipulated TINs (e.g. Lee, 1991; De Floriani et al., 1994; De Berg, 1997; De Floriani and Magillo, 1997; Kidner et al., 2001), while several others have utilized RSGs (e.g. Fisher, 1993; Franklin and Ray, 1994; Fisher, 1996b; Maloy and Dean, 2001; Israelevitz, 2003; Kim et al., 2004) to treat with viewshed estimations via various algorithms.[3] Below, the viewshed operation is approached in more detail, with reference to the two more prominent digital terrain representations, through the description of the specific properties of each such representation. And, as far as these representations serve both in elevation description/ representation, and in horizontal domain partitioning, they constitute the major data inputs for implementing visibility operations. Consequently, the general principles of the algorithms implemented should correspond to the "architecture" of the model chosen, and, therefore, the relevant algorithms are described with respect to the selected DTM.

2.3.1. TINs

2.3.1.1. Structure

The Triangulated Irregular Network (TIN) includes a set (S) of irregularly distributed points which are stored along with their elevations, and planar triangulation of the domain is applied on them (van Kreveld, 1997). It consists of a multitude of non-overlapping triangles which completely cover a topographic surface (Robinson et al., 1995). In essence, each one of these triangles is produced by selecting three points of identified elevation (constituting its vertices) according to the *Delaunay Triangulation*[4] which leads to a unique triangulation (Στεφανάκης, 2003). Now, each point of the domain will lie either on a vertex, an edge or on the facet of a triangle. Therefore, the elevation of each point, apart from those that lie on vertices, will be estimated utilizing linear interpolation from two or three points if they lie on edges or somewhere on the facet of a triangle

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[2] The "discretization" of geographic reality in GIS is a generic property for computer storage, and is not to be confused with discrete and continuous DTMs, such as TINs and RSGs.

[3] For a summary of algorithms reviewed with relation to the selection of DTMs, see De Floriani and Magillo (2003).

[4] Delaunay triangulation leads to the maximization of the minimum angle of all the angles of the triangles, tending, thus, to prevent the formation of 'skinny triangles'.

respectively (van Kreveld, 1997). A doubly connected list constitutes one of the alternatives for storing a TIN. Another alternative could be the storage of triangles, edges and vertices as separate files: every triangle then would be a record in a file with three fields with pointers to each of the three incident edges, while every edge would be stored in a file with four fields with pointers – two of them directed to the incident triangles and the rest two to the incident vertices; vertices would have three fields storing x-coordinates, y-coordinates and the elevation (van Kreveld, 1997).

2.3.1.2. Algorithmic Processes

Visibility analysis when working with TINs is related to the visualization of the terrain and it has emerged in parallel to the visualization or rendering of a 3D scene or a set of 3D objects. In comparison to algorithmic processes for visibility analysis related to RSGs, these processes are much more complex and complicated due to the explicitly defined topology of the TIN model (Theobald, 1989 – cited in Kidner et al., 2001) and the augmented sophistication of the relevant data structures suitable for encoding the visibility on a terrain (De Floriani and Magillo, 1999).

De Berg (1997) has suggested some fundamental algorithmic processes in order to resolve the visibility problems, when terrain is represented by triangles: Basic terms are the *viewing volume*, the *viewing plane* and the *scan-conversion*. Depending on the projection that is considered to be proper, a rectangular block (for parallel projection) or a truncated pyramid (for perspective projection) specifies the 3D region of interest. Objects are clipped onto this volume and are projected afterwards to the viewing plane (Fig. 3). At the stage of scan-conversion, rendering of the visible objects (within the viewing volume) is related to the definition of the set of pixels corresponding to these objects and the assignment of color to these pixels of the respective objects from the *frame buffer* – an array that stores the color for each pixel. The *hidden-surface-removal problem* in which it is sought "what is seen of a TIN […] from a given viewpoint or in the given viewing direction" determines which parts of a 3D object are visible, and thus contributing to terrain visibility. There are two possible solutions to respond to this problem (visualize what is visible and what is hidden): through the *image-space algorithms*, and the *object-space algorithms*. In the first category, the objects are first projected onto the viewing plane and the visibility of each pixel is determined during scan-conversion, in contrast to the second category in which only those parts of objects that are specified as visible are projected and then scan converted (De Berg, 1997).

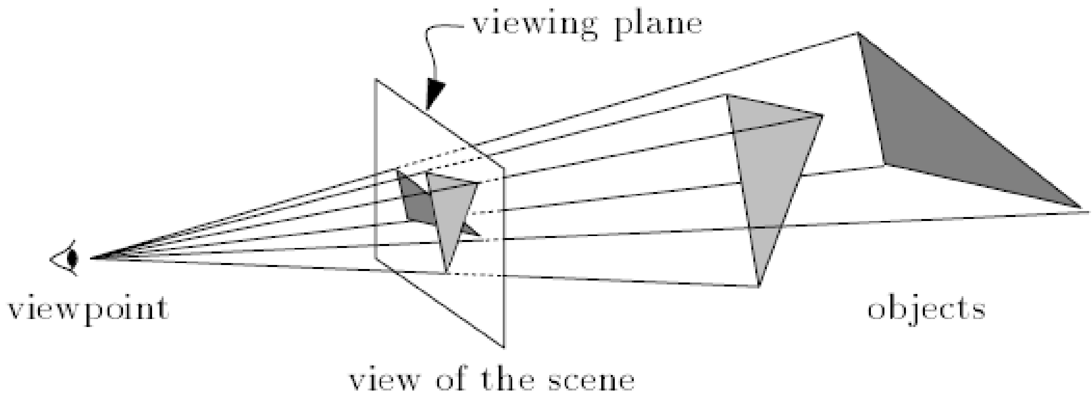

Figure 3: Visualization of the objects of 3D scene – projection and hidden surface removal. After De Berg, 1997.

Image-Space Algorithms

Algorithms befalling in the first category are the *z-buffer* and the *painter's* algorithm. The first one requires except for the frame buffer (FrameBuf), the z-buffer (ZBuf) which is a 2D array where ZBuf(x,y) stores the elevation or z-coordinates for pixel x,y. So, when the scan-conversion procedure is executed for every object present at the scene in an arbitrary order, the utilization of the color in frame buffer is augmented with the z-coordinate of the object currently visible at each pixel, and a comparison (visibility test) takes place: For an object *t* (let t be a triangle), the z-coordinates of *t* at x,y – $z_t(x,y)$ – is compared to the ZBuf(x,y); if $z_t(x,y)$ < ZBuf(x,y), then FrameBuf(x,y) := $color_t$ and the ZBuf(x,y) := $z_t(x,y)$, for t lies in front of the already processed triangles; otherwise, FrameBuf(x,y) and ZBuf(x,y) remains unchanged. The second one is considered to be a *depth sorting method* implementing *depth-order* or *back-to-front order* in scan-conversion. These types of algorithms, scan-convert the objects (triangles) in a back-to-front order; thus, if a triangle is scan-converted, then it is in front of every other object scan-converted that far. As a result, visibility test is avoided; however there is a trade-off: an additional pre-processing step of back-to-front order or depth order is required instead. Furthermore, in some cases this order is difficult or even impossible to be resolved (e.g. cyclical overlapping of triangles).

Implementation of depth sorting methods specifically proper for TINs has been proposed by De Berg (1993). The particularity here lies in the computation of the depth order of the triangles (of the TIN) that represent the terrain itself. In the case of *parallel view* it is presumed that in a direction of a line (of view) $\vec{d}$, a triangle t_i is in front of t_j, if $\vec{d}$ intersects first t_i and then t_j (or some point of t_i hides some point of t_j). Then, in a set (*T*) of triangles their ordering t_1, t_2, … t_n in a TIN, where t_i is in front of t_j, results from depth order and is written as: $t_i \prec t_j$; in addition, $i > j$. To elucidate, a triangle that is in front of all other triangles will come last in ordering, and, therefore it will be scan-converted last, or "on top of objects". Given that this is an image-space algorithm and that TIN has been created in a way that the planar projection of triangles results in non-overlapping triangles, if $\vec{d}$ is projected onto the x-y plane as well, it will intersect in the same order the planar scene (projected triangles). For a dual graph (G_T) where every node (V) correspond to the projected triangles and an edge (E) exists between adjacent triangles (reflecting the in-front-of relation), it is proper to store it on a doubly connected list. If we utilize this topological structure converting, afterwards, G_T to a directed graph $G_T(\vec{d})$, then the edge connecting adjacent triangles will be directed from t to t' if $t \prec t'$ and from t to t' if $t \prec t'$. Otherwise, the connection will be deleted. If an edge with direction from node v' to v connects these two nodes, then v' comes before in topological ordering; consequently, if there is a directed path from v' to v, then the same is valid. As far as nodes represent triangles, therefore, a path exists from t to t' in $G_T(\vec{d})$, as well as a topological order corresponding to the depth order of the $G_T(\vec{d})$. In the case of *perspective view* from a viewpoint (p_{view}), we assume that a ray (line of sight) emanates from the viewpoint and it intersects first t rather than t', provided that t is in front of t'. The depth order is computed as above, harnessing the topological ordering on the dual graph $G_T(p_{view})$. The problem of cyclical overlapping of triangles may come about; however, this is not the case for TINs created using Delaunay triangulation.

Object-Space Algorithms

The second great category of algorithms compute a discrete combinatorial representation, subdividing the viewing plane into maximal connected regions where a (part of a) single object or no object is viewed (Overmars, 1991; De Berg, 1993). Despite their relatively low implementation speed, among other advantages that they exhibit, these algorithms are more proper for viewshed analysis due to their capacity to compute explicitly what is visible from a viewpoint (De Berg, 1997). For TINs in particular, object-space hidden-surface-removal algorithms that adapt the parallel view in a direction $\vec{d}$ are described by De Berg (1997). One such algorithm takes advantage of the back-to-front ordering approaches described above, utilizing it inversely. The treatment of triangles in a front-to-back order (with respect to the viewing direction) involves: the maintenance of the (current) contour – i.e. the union of the projected triangles processed that far –, the computation of the portion of a new triangle that protrudes the current contour, and the determination of the new contour – which is computed as the union of the current contour and the new one (Fig. 4). Another algorithm initially developed from Katz et al. (1992) for several objects has been adopted by De Berg (1997) to implement it on TINs (and on any set of triangles or other objects that are subjected to depth ordering): Let T be a set of triangles in 3D space and $\boldsymbol{T}(v)$ a balanced binary tree storing triangles to its leaves where the depth order is indicated by the left-to-right order of its leaves; in addition, $T(v)$ denotes the triangles rooted at node v. Two other sets are also fundamental: $U(v)$ – the union of the triangles of $T(v)$ onto the viewing plane – and $V(v)$ – the visible part of $U(v)$ – for each node (v). To elucidate, let $U_{left}(v)$ store the union of the projected triangles in leaves to the left of T, and therefore these triangle come first in depth order (before triangles in $\boldsymbol{T}(v)$) and might hide the latter (triangles in $\boldsymbol{T}(v)$); $V(v)$ could then ensue as follows: $U(v) - U_{left}(v)$ (Fig. 5). So, if the leaf that contains $t \in T$ is denoted by v_t, then $V(v_t)$ will correspond to the visible portion of t, and by implementing this procedure to all nodes, then the problem of surface hidden-surface-removal is resolved for every triangle of the TIN (or for every object in a 3D scene).

Even though the visualization of TINs in the domain of computer graphics treat with the hidden surface problem which clings to the visibility algorithms, hidden-surface-removal algorithms focus mostly on how an image/ scene appears from a given viewpoint (or given direction), "reporting the limits of visible areas as coordinates on an image and not on the model" (Lee, 1991). Thus, they are not totally appropriate for "extracting" the visibility information in geographic/ cartographic terms.

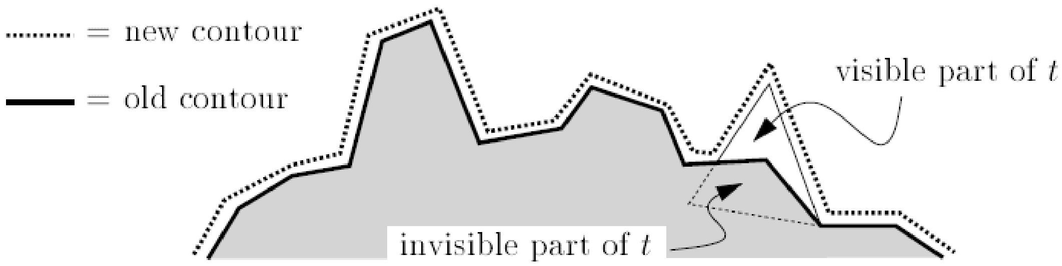

Figure 4: Illustration of the front-to-back "contour" algorithm for visible (portion of) triangle visualization.
After De Berg, 1997.

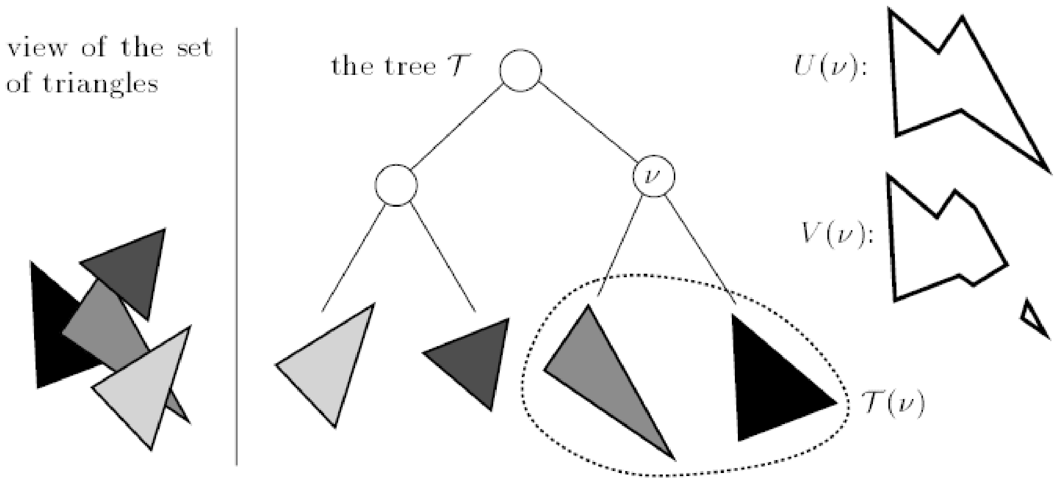

Figure 5: The tree T and the sets $U(v)$ and $V(v)$.
After De Berg, 1997.

Therefore, we refer to the algorithm of Lee (1991) who, based on algorithmic foundations of De Floriani et al. (1986) and Goodchild and Lee (1989) finding visible portions on TIN surfaces for given viewpoints, has suggested a *binary* *visibility information* computation among each pair of triangles and viewpoints on TINs. In essence, this computation is supported by an algorithm according to which for a triangle (*T*) to be entire visible, it is required that all of its edges (*E*) are entirely visible from a viewpoint (*P*). In the beginning, the sorting of its edges in ascending order depending on their distance with the viewpoint, and the discrimination of each edge as visible or invisible take place. In the next step, edges are tested to find out whether they *2-block* each pair of *P-T*. Let *P* be the viewpoint and E_i, E_j the two edges. Connecting P to the endpoints of E_i, E_j, four line segments are created (Fig. 6). E_i, is considered to be 2-blocked by E_j if: (i) E_j intersects with either pa or pc (Fig 6b), or if (ii) E_i intersects with either of the extensions of pd or of pf (Fig 6b), or if (iii) E_j lies in its totality within the triangle formed by P and E_i (E_j totally 2-blocks E_i) (Fig. 6a). In the case that E_j totally 2-blocks E_i (case iii), E_i is visible from P if and only if the endpoints of E_j lie below the plane forming from P and the endpoints of E_i. In the case that E_j partially 2-blocks E_i (cases i, ii), E_i will be decomposed into its constituent segments, and the segment of E_i that is 2-blocked by E_j – respectively to P – will be subjected to visibility testing as if it was a separate edge that was totally 2-blocked by E_j (as previous: case iii); the segment not 2-blocked by E_j, will be subjected to visibility testing against other 2-blocking edges, if any. The relevant algorithm, expressed in pseudocode can be sought in Lee (1991). \

However, apart from the binary visibility algorithm, an algorithm defining the *minimum visible height* between any pair of a viewpoint and a sub-region is required, in order to be able to solve visibility problems of variable heights. Both the relevant algorithm, in pseudocode, and its description can be retrieved by Lee (1991).

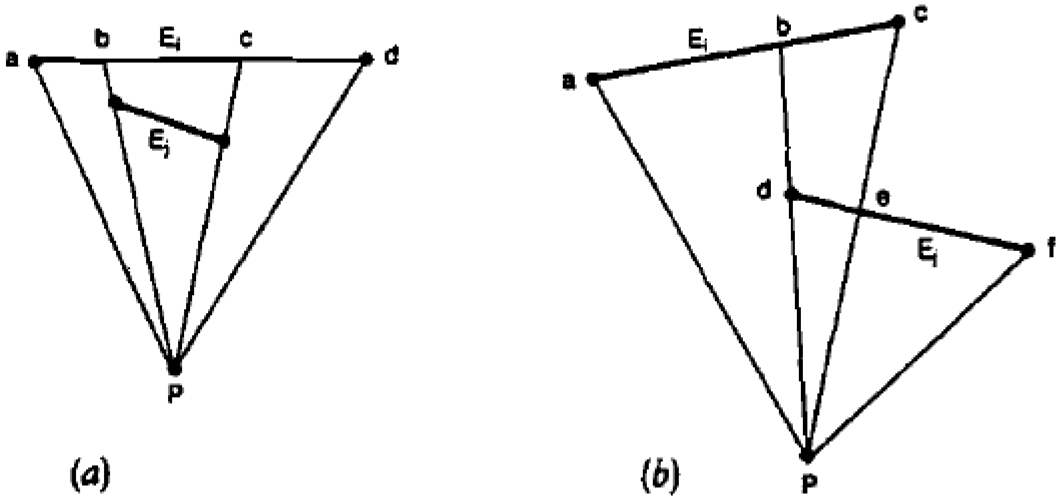

Figure 6: Blocking status between two edges and a viewpoint. In both cases, E_i is 2-blocked by E_j. Special treatment is required if E_j totally 2-blocks E_i (a). E_i is partially 2-blocked by E_j and, therefore, should be decomposed to two segments, ab and bc, for the subsequent testing of visibility (b).
After Lee, 1991.

2.2.2. RSGs (Gridded DTMs)

2.2.2.1. Structure

With Regular Square Grids, a tessellation of the domain into regular squares is induced, and values are specified for each square (van Kreveld, 1997). When it comes to DTMs, this domain refers to the contiguous topographic surface, while the value assigned in each square area, or raster cell, is the elevation representing the terrain at the extent of the cell (DeMers, 2000; Maloy and Dean, 2001). So, a DTM is a regular grid, or a regular lattice of which regular shapes (square raster cells) simultaneously partition space while containing a single absolute elevation value[5], converting, thence, the continuous data variable of terrain elevation to a discrete representation (Chang, 2003; DeMers, 2000). As every other grid model (data structure), DTMs are proper means for domain tessellation representation within a computer. As an effect, for their storage, two-dimensional arrays are required, where exactly one value (elevation) is specified for each entry (cell) of the array (van Kreveld, 1997).

2.2.2.2. Algorithmic Processes

In contrast to algorithms computing terrain visibility in TINs, which are complicated and require depth and/ or topological ordering, the algorithmic process when working with RSGs is rather simple and straightforward. Furthermore, unlike the graphical/ manual method described in § 2.1., intervisibility control is executed for every point of the RSG DTM individually (Yoeli, 1985). The basic algorithm underlying visibility computation in RSGs entails two essential steps in its simplest form, according to Fisher (1993): In the first step, the LOS emanating from the viewpoint intersects the grid of the RSG at an intersection point, and the horizontal location (x,y coordinates) of this point is identified. In the second step, the elevation (z) of the RSG at the intersection is determined, and then compared to the elevation of the LOS towards the target (this time). If the latter is higher, then this target is visible and the procedure can carry on to further inspect the next intersection point; if the former is higher, the procedure has come to an end, and a new target is to be evaluated (Fig. 7).[6] In order to delineate the viewshed for a whole RSG, each region of the RSG is treated as a target by the algorithm, iteratively; after determining vertical angle and orientation of the LOS, the comparison occurs among all surface elevations along each LOS to this line, and in such a way the computation of visibility is applied (if no intermediate elevation points rise above the line of sight, the targets are

[5] This means that elevation value is not modified within the extent of a cell.

[6] Sorensen and Lanter (1993: 1149) have defined the algorithm in a similar way: "If the slope between the source [(viewpoint)] and any intermediate cell in the line of sight is greater than the slope between the source and the destination cell [(target)], then the visibility between source and destination is at least partially blocked."

considered visible) (Fisher, 1996a; Burrough and McDonnel,1998 – cited in Kim et al., 2004; Maloy and Dean, 2001).

Although this process is relatively straightforward, its accuracy is liable to the accurate representation of the RSG in the area of interest (Walsh et al., 1987; Lee et al., 1992 – both cited in Maloy and Dean, 2001; Fisher, 1993). The quality and density of the initial points (primarily), the size of the cell and the inference/ extrapolating methods of the elevation and the way that viewpoints and targets are represented within the lattice are crucial parameters that modify the validity of an RSG as a proper DTM for viewshed operations. Some of them are discussed in the following.

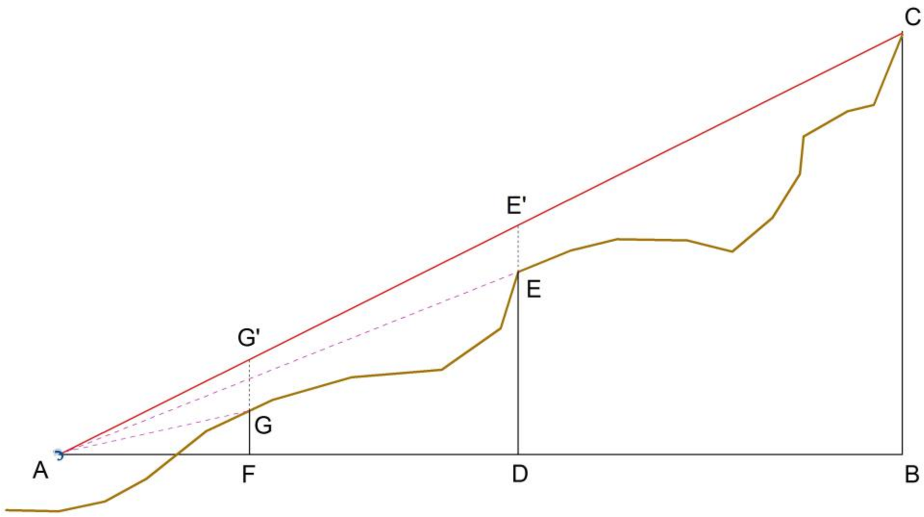

Figure 7: Intervisibility between A (viewpoint) and C (target) is attained, since FG' > FG, DE' > DE and AC (LOS) does not intersect the terrain – topographic profile (brown curve) in general.

As previously mentioned, the cartographic output out of a viewshed operation (viewpoint-to-region visibility function) is a two-dimensional (binary) *choropleth* map dividing visible and invisible regions. In the case of TINs, the minimum enumeration unit is each triangle since they serve to the horizontal domain partitioning. So, one would expect (binary) values of visibility to be assigned at the extent of each triangle. Nevertheless, utilization of binary algorithms that allow partial visibility within a triangle such as Lee's (1991) can yield visibility matrices where the rows are viewpoints and the columns are sub-regions of TINs (formed by segments/ portions of partially visible edges and the line segments drawn from viewpoints). These matrices $VB(i, j)$, i=1, np (number of viewpoints) and j=1, nt (number of triangles) record information (values) about visibility in each subregion (of triangles) and for every viewpoint; so $VB(i, j)=1$ if a subregion is visible and $VB(i, j)=0$ if a subregion is not visible from a viewpoint (Fig. 8). The final output can also be a binary map where subregions of triangles are attributed the values that correspond to them, and therefore, visible and not visible subregions can be represented by light and dark tones respectively (Fig. 9).

In the case of RSGs, the mapping procedure is as straightforward, as the computation of the basic visibility algorithm. A new RSG output is developed for every cell of which a new value is assigned: if it is visible, the value 1 is assigned, whereas if it is invisible, the value 0 is assigned. So, the enumeration units at such maps are the cells of the grid, and the proper binary value is assigned (uniformly) in such enumeration units. In most GISs (e.g. ArcGIS 10), viewshed operations are implemented on DTMs in raster format (RSGs). Visibility maps are the result of the assignment of a color for each binary value discriminating visible and not visible regions (Figs. 10, 11). It is also possible to compute visibility from various viewpoints, storing in the visibility's RSG attribute table (matrix) how many viewpoints can be seen from each region (set of cells).

	T1	T2	T3	. . .	Tn
P1	0	0	0	. . .	1
P2	1	0	0	. . .	0
P3	1	1	1	. . .	0
.					
.					
.					
Pn	0	1	1	. . .	0

Figure 8: A binary matrix recording visibility between all pairs of viewpoints (P) and triangles (subregions of triangles) (T). Elements assigned the value 1 imply visibility while elements with the value of 0 imply non-visibility.

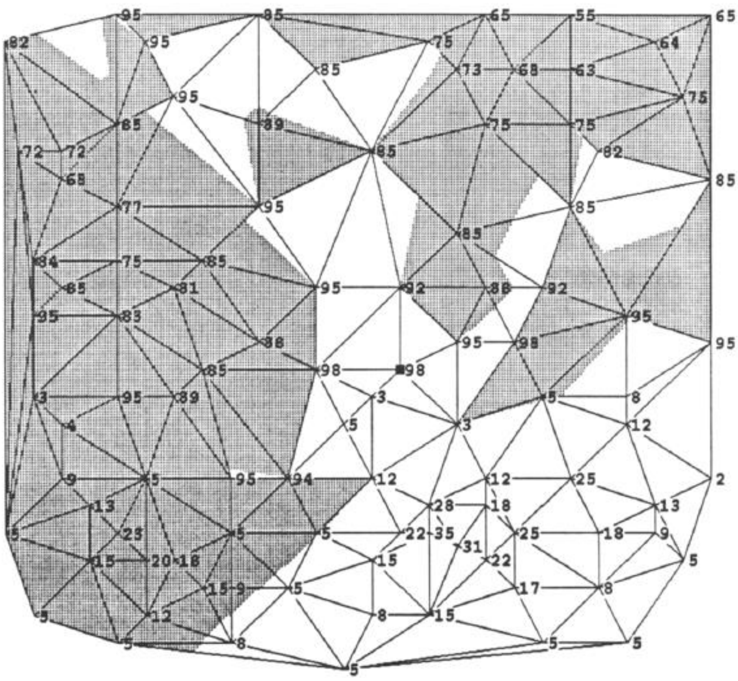

Figure 9: A visibility map based on a TIN. The light triangles/ subregions are visible from the viewpoint (near the center), while dark areas are invisible.
After Nagy, 1994.

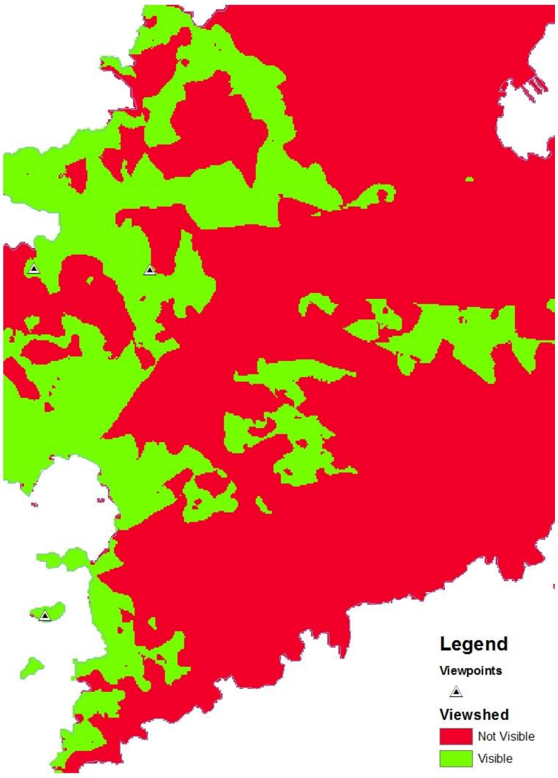

Figure 10: Binary map of visible and invisible regions. Visible regions are observed by at least one viewpoint.

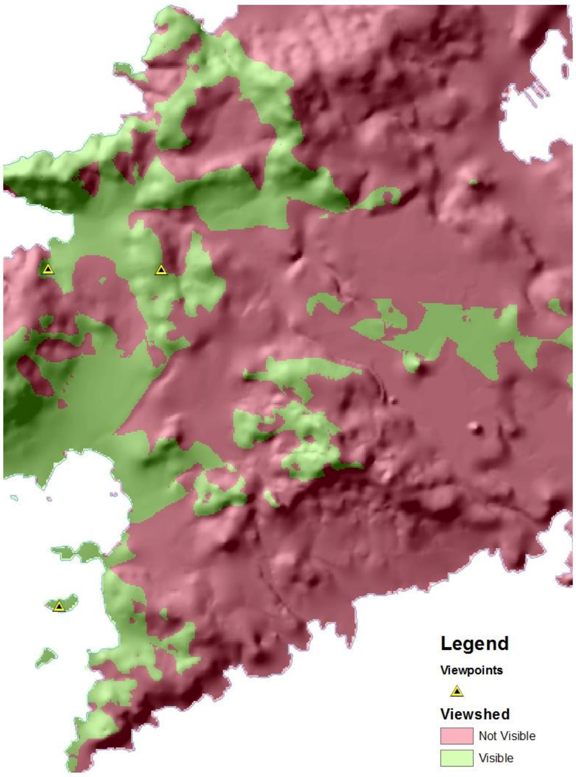

Figure 11: Visibility map (as in Figure 9) overlaid on the background of a processed RSG DTM (hillshading).

2.3. UNCERTAINTY: BINARY (BOOLEAN) vs. FUZZY VIEWSHEDS

In the previous sections, visibility has been dealt with in a binary means; that is, a region (i.e. a set of triangles or cells) on a DTM has been considered to be either entirely visible, or entirely not visible from one or more observation locations. Nonetheless, it has been implied that various factors pertaining principally to the digital representation of the terrain (at its interplay with algorithmic processes) impose uncertainty to the viewshed outputs. In fact, binary viewsheds have been proven insufficient in modeling the visibility of an area (Fisher, 1992; 1993; Sorensen and Lanter, 1993; etc.). Beyond the apparent fact that elevations' measurement lack adequate accuracy and these errors can have impacts on the estimated viewsheds (Fisher, 1992; Fisher, 1996b), there are other main factors plaguing Boolean viewsheds. Below, some fundamental research attempts towards proceeding to more probabilistic versions of viewshed estimation, utilizing RSGs.

Fisher (1993: 331) has promoted such factors by examining: "how elevations in the digital elevation model are inferred [and] how viewpoint and target are represented". By discerning between alternative methods/ strategies for inferring elevation across the edges of DTM meshes (Fig. 12) and approximating viewpoints-targets on gridded DTMs (Fig. 13), and by empirically experimenting on them, he points out that the alterations based on different conceptualizations significantly affect the outputs of the implementation algorithm. As an effect, uncertainty (not accuracy) is rather inherent to the viewshed (phenomenon) within a GIS (Fisher, 1993).

In a similar vein, Sorensen and Lanter (1993) address the issue of error introduced by the geometry of the raster structure itself. So, they propose two methods in order to reduce 'data-structure induced errors' and determine the degree to which cells are visible or blocked. Figure 14 shows the two different ways in which a cell may block/ obscure either entirely or partially the LOS between a source and destination point (observation and target point) in a DTM grid with regard to their relative positions on the latter – either lying on the same row/ column, or lying diagonally with relation to each other. Moreover, the two algorithmic methods proposed are: i) the 'vector analysis' one assigning partial visibility values to each cell and ii) the 'sub-cell binary analysis' method yielding visible and non-visible areas on a sub-cell level extent (Fig. 15).

In general, these attempts, along with others, penetrate the factors related to the uncertainty originating principally from faulty assumptions/ insufficient conceptualizations (Fisher, 1993; Sorensen and Lanter, 1993) or inaccurate representations (DTM error: e.g. Felleman and Griffin, 1990; Fisher, 1992; Fisher, 1995) and not from erroneous sampling or inaccurately measuring elevations in the field. So, by either calculating multiple times viewsheds adding to them variable amounts of noise (Felleman and Griffin, 1990; Fisher, 1992; Fisher, 1995), or computing viewsheds under different parameters (Fisher, 1993; Sorensen and Lanter, 1993), probabilistic versions of viewsheds emerge with varying levels of fuzzy membership; each cell of a DTM is assigned a value in [0, 1] reflecting its potential of being visible (Fisher, 1992; De Floriani and Magillo, 2003). Furthermore, some authors have proposed rules for combining fuzzy viewshed (through union/ intersection) (e.g. Fisher, 1996b). Even though the advancements in this field (fuzzy sets and viewsheds) are important, the scope of the thesis deters a more thorough analysis – it has been sufficient to promote the limitations of binary viewsheds.

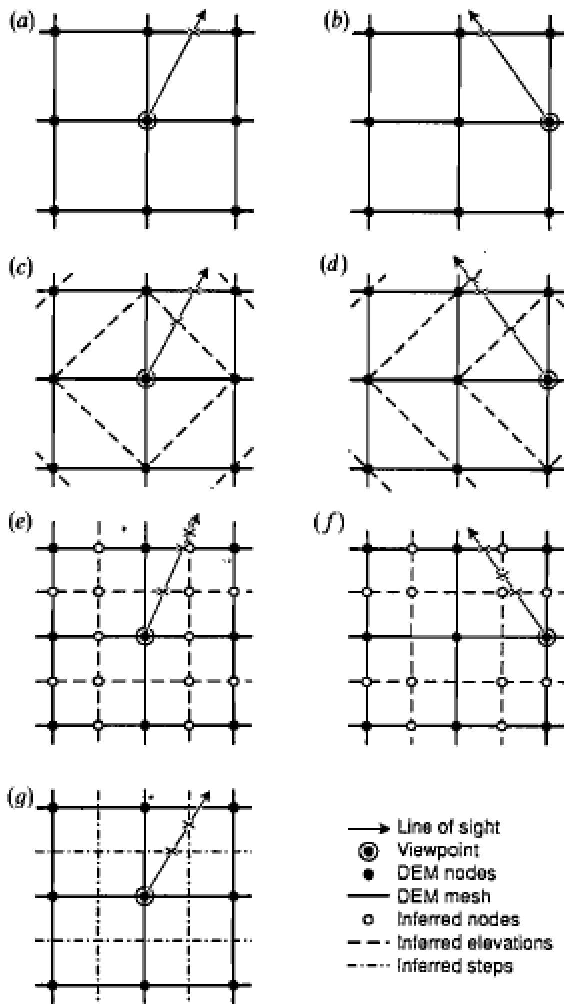

Figure 12: Alternative methods of inferring elevations from the basic DTM to a network of elevations based on: linear interpolation between grid neighbors (a) and (b); triangulation of the grid (c) and (d); grid constraint of the mesh (e) and (f); the stepped model (g).
After Fisher, 1993.

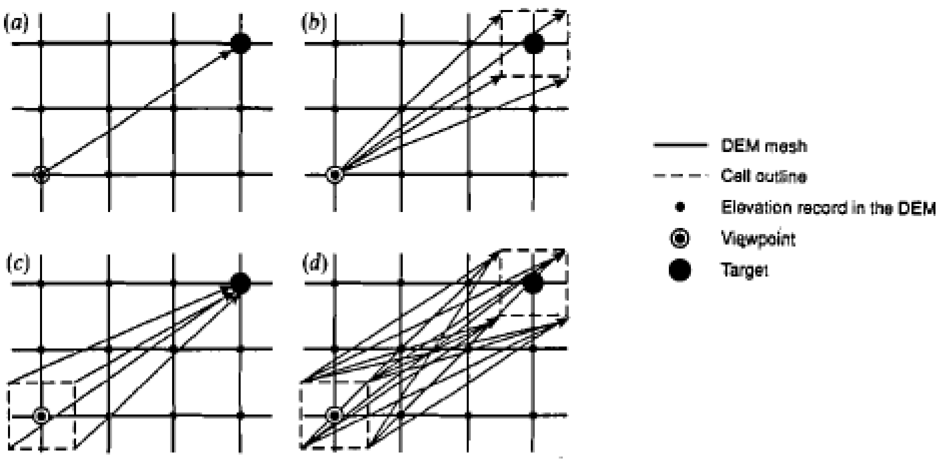

Figure 13: Alternative approximations of viewpoint-target location pairs: point-to-point (a); point-to-cell (b); cell-to-point (c); cell-to-cell (d).
After Fisher, 1993.

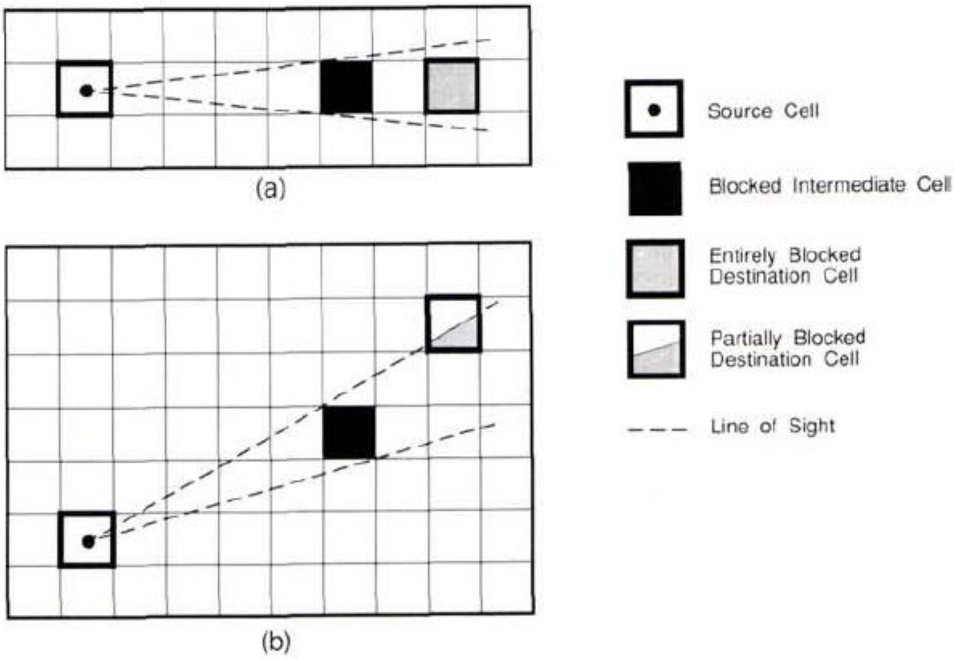

Figure 14: The two cases in which an intervening cell blocks the view (visibility) between the source (viewpoint) and the destination (target) entirely (a) and partially (b).
After Sorensen and Lanter, 1993.

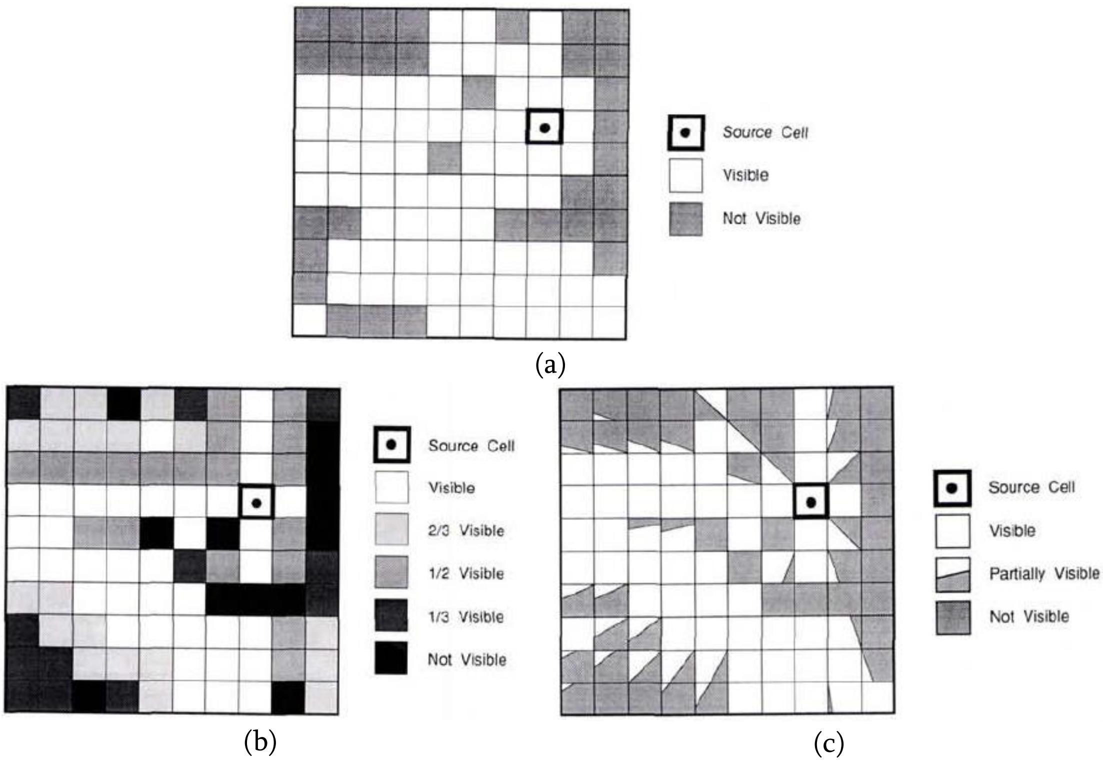

Figure 15: Standard binary viewshed (a); (fuzzy) viewshed computed with the vector analysis algorithm (b); (partial) viewshed computed with the sub-cell analysis algorithm (c).
From Sorensen and Lanter, 1993: Modified.

2.4. SYNOPSIS

What is distinctive about viewshed analysis is that terrain's visualization is based neither on a value that is related to a function of x,y position of the DTM (elevation), nor on a function within a neighborhood of its position (slope, aspect), but to a property that rather emanates from one or more specific points (of view) that lie upon or above the DTM, or from a viewing direction in general; so, the classification of the DTM according to visibility requires a "double projection". Thus, it is an operation in which the representation model serves both in terrain (elevation) modeling and in domain partitioning. As an effect, its suitability with respect to the importance and distribution of the initial (elevation) points and its quality are essential to the proper (realistic) visibility representation of/ on the terrain and the algorithms implemented on each DTM differ, depending on the model chosen.

In the abovementioned, it is shown that the two distinct DTMs, as prerequisite inputs for visibility/ viewshed analysis, harness different means for terrain representation (data structures) and algorithms for visibility analysis. However, each of the two models' specific traits, strengths/ weaknesses, render them especially popular for some cases, while for some others not: The simplicity of the data structure in the encoding of regular grids when utilizing RSGs is an undoubted asset, which, however, seem to be traded-off by the capability of TINs to adapt to the characteristics of the terrain (De Floriani, 1994). The triangulation of the domain can work for irregular distributions of points; such a property serves in the adaptation of the roughness of the terrain and in achieving: an adequate terrain representation utilizing far fewer TIN facets than raster cells, or better terrain approximations for a fixed number of vertices (Goodchild and Lee, 1989; De Floriani and Magillo, 1997). On the other hand, due to this simplicity of the format in RSGs, viewshed analysis is implemented more often and in a more straightforward manner on them (Wang et al., 1996). Nevertheless, this simplicity in processing algorithms is derived by the "faulty assumption" that raster cells are planes (Lee, 1991; Maloy and Dean, 2001). In contrast, viewshed computation on TINs is afflicted by the fact that the plane of each facet is determined by its three vertices, being, however, its basic strength for visualizing exactly "what is seen of a TIN from a viewpoint", depending on the available/ required level of detail. Table 1 summarizes this overall evaluation.

Table 1: Evaluation of DTMs across several criteria.

		Criteria for terrain representation and visibility implementation				
		Data Structure Simplicity	*Terrain Adaptation/ Approximation*	*Visibility Algorithmic Efficiency*	*Visibility Algorithmic Effectiveness*	*GIS Popularity*
DTM	RSG	✓		✓		✓
	TIN		✓		✓	

To conclude, visibility analysis has arisen to a great extent by the need to address the hidden-surface-removal problem in the domain of computer science/ graphics. Therefore, algorithmic processes supporting visibility computation in TINs have been primarily dedicated to the rendering of "what is seen of a TIN", with object space algorithms being found more suitable. Nevertheless, the algorithmic procedures have proceeded towards the domain of geographic information handling and analysis as well. Analogous algorithms have been developed for RSGs, depending on procedures much less complicated. Despite the widespread usage of algorithms suitable for RSGs in many commercial GISs – due to the grid structure simplicity – TINs, harnessing their explicit topology and being endowed with the propensity to fit the initial elevation points, carry great potential. The debate of either TINs or RSGs should optimally treat with GIS viewshed analysis seems to correspond highly to the nature and purpose of each application, where different requirements are to be met. As usual, 3D topographic data availability, density and overall quality (horizontal, vertical accuracy etc) lie in the core of the problem, while mutual conversions between models can be a key operation in various cases. Furthermore, the issue of uncertainty plaguing the most popular existing representations of terrain visibility – they are discrete (due to the inevitability of digitally representing the continuous topographic relief) and principally binary (due to conceptual and implementation causes) – still remains. Even so, since this thesis' primary scope is not to optimally approximate visibility algorithms in a non-typical manner, the fuzziness of the phenomenon is not directly addressed. As a consequence, with an aim to simplifying the algorithmic procedures concerning static terrain visibility, the standard binary viewshed analysis implemented on RSGs is adopted in this thesis (in aid of other core issues of the thesis).

As it has been preceded in the introduction, prominent on the purpose of this thesis is the approach of viewshed analyses from a dynamic perspective. Aspects of *cartographic visualization*[7] that tend to transform the static viewshed implementation are promoted, imbuing with interactivity this attempt – on the basis of computer-enabling technologies (e.g. GIS). As a consequence, theoretical foundations and principles in cartographic, representational and geomorphologic terms are analyzed in the following chapters in order to perform these computational issues in a dynamic 'digital environment'. Yet, before dealing with these issues, it appears necessary to determine the relation between the theoretical foundations of landscape apprehension, perception and interpretation in a venture to subsequently strengthen the perspective of landscape exploration, integrating the hidden-surface-removal problem and the locomotive behaviours of real, active human observers within their surroundings – and their practical aftermaths for visibility and viewshed visualization.

[7] This notion - scientific procedure/ domain is analyzed in the 4th Chapter.

3. THEORETICAL FRAMEWORK AND APPROACHES IN LANDSCAPE ANALYSIS: THE NOTION OF (DYNAMIC) VISUALSCAPES

[“A point of observation at rest is only the limiting case of a point of observation in motion, the null case. Observation implies movement, that is, locomotion with reference to the rigid environment, because all observers are animals and all animals are mobile.”]

James Gibson

The previous chapters have rendered clear that efforts towards visibility delineation and computation are implicating landscape and the perception, interpretation, understanding and meaning attached to the former. Despite the fact that it is not the scope of this thesis to fully and articulately describe and analyze landscape, it appears, though, an indispensable task to provide a fundamental conceptual framework pertaining to landscape.

3.1. THEORETICAL FOUNDATIONS FOR VISUAL LANDSCAPE PERCEPTION AND UNDERSTANDING

The word landscape is synthetic and consists of two terms: ‘land’ and ‘scape’. Both terms owe their origin to the Indo-European language family. Since their roots are Germanic, they were introduced to the UK via Germanic groups (Saxons, Angles, Danes); older English versions of the word landscape were words such as ‘landskipe’ or ‘landscaef’. Historically, the generic meaning of ‘land’ has been a bounded portion of space, a place or a subset of land surface with predefined dimensions; ‘scape’, on the other hand, refers to shape and to a synthetic agglomeration of similar objects. So, landscape used to be viewed as a mere subregion without any sense of consideration about its physical inherent traits, neither as a scenic representation, nor including its aesthetics. Later on and chiefly after the second half of the 20th century does landscape is perceived, analyzed and interpreted under the perspective of such components/ aspects so as to acquire its multiple properties and modes of characterization. Irrespectively of the different disciplinary and research approaches that the landscape concept is treated with – as it will be shown next – it is essential that the theoretical foundations providing insight about landscape’s fundamental reason and purpose in the very human-environment interrelation and interaction be probed.

3.1.1. Theoretical Aspects of Landscape

In such an attempt, the important matter is at first placed on *how* landscape *is perceived by* and *what* landscape *stands for* humans. These questions imply what humans seek out of the environment or landscape they are experiencing. Appleton's (1975) *prospect-refuge* and Kaplan's and Kaplan's (1988; 1989) *information processing* theories invoke our evolutionary origin to explain the importance of landscape qualities and preference for human survival and thriving (Lothian 1999; Tveit et al., 2006): The necessity of the ability to "see without being seen" within a landscape (Appleton, 1975) or the ability to easily "read" and process a landscape (Kaplan and Kaplan, 1989) seem to be integrative constituents which interlock landscape perception, aesthetics and preferences with biological survival. Thus, landscapes with that kind of properties that offer legibility, immediate capability for processing, or favoring conditions for "vantage viewing", are to be assessed as "preferable" by humans. However, apart from the evolutionarily/ innately (biologically) determined factors that underlie landscape preferences, several authors have claimed that culturally or individually induced (cognitive, socio-economic, demographic etc.) attributes specify the preferences for landscapes as well (e.g. Tuan, 1974 – cited in Tveit et al., 2006; Bell, 1999; Sevenant and Antrop, 2009). Even though these two approaches appear to be in conflict, it is their synthetic perspective that several authors argue to be the optimal for landscape aesthetic experience (Bourassa, 1991; Hartig, 1993; Bell, 1999).

If landscape perception is a process by which humans pre-cognitively or cognitively gain *amenity* and/ or *affordances* from landscapes they experience in order to thrive – as shown above –, another important question is *how landscape is understood* by humans. Landscape understanding requires – in contrast to landscape perception – analysis of the perceptual stimuli and development of proper memory systems for the recollection of past experiences via intellectual systems which categorize these memories (Aoki, 1999). Such a "phenomenon [that is] peculiar to humans", according to Aoki (1999: 86) is fundamental for further landscape representation, forming the basis for a meaningful landscape classification. Given that we all share this common evolutionary trend, it would be rather rational to deduce that there must be some universally accepted fundamental properties for landscape preference that tend to be modified on the basis of cultural and personal parameters, providing the opportunity to apprehend and classify landscapes in a relatively univocal manner.

Nevertheless, apart from the personal and cultural deviations in perception and understanding, the landscape concept itself is modified accordingly to the discipline by which it is approached and the scope of the research. For instance, the landscape ecology disciplinary approach defines landscape as: "a kilometres' wide mosaic, over which local ecosystems recur", with structure, function and change being its three fundamental components (Forman, 1995: 20). Earlier, Richard (1973) has suggested that landscape itself offers the very structure of an ecosystem (with its distinctive spatial patterns) in contrast to the ecosystem function (processes). More recently, Turner et al. (2001b: 2) provides an integrative framework of interaction “between spatial pattern and ecological process” assigning them, respectively, the role of “the causes and consequences of spatial heterogeneity across a range of scales”. From a more ‘anthropocentric’ perspective, the European Landscape Convention (ELC) defines landscape as: ‘‘an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors’’ (Council of Europe, 2000); such a definition asserts the pivotal importance of the human experience of landscape, emphasizing both intrinsic (e.g. patterns) and perceptual character of a landscape (Ode et al., 2008).

3.1.2 The Visual Landscape: Concepts and Classification

In fact, in many approaches there has been made an election among the whole sensory system/ perceptual spectrum, adopting the visual system as the most essential and congruent towards landscape conceptualization. In this vein, Dollfus (1973) refers to landscape as if it were the visual perception of the surrounding space. Other researchers have explicitly excluded all not visible biological, cultural and historical forms and processes which are related to other sensory system apprehension or sentimental arousal, accepting only the (visual) properties and features of the environment that can be visually identified, either they are of natural –abiotic/ biological – or anthropogenic origin (Daniel and Vining, 1983; Amir and Gidalizon, 1990). This approach which tends to defy non-visual apprehension (e.g. olfaction) or emotions induced by gazing (Terkenli, 2004) is not to be taken for granted for a generic landscape perception, understanding and evaluation process, for landscape experience is not merely about ‘seeing’; even though, it can be utilized as a *de facto* fragmentary but also as an abstracted means to examine *in vacuo* some of the landscape properties or aspects promoting insight on the landscape that we, *humans, explore*. This can be attained taking into consideration both landscapes’ physical properties (innate traits), and human perception about visual landscapes.

As Grano (1977) states, human perception is ‘full-ranged’ (utilizes all its senses) *only* in its immediate vicinity while sight alone functions “further away the landscape”; therefore, Appleton’s (1980; 1994) definition of *visual landscape* being the environment that is (in particular) visually perceived, corresponding to a (specific) way of seeing the environment can be helpful so as to segregate the *visual perception* of the landscape adopted in this thesis. As this “appearance of land” (Brabyn, 1996) is based on both physical reality and human perception, the “wide range of meanings” that the latter entails complicates, to some extent, landscape classification (Brabyn, 2009). However, this thesis attempts to approach landscape exploration primarily identifying landscapes’ visual properties, positing, thence, a compromise between the 'scape' itself and the visual perception of the environment.

That far, the focus on the visual aspect of perception (which is liable to subjectivity) is one fundamental premise; another one is the discrimination of landscapes respectively to the way they relate to *structure*, *function* or *value* concepts, as Parris (2002) has suggested when describing agricultural landscapes[8]. According to Parris, structure merely interrelates various environmental elements with land-use patterns and man-made objects; function introduces provision of/ access to livelihoods, enjoyment and recreational activities for local people (farmers) and the society as a whole; value entails both the value society attributes on a landscape because of its cultural status and its amenities, and the costs for its maintenance or enhancing (e.g. willingness to pay for a view). It is worth noticing some similarities and analogies between this perspective and the landscape ecology perspective: *structure* pertains to the spatial arrangement of attributes and features for both perspectives – the former includes cultural features while the latter stresses out ecological and physiographic ones (e.g. the formation of hedgerows); *function* entails a sharper distinction between human and social *activities* on the one hand, and biological (flora and fauna) *processes* on the other; the third dimension of the anthropocentric/ perceptual perspective, *value*, introduces several ambiguities, while in the ecological perspective other components like *change*, *time* and *scale* substitute value. No matter how these perspectives reflect a constraining view of the environment around us, it is considered appropriate to provide a certain amount of comprehension elaborating on Parris' (2002) discrimination.

So, Swanwick (2002), Tveit et al. (2006) and Ode et al. (2008) have clung to the landscape *structure*, that is, the physical attributes inherent to the landscape an observer can read into the landscape, independent of its (the observer's) attributes (Lothian, 1999). The "value-free processes of characterization" which serves in identifying the distinctive visual character of an area, could be considered as a preliminary stage in order to treat with more evaluative dimensions of landscape (Swanwick, 2002). Thus, visual landscape characterization or landscape character classification which is closely related to landscape structure emerges as the first, and possibly the most fundamental dimension for landscape perception representation. It is a description of the landscape in terms of important traits and does not involve assigning value, differently to landscape evaluation, which is about quality assessment (Brabyn, 2009). Key concepts contributing to visual

[8] From another point of view, Jessel (2006) develops a method for categorizing visual landscapes with regard to levels of different complexity: i) 'element level' (based on 'elements'): describes the different land use types and structural elements within a landscape unit, ii) 'shape level' (based on 'characteristics'): involves typical combinations of elements, shapes and proportions, and iii) 'space level' ('character') characterizes the overall area perception of a landscape by segmenting, depicting and classifying regions that are similar in overall appearance. Their application investigates the impacts of streets on visual landscape under this method.

landscape character suggested from Tveit et al. (2006) and Ode et al. (2008) are summarized in Table 2.

While structure promotes the 'extraction' of landscapes' character and it is in general independent of observers' personal attributes, *function* and *value* befall in a rather evaluative framework. Purcell et al. (1994) find evidence that measures for environmental preference should be other than unitary, i.e. cognitively coding of different scenes with respect to the expectation that a place can offer to people. Other examples for (further) preference judgments referring to the restorative value of a scene (Ulrich, 1981; Purcell et al., 2001), to the appropriateness of farming from different groups (Rogge et al., 2007), and, more generally, to the differential assessment derived from the public (Scott, 2002). Coeterier (1996) inspects eight attributes that tend to determine landscape perception and evaluation interviewing respondents which are very familiar with the landscape under study; these dominant attributes are elicited utilizing a user-dependent method (Penning-Roswell, 1973, 1982). In the same vein, Sevenant and Antrop (2009) form sixteen cognitive attributes (ratings) examining their interrelation and their correlation with aesthetic preferences across varying landscape vistas on a number of landscape photographs, using undergraduate students in geography familiar to landscape science as respondents. At this point, it appears helpful to discriminate between the different samples and methods suitable for extracting *object-directed*, *action-directed* and other *existential-values* related to the perceptual and evaluative perspective of landscape (Coeterier, 1996)[9].

In contrast to structure which is rather adequately differentiated from function and value, the conceptual boundaries between the latter two are not that crisp. Cassatella (2011) distinguishes the visual and social perception of landscape, suggesting a list of indicators befalling to each category. In the category of social perception she makes a distinction between *value in itself* (intrinsic) and *fruition* value. These two types of value seem to match to Parris' value and function respectively. Although their differentiation is not explicit (at least at an implementation level), it emerges, intuitively, that it would be rational to entail this distinction both in theoretical and practical terms: At an abstract level, the conceptual discrepancy between intrinsic and fruition value carries, by all means, great importance, while at an implementation level the importance is shifted towards the preservation or enhancement of a (unique) landscape, since averting the aggravation of the landscape in a changing environment is a fundamental effort.

[9] In-depth interviews of inhabitants tend to reveal existential values and action directed evaluation, whereas ordering/ ranking of photographs (or landscape views) by outsiders rather corresponds to an object-directed approach. Therefore, one could deduce that the latter set is suitable to identify and conceptualize landscape structure, while the former pertains to landscape function and value.

Table 2: Key concepts related to landscape visual character assessment (landscape structure) and corresponding terms.
From: Tveit et al., 2006; Ode et al., 2008; Modified.

Concept	General Definition/ Term
Complexity	refers to the diversity and richness of landscape elements and features and the interspersion of patterns in the landscape.
Coherence	relates to the unity of a scene, the degree of repeating patterns of color and texture as well as a correspondence between land use and natural conditions
Stewardship	refers to the sense of order and care present in the landscape reflecting active and careful management.
Naturalness	describes the perceived closeness to a preconceived natural state
Visual Scale	describes landscape rooms/perceptual units in relation to their size, shape and diversity, and the degree of openness in the landscape
Imageability	reflects the ability of a landscape to create a strong visual image in the observer and thereby making it distinguishable and memorable
Historicity	describes the degree of historical continuity and richness present in the landscape
Disturbance	refers to the lack of contextual fit and coherence in a landscape
Ephemera	refer to landscape changes related to season or weather

Summing up, landscape concept inquiry gives prominence to a variety of dimensions and components. Such dimensions relate to the ability or the propensity of human observers to characterize, classify and subsequently assess or evaluate landscape on several bases. And even though evaluation can be a confusing notion and process, it is undeniable that every individual is 'urged' to make rating judgments – at least subliminally. Regardless of personal beliefs and values, Appleton (1996) poses the matter in the relativistic and experiential context between the individual and his environment, for a landscape to be discovered. Yet, experience within an environment cannot comply with a static aspect of the environment, but rather begets dynamism; in other words, landscape conceptualization requires what Risser et al. (1984) calls "focus on its (landscape's) spatial-temporal patterns", as a means to integrate space and scale, time and motion to the fabric of the observer's conception. More acutely expressed, Ekbo (1964) has presented landscape as the synthetic array of features within a zone that we move, a claim signifying that "landscape is not a static aspect, but a dynamic visual perception of an areas' view/ vista, due to human motion activity"(Menegaki, 2003: 9).

As it gradually emerges that a 'stagnant perspective' of landscape is not sufficient to grasp its essence, it is rather imperative that landscape visibility is explored in a dynamic manner – including motion. However, before proceeding to a more penetrating insight towards this dynamic exploration – given that the visual dimension of perception is prioritized – we should first delve into a research series revealing the visual properties and visual configuration of landscape, presenting the notion of *visualscapes*.

3.2. VISUAL PERCEPTION AND STRUCTURE OF LANDSCAPE: ISOVISTS, VIEWSHEDS AND VISUALSCAPES

Landscapes can befall into a variety of classification schemes with respect to the different conceptualizations impinging on them. It has been rendered lucid, though, that the visual apprehension or at least the concentration on attributes or properties that are visually perceived play the primal role in the analysis of this thesis. Research pertaining to archaeology and landscape supports this primacy of vision in a manner that it includes several other fields of knowledge and experience; so, as Thomas (1993: 22) asserts: "the prioritisation of vision, its separation from and privileging over the other senses, can be detected in [several] other areas of life, substantiating the claim that we live in a 'specular civilization'".

3.2.1. Isovists: The Architectural Visual Record

More specifically, not only the sense of vision and the pertinent properties of landscape are promoted and 'extolled', but an approach that tends to analyse and assess the visual structure of a landscape – or the "visual perception and spatial description" (Turner et al., 2001a: 104) – is put forward. Furthermore, there is a stunning adhesion to geographical information science (and systems) and a potential from pertinent analytical functions (like viewshed) for extracting landscape properties from gridded DEMs or TINs ensuing from the research pertaining landscape experience in spite of "the possible discrepancy between the objective result of visible area analysis in GIS and our subjective landscape perception" (Baldwin et al. 1996). However, the initial rationale backing this generic approach has originated from Tandy's (1967) harnessing the concept of *isovists*. The latter concept, being present within the fields of geography, architecture and mathematics is raised from Tandy to a method of "taking away from the [architectural or landscape] site a permanent record of what would otherwise be dependent on either memory or upon an unwieldy number of annotated photographs" (Tandy, 1967: 9, comments on parentheses from Turner et al., 2001a: 104). In fact, isovists have been utilized as a means to characterize a rather architectural space, or the built environment identifying "the set of all points visible from a given vantage point in space and with respect to an environment" (Benedikt, 1979: 47) or "the area in a spatial environment directly visible from a location within the space" (Turner et al., 2001a: 103). The research on the visual scheme of the architectural landscape has been carried on with the related work of Benedikt (1979). According to his point of view, a single isovist (from one location) does not describe the whole structure or configuration of a built landscape; instead, an 'isovist field' that integrates the interaction among separate isovists for every location can render the spatial variation and distribution of the aggregate visual/ visibility properties for a landscape through contours (Fig. 16).

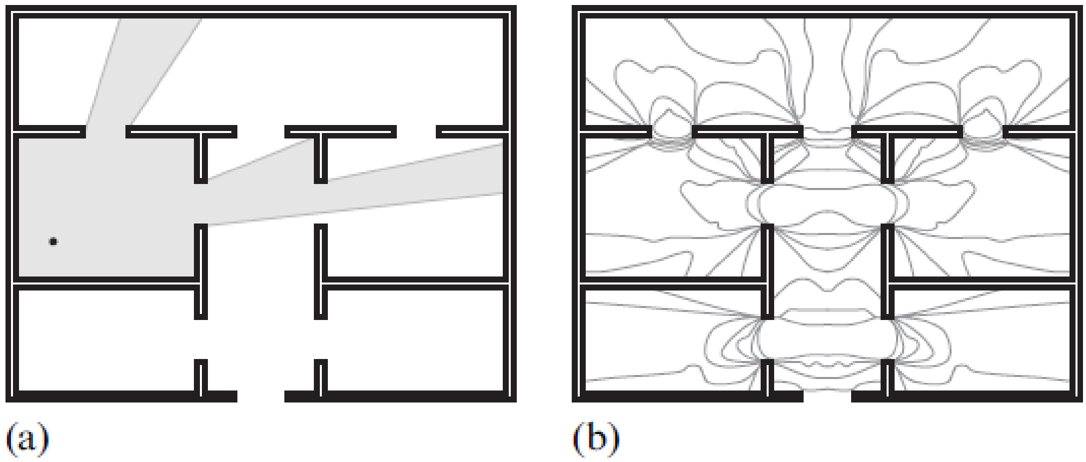

Figure 16: An isovist polygon as a two-dimensional slice through the volume visible from a location (a), and an isovist field of isovist area yielding contour lines of equal visible area (b). After Turner, 2003.

While this effort towards quantification of the visual spatial morphology of a landscape has been criticized from Turner et al. (2001a), it has been utilized by them as they have drawn upon Hillier's and Hanson's (1984) visibility relationships into *graph analysis* of buildings and urban systems, and the small worlds analysis of Watts and Strogatz (1998) to introduce *isovist graphs*. These graphs are constructed by i) selecting a proper set of isovists (which equals to selecting appropriate generating locations) to form the *vertices* (or *nodes*) of the graph and ii) establishing the crucial interrelations among them (isovists and generating locations) to constitute the *edges* (or *connections*) of the graph. For the first requirement, they assume as the most straightforward and adequate for 'near-full' description of the space approach to select locations for isovist generation at 'some regularly spaced interval' throughout a spatial distribution. So, they suggest a *lattice* or a *regular grid* for the demands of the promoted spatial distribution whose resolution would approximately equal 1 m, so as to comply with 'human-scale' (but in an architectural context) spacing. For the second one, apart from the spatial intersection between isovists (polygons) that tends to emerge as an indisputable relation, another relationship that further enhances and empowers the identity of this interplay is the intervisibility between the generating locations whose respective isovists are intersected; under this premise the discrimination between *first-* and *second-order relationships* are established, analogously to whether two vertices of a set that describes the spatial organization are mutually visible and therefore are interconnected directly by an edge (first order), or if an intermediate point exists, requesting (two) in-between visibility 'steps' (Fig. 17). Even though second order relationships are important, only the first-order visibility graph is required – for it contains all the necessary information to derive the second-order visibility graph and, more generally, to provide a 'near-full' description of the space (Fig. 18).

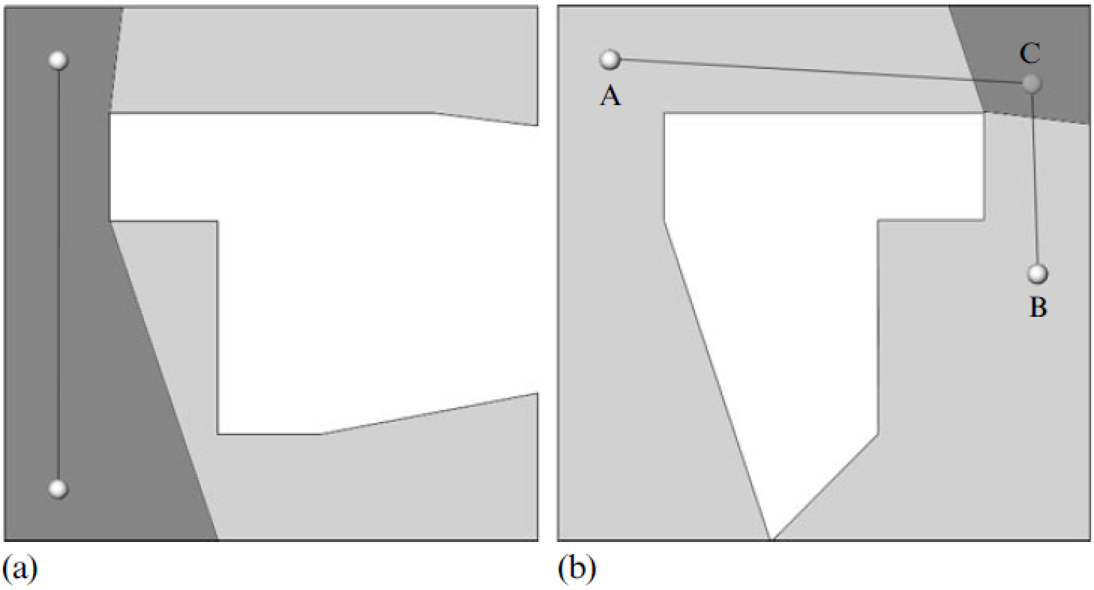

Figure 17: First-order (a) and second-order (b) visibility relationships between isovists. The second-order graph is just a 'flattened' first-order graph.
After Turner et al., 2001a.

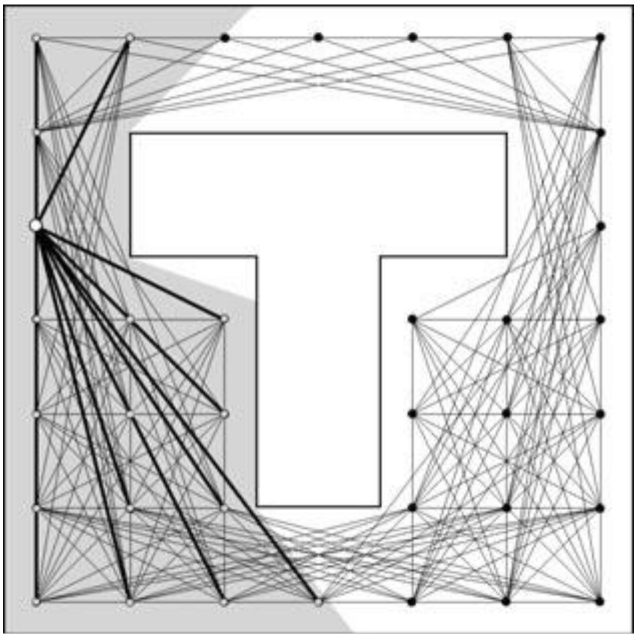

Figure 18: First-order visibility graph depicting the pattern of connections for a simple configuration.
After Turner et al., 2001a.

3.2.2. Enabling the 3rd Dimension: Viewsheds and Visualscapes

Moving from the architectural to geographical space, O'Sullivan and Turner (2001) have used *visibility graphs* to manipulate viewshed analyses in order to gain facilitated accessibility and 'explorability' of a landscape's visual properties.[10] In particular, their attempt has been directed towards the GIS users capability for rapid access, retrieval and display of viewshed information within a neighbourhood of a corresponding vertex in the case where a visibility graph has previously been created and stored, utilizing: the mutual visibility principle between (adjacent) vertices (i.e. viewpoints) of the graph, indices reflecting the landscape's metric and geometric properties (e.g. clustering coefficient) and vertex selection – with relation to scale, resolution and the landscape's particularities. As they characteristically assert:

> *"In landscape settings a highly connected graph typically results, which can be used both as a convenient data structure to explore visibility characteristics of the landscape, and as a tool to provide further analyses not calculable directly from viewsheds"* (O'Sullivan and Turner, 2001: 222).

Although they claim that visibility graph construction is not a reversible process, meaning that several points of view in a landscape or in different landscapes might yield similar, even the same 'punctiform' viewshed and thus landscape represented in such a way does not provide necessarily the identity of the latter, it seems rather unlikely that the pattern of viewshed form a specific vertex-viewpoint tends to be in general indistinctive. Viewshed analysis is focused on landscape, in contrast to isovists which are derived from urban and architectural plans, disregarding any elevation information (Turner et al., 2001a; Llobera, 2003). Therefore, isovists refer to 'continuous space' and do not present 'holes' – since whenever a LOS has reached an obstacle it is never considered what lies beyond it (Llobera, 2003); as an effect, isovists cannot display the irregular and fragmented distributions that viewheds exhibit, attributed to topographic relief. As Wiens and Moss (2005) mention, landscape comprehends the heterogeneity of ecosystem and land cover/ use patterns, plus the effects of topographic configurations; but topographic relief is an ambiguous concept which is in general thought to be a function of elevation (Mark, 1975; Evans, 1980). So, an algorithm or a function that implements viewshed analysis (or terrain visibility analysis) on the one hand requires a DTM storing the elevation of the relief (rendering the computation much more complicated) while on the other both its observing locations and its observable areas are subjected to the effects of topography. Thence, viewshed computation is more generic than isovists computation, while its products (outputs) are much more distinctive and depended on the altitude of the viewing points and the particular topographic relief.

Relief enabling in the context of 'human' visual space has been attempted by Llobera (2003) who has introduced the notion of *visualscapes*, being the conceptual counterparts of isovist fields. He articulately defines a visualscape as

[10] The term visibility graph was infiltrated to landscape analysis by De Floriani et al. (1994) and it is also widespread in the fields of computational geometry and artificial intelligence (see de Berg et al., 1997).

"the ***spatial representation*** of any ***visual property*** generated by, or associated with, a ***spatial configuration***. (Llobera, 2003: 30). In essence, visualscapes constitute the way that any visual characteristic at any (sample) location is stored and represented, rendering effective varying analytical and computational functions with relevance to the selection of spatial components and their visual structure. Visual properties like *cumulative* and *total viewsheds* – pertinent examples being discussed in the following chapters – attribute a range of values to a landscape according to its visual traits, while its subsequent structure draws upon these traits. Yet, whereas several studies have related the visual structure and properties of viewsheds to the content and structure of the landscape (Bishop and Hulse, 1994; Miller et al., 1994; Bishop et al., 2000; Germino et al., 2001; Dramstad et al., 2006; Brabyn and Mark, 2011), the parameters and indexes derived from these interrelations have not been broadly harnessed to return new cartographic surfaces containing the generated information (Llobera, 2003). Such a procedure has even more rarely probed or implemented for the active progression of human visual perception within landscape. The changing optic information due to the *de facto* changing location following from human movement is the focal point of the next section.

3.3. LOCOMOTION AND VIEWSHED: THE DYNAMIC VISUALSCAPES

The major role of the previous section has been to provide a conceptual means to derive from a landscape an (or more than one) abstracted spatial configuration and properties to represent its visual pattern. Nevertheless, a persistent research issue relates to the ideal way of sampling a region posing points of observation in order to fully or optimally describe this region in terms of visibility (see Turner et al., 2001a; O'Sullivan and Turner, 2001). There have been proposed several approaches to satisfy the above issue, with regularly sampled points (see Turner et al., 2001a; O'Sullivan and Turner, 2001) and points on prominent topographic features (see Lee, 1994; Rana and Morley, 2002; Rana, 2003; Kim et al., 2004) being the most dominant ones. Computing viewsheds from a multitude of viewpoints and generating their overall visual properties posits a static perspective of the landscape; yet, this multiple computation can be considered as the other side of the coin, with reference to a dynamic visual landscape exploration, as it latently encapsulates dynamism. The respective argumentation lies in the following.

The human visual perception of landscape is by definition experiential; and experience in nature and in landscape enables *ecological processes*. Therefore, (visual) perception is to be regarded as an active process intertwining the agent with his environment, involving the notion of autopoiesis[11] (Maturana and Varela, 1980 – cited in Turner, 2003). This active process negates a single or a frozen field of view (Gibson, 1986). In fact, Gibson (1979) cannot identify perception unless it

[11] Autopoiesis relates to the process by which a closed system is capable of creating itself.

entails movement, within the interactive ecological process between the occupant (agent) and the environment – referring to ambient optic array and optic flow (Fig. 19).[12] In all, Gibson (1986: 2) draw his argumentation from our biological history and evolution, asserting that visual awareness and perception is ***panoramic*** and does 'persist during ***long acts of locomotion***', for animals do need to rotate their gaze around when moving from a place to another place, although this is not the entrenched idea for visual perception.

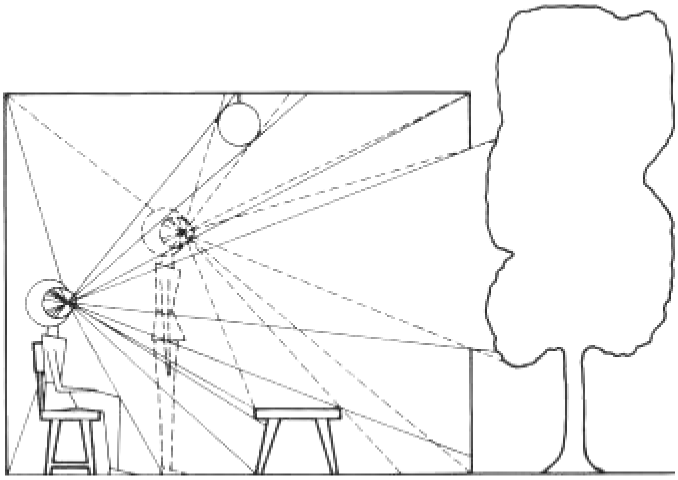

Figure 19: The change of the optic array brought about by a locomotor movement of the observer. After Gibson, 1986.

Herein, there is an effort to go through a perspective of a static view of the landscape containing one or more *fixed* points of view, to another perspective that entails *mobile* ones. As such, these points typically advance along a path of locomotion (route), while the 'forms' of the respective optic array change with locomotion; nonetheless, this change do not refer to the totality of the array: changes originate from locomotion and hold information about locomotion itself (perspective structure) against a layout of non-changes which provides information about this layout (invariant structure) (Gibson, 1986). It is, thus, a challenge to find ways to perceive and render lucid the optical transition, the change from visible to invisible and vice versa (see Gibson et al., 1969). Yet, if and only if a twist in the mental and cognitive (geometric) habit comes about, whereby locomotion and the persistent change of optic array (optic flow) are now accepted as the mainstream and not the extremity, then a proper approach can be attained to approximate a pragmatic visual perception. It is what Gibson (1986: 75) has postulated:

[12] Ambient optic array is the optical information from the environment (structured pattern of light from all possible directions) available to the eye, whereas optic flow refers to the change of the optic array as the viewer moves, that is the image motion of the environment projected on the retina during movement in the world.

> *"[Only] when the moving point of observation is understood as the general case, the stationary point of observation is more intelligible. It no longer is conceived as a single geometrical point in space but as a pause in locomotion, as a temporarily fixed position relative to the environment."*

In this effort, the major concern is the generation of an abstracted but also a dynamic representation scheme to represent and visualize the process, founded on this conceptual acknowledgement. Thiel (1961) has been a pioneer suggesting an explicit analysis of spatiotemporal visual properties for the architectural space. Visibility graphs and visualscapes, on the other hand, are the potentially dynamic counterparts in the transition from the architectural to geographical space (including elevation information). Therefore, in a way, (our) intuition dictates to harness the potential of visual/ visibility configurations (viewsheds, visualscapes) within a medium that can adjust to the spatiotemporal particularities of the locomotive visual perception with a view to apprehending the landscape itself (or its landscape properties) via a dynamic investigation, endowed with analytical capabilities. The explorative character of this intuitive conception could be compatible to the perceptual behaviour of the subjects of landscape exploration, meaning, us, humans, who move; yet, to our scope, the core of dynamic visibility computation, whereas it resembles viewshed analysis from 'frozen' multiple points of view, it should concentrate on the election of proper points and the ensuing sequential visualization of their visible areas so as to procure the active visual perception. Ideally, these points should be considered only as mediums within a structured flow where their respective optical pattern alterations are merely variances among any possible transition within such a flow (environment), or as Gibson (1986: 74-75) eloquently puts it:

> *"The geometrical habit of separating space from time and imagining sets of frozen forms in space is very strong. One can think of each point of observation in the medium as stationary and distinct. To each such point there would correspond a unique optic array. The set of all points is the space of the medium, and the corresponding set of all optic arrays is the whole of the available information about layout. The set of all line segments in the space specifies all the possible displacements of points of observation in the medium, and the corresponding set of transformation families gives the information that specifies all the possible paths. This is an elegant and abstract way of thinking, modeled on projective geometry."*

And he continues:

> *"But it does not allow for the complexities of optical change and does not do justice to the fact that the optic array flows in time instead of going from one structure to another. What we need for the formulation of ecological optics are not the traditional notions of space*

> *and time but the concepts of variance and in variance considered as reciprocal to one another. The notion of a set of stationary points of observation in the medium is appropriate for the problem of a whole crowd of observers standing in different positions, each of them perceiving the environment from his own point of view. But even so, the fact that all observers can perceive the same environment depends on the fact that each point of view can move to any other point of view."*

All of the abovementioned Gibson's statements, with all their significance pertaining to the conception of locomotion and optical array (or viewsheds, or even visualscapes) cannot defy the advent of a digital age; neither can promote an instant solution suitable for the discretized world of computers and Virtual or Augmented Reality in the context of *Virtual Environments (VEs)*. Certainly, this is not about a conflict between analogue and digital worlds. On the contrary, it is an opportunity (for geosciences) to develop tools promoting understanding, in parallel with improvement of the landscape experience (Turner, 2003). If visualscapes are to play an important role in the representation of human optical perception about landscapes' composition and structure by assigning their visibility properties and patterns on them, then *dynamic visualscapes* might be the facilitator to provide insight about the pragmatic interactive experience between agents and their environment. Under this premise, our research venture should be directed towards enabling 'modifiable illustrations' of the visual-scape. This predisposition is being carved in the following chapters under a different guise, where Geographic Information Science and Systems 'are invoked' to remediate this research issue. More specifically, the next chapter enters into the domain of temporal cartography, and its potential to depict a dynamic or interactive progression of phenomena or processes involving change with the prompt of a scientific approach/ field known as *cartographic visualization*.

4. ANIMATED AND INTERACTIVE VISUALIZATION FOR CHANGING AND ABSTRACTED VIEWS OF GEOGRAPHIC REALITY

[“Abstraction is one of the greatest visionary tools ever invented by human beings to imagine, decipher, and depict the world.”
“Abstraction brings the world into more complex, variable relations; it can extract beauty, alternative topographies, ugliness, and intense actualities from seeming nothingness.”]

Jerry Saltz

Landscape apprehension entails intriguing perceptual and cognitive aspects of the human sensory and mental capabilities. Visual landscape experience, on the other hand, is an inherently dynamic and active process. As such, it can be vaguely approximated through subjective approaches ‘plagued’ by an even more complicated nexus of perceptual and cognitive elements, due to the inclusion of the additional parameter of time or change.

Maps are abstracted representations of (geographic) reality; so, in their generic form they are to represent and depict this reality in a means perceivable from a multitude of map readers/ users. Moreover, geographic reality includes phenomena which, similarly to landscape experience, are dynamic in nature. Although conventional mapping neatly corresponds to the static picture of the earth, recent advancements in Cartography and Geographic Information Science have significantly shifted the scientific paradigm (tradition) from static mapping. The theoretical analysis and discussion below gives prominence to the overall benefits stemming from cartographic visualization, while it focuses on the strategies dedicated to afford an effective dynamic and “object-oriented” perspective for visual landscape exploration.

4.1. THE CHALLENGE OF TIME/ CHANGE REPRESENTATION AND VISUALIZATION IN GIS AND CARTOGRAPHY

4.1.1. Space, Time and Change in Geography

It has been argued that geography is discerned from geometry, in that the former embeds both space and time in its ‘fabric’ (Parkes and Thrift, 1980). Although objective measurement of space and time has led to their conventional segmentation into discrete units, in principle, they both share the same space-time continuum (Peuquet, 1994). Time had not been always considered as being inextricably interwoven to the space-time continuum. Nevertheless, time has often been thought “as an extension of space or in analogy with it”, with the geographic perspective providing the oldest, empirical way of perceiving both space and time at geographical scales: since antiquity, a refined body of practical knowledge referring to the spatial properties and relations of geographic entities (rivers, forests etc), as well as to the changes the latter undergo has been evolved and recorded by geographers (Couclelis, 1999: 30). No matter how the inquiry regarding time (and space) *per se* enters the domain of metaphysics and calls for philosophical contemplation and debate, Pequet (1994) and Vasiliev (1997) suggest that casual perception of the passage of time is tractable through changes – transformations, movements – to which objects and us are subjected. As a consequence, in essence, in the geographic and cartographic realm, we can suffice to deal with the manifestations and effects of time in the (objects of) real word; and the purpose and means of cartographically representing and visualizing these effects.[13]

Given that the overwhelming majority of geographic phenomena are dynamic (Blok, 2000) and geographers are meant to tackle the modern large-scale and intensively-complex problems (e.g. global warming), a significant methodological shift is required: from studying *spatial patterns* to studying *space-time processes* (Graf and Gober 1992; Harrower 2001). In fact, this shift specifically focuses its analysis towards "*how* spatial patterns *change* over *time*" (Peuquet, 1999). Time in geography implicates alterations, mutations and, generally, *changes* onto the entities of the real world; in addition, as Harrower (2001) asserts: "change is one of the fundamental elements of geographic process". Therefore, for an approach to meet present and fundamental challenges of geographic (environmental), non-static phenomena, it has not only to encompass, but also to embody the notions, properties and relationships of time and change. In a very concise manner, Kraak and Ormeling (2010, p. 152) condense: "in the geosciences it is all about events and change", while geoscientists themselves head their research agenda towards environmental monitoring by tracking changes whose impact on the landscape is directly or indirectly perceived (Blok, 2000).

Consequently, it is essential that change be defined and further categorized. According to Peuquet (1999: 92): "change is normally described as an *event* or collection of events", while Mackaness (1993) determines an event as something of significance that occurs. In a sense, it is the transition from an instant in the history, a *situation* (Szego, 1987), or a *state* (Langran and Chrisman, 1988; Langran, 1992) to another situation or state. Yet, for changes to issue (though often somehow latently or implicitly) should this transition incorporate shifts from a 'significant something' to another 'significant something' within a pertinent series. Therefore, as it will be described in following sections, within a "series of states punctuated by events that transform one state into the next" (Langran, 1992: 32) such geographic phenomena or processes can be 'remanufactured' – when this transition is perceived as a dynamic sequence and with the prompt of a proper spatiotemporal model. In the context of space-time representation and modelling,

[13] For a comprehensive analysis of Time in Geography, Cartography and GIS, see Vasiliev (1997).

Peuquet (1999) extrapolates these definitions and concludes that this transition (at significant moments) pertains to a change in state of some *locations*, *entities* or both[14]. Harrower (2001), in a more detailed classification, separates *continuous* from *discrete* change (i.e. gradual transitions or flows *vs*. abrupt changes or twists), suggesting that within these two categories there are basically four types of geographic change referring to: i) location, ii) shape/size/extent, iii) attribute, and iv) state/existence; he further specifies this classification linking types of change with level of measurement via the example of tropical cyclones (Table 3). However, we should bear in mind that he adopts an *object-oriented* approach of geographic reality.

Table 3: Types of geographic change
From Harrower, 2001: Modified.

Change in:	Example (tropical cyclone)	Level of Measurement
Location	Path	Ratio
Geometry	Shape, Swath, Areal Extent	Ratio
Attribute	Wind Speed/ Scale (of Intensity)	Ratio/ Ordinal
State/ Existence	Downgrade to Tropical Storm, Tropical Depression	Nominal

4.1.2. Concepts of Cartographic Time and Change

Theoretically, the representation of geographic time and change in GIS is prompted by temporal databases, via their potential to record and portray change over time (Peuquet, 1999). In practice, the attempt to map the temporal dimension equals to mapping the respective change, pertaining to either location, or geometries, or attributes, (or existence), or all of them (Harrower, 2001; Slocum et al., 2009; Kraak and Ormeling, 2010). Nevertheless, portraying temporality in maps implicates various concepts of time. The events or changes punctuating cartographic time are recorded along a two-axis configuration, as suggested by Langran and Chrisman (1988): the one axis reflects the temporality of 'events'/ changes in the real world, representing *world time*, while the other traces the moment when changes are captured in the database, representing *database time*. This orthogonal dual of temporality has been further enriched, and another component of time has been introduced: the *display time* signifies the moment a change is displayed on a map (Langran, 1992; Peuquet, 1999; Kraak and Ormeling, 2010). As an effect, the cartographic process implicates the concepts of time for the real world phenomena, their database recording and their subsequent visualization, forming a three-dimensional configuration.

[14] Herein emerges the well-known debate between the location/ field- (grid) and object-based/ entity-based (vector) "world views" and corresponding representations and modeling (see Peuquet, 1994).

Maps, apart from their conventional (space-space) metaphoric contribution, can serve as metaphors for a variety of types of data, even non-spatial (Fairbairn et al. 2001). The metaphor of time/ change in spatio-temporal representation and its subsequent visualization remains a crucial issue in the fields of GIScience and Cartography. To this end, Harrower (2001) puts emphasis on the manners in which understanding of conceptualization and measurement of change might emerge. As evident as it may seem that this augmented and improved understanding may be procured by an upgraded access to time-integrative maps (Langran, 1992), geographic processes have been proven hard to reveal. Though temporal information is both inherently bounded to the geographic perspective and essential to geographic processes' understanding, cartographers have not attained to a satisfactory outcome in representing the former (Langran and Chrisman, 1988).

A generic reason for temporal representation having been hampered is related to cartographers' propensity to exclude time (Wood, 1992). Whereas Wood states that maps encode time as much as they encode space, the former (time) has been rendered 'the hidden dimension' in cartography. From a historical perspective, the reason is attributed to the fixation and 'allegiance' of cartographers treating digital maps similarly to their analogue predecessors (Langran and Chrisman, 1988; Langran, 1992). To elucidate, it appears that the prevailing 'print mindset' or 'paperthinking' had forced digital map designing to replicate the analogue mapping processes (Cartwright, 1994; Peterson, 1995). Considering the constraints of static display analogue technology to represent and depict time, it is not surprising that on printed maps the temporal component is mostly fixed (see Sinton, 1978), and theme and space is emphasized over time (Langran and Chrisman, 1988; Langran, 1992; Harrower and Fabrikant, 2008). This 'inadequacy' has induced cartographers' deliberate evasion of addressing time by mapping chiefly relatively static phenomena with static maps, while the burdensome task of dealing with temporality has been 'transferred' to the map users (Muehrcke, 1978). As an effect, despite the potentiality of maps in depicting time, cartographers have maintained their composure against an ever-changing and ever-moving world, portraying it in timeless maps which are problematic in that they promote the concept of 'eternal present' rather than embracing the concept of process (Muehrcke, 1978; Langran, 1992; Peuquet, 1994). In other words, this tendency of Western maps to emphasize space over time equals to a systematic preference and 'reward' of static over process (dynamic) representation (Harrower and Fabrikant, 2008).

To our scope, the deduction occurring from the abovementioned is two-folded: First, cartographers dealing with the diffusion of maps that integrate temporal or dynamic components should 'forget' the analogue past of cartography and treat time and change within the present versatile digital environment, harnessing its full-range potential. Second, research on the manner in which spatial patterns change (study of unrevealed dynamic phenomena and processes) should be elicited from spatiotemporal databases, which, under the light of dynamic (temporal) analysis and visualization, will provide useful information. Thus, the venture for modern change-integrative cartography comprises both i) growing insight to the temporal component of spatial patterns of dynamic phenomena and ii) rendering those already sufficiently understood lucid enough for the public through suitable geographic visualization processes. The next section is dedicated to the advances of those approaches and processes that have addressed these issues.

4.2. CARTOGRAPHIC VISUALIZATION AND ITS INTERACTIVE AND DYNAMIC EXPRESSION: GEOVISUALIZATION

4.2.1. A Brief History of Cartographic Visualization

Cartography refers to the process of externalizing *internal representations* similar to maps that emerge from memory – that is *mental maps* –, in the form of generalized, helpful visual depictions (*abstractions*) of the environment (Peterson, 1995). Although the *communicative purpose/ function* of these abstractions was implicit from past times, it was not until the decades of 50's, 60's and 70's that the *communication model* (see Kolácný, 1969; Robinson & Petchenik, 1976; Guelke, 1977; Petchenik, 1983) dominated (for map functions in the history of cartography, see Freitag, 1993): Cartographers have devoted a presumably large amount of energy in research of making visible certain aspects of reality through maps, setting the goal of optimizing the latter for presentation tasks and visual communication in general (Petchenik, 1983; MacEachren and Kraak, 1997). However, since the late 80's and the early 90's, this conventional view of maps – being solely destined to store 'stagnant' data and serve as tools for communication of such data to users – has started to be questioned (Van Elzakker, 2004). DiBiase (1990) was among the first ones to dispel this one-sided perspective for cartography and to pose the foundation of 'multi-purpose/function' in *cartographic visualization*. Adopting the point of view of MacEachren and colleagues (1992) (a publication then in preparation) and of Ganter and MacEachren (1989), he linked the potential of visualization mostly to biological evolution, and to a lesser extent to technological evolution; furthermore, towards gaining the 'full potency' of visualization, he promoted the underlying tendency of (active) visual perception to be integrated with visual cognition and thinking, utilizing psychologist's Rudolf Arnheim's observations. The latter had noticed that: "an abstractive grasp of structural features is the very basis of perception and the beginning of all cognition", so he thereafter connoted that the cultural bias against graphicacy signifies "an unwholesome split which cripples the training of reasoning power" (Arnheim, 1969 – cited in DiBiase, 1990). In his well-known scheme (Fig. 20), DiBiase portrays the functions of maps and other visual depictions in scientific research; the pertinent research process of visualization is taking place within a continuum of 4 stages: i) data *exploration* giving rise to research questions, ii) data interrelationships *confirmation* under the test of a formal hypothesis, iii) *synthesis* of findings, and iv) research results *presentation* in a scholarly and academic manner.

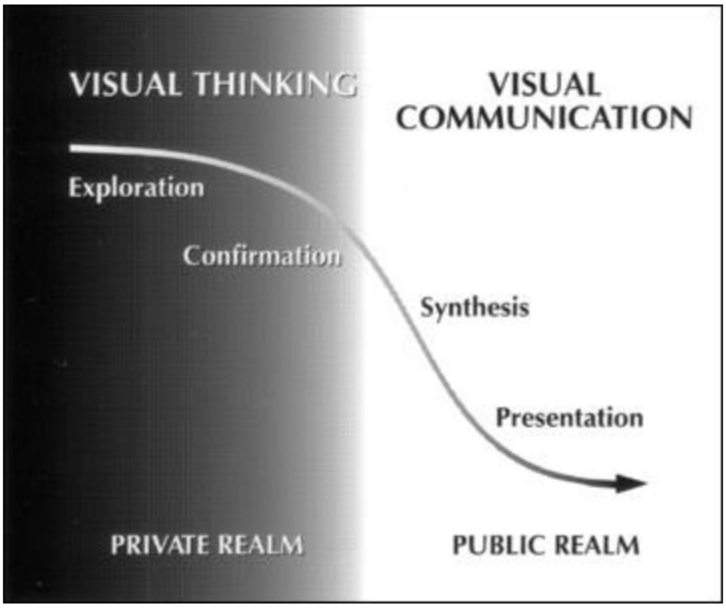

Figure 20: The range of functions within the scientific research of visualization. After DiBiase, 1990.

Since this 'making visible process' characterises every cartographic effort, "all mapping can be considered a kind of visualization" (MacEachren and Kraak, 1997: 335). However, despite cartographers' fervent assertion that they have always dealt with visualization, their negligence of the current conceptions and alternative definitions of visualization in geography – and cartography in particular – could not nullify the expansion of this emerging discipline (MacEachren and Kraak, 1997) only just because they were traditionally involved in the process of 'making visible'. Thus, it becomes apparent that this new discipline entails much more than merely presenting spatial data and communicating geographic information to the public. Actually, according to Peterson (1995: 7-8), "visualization is the creation of computer graphics images that display data for human interpretation, particularly of multidimensional scientific data". Cartographic, or geographic visualization (or geovisualization) shares similar techniques, albeit for map displays (Peterson, 1995); more specifically, the pertinent cartographic visualization process exploits spatial data, while it enables cartographic methods and techniques to provide insight in spatial relations and patterns through maps (Cartwright and Peterson, 2006). As MacEachren and Kraak (2001) sum up, this discipline dissolves the boundaries of diverse approaches of: cartography, image analysis, scientific computing (ViSC), information visualization, exploratory data analysis (EDA) and geographic information systems (GISystems) with an aim to: establishing the theoretical foundations, regulating the methodological rigor, and inventing techniques and practical tools for the four main situations to visualize any data having geospatial referencing (geospatial data), that is to: explore, analyse, synthesise, and present.

These four main situations or map-uses or goals of use in visualization have been evolved through the publications of DiBiase (1990), MacEachren, (1994a), Kraak and Ormeling (1996) and MacEachren and Kraak (1997). In Figure 21a, the map use cube is depicted, in its latest version, as it has been adapted by Kraak and Ormeling (2010).

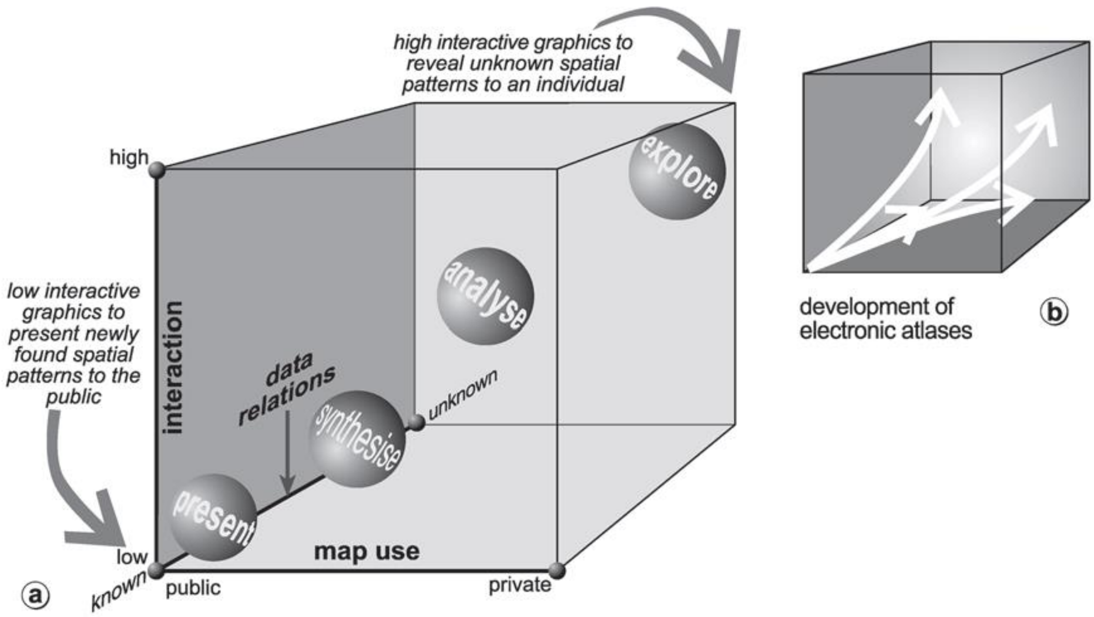

Figure 21: The map use cube; the four main situations to visualize data in a GIS, that is to: i) present, ii) synthesize, iii) analyse and iv) explore (a); the evolution of the electronic atlas since 1987 plotted in the map use cube (b).
After Kraak and Ormeling, 2010.

It can be concluded that within this range of both GIS functions and users drawing upon the expertise of such cognate disciplines, it is a matter of (conscious) choice "whether the process of discovery is private or collective and whether it is related to the acquisition of established knowns or the search for insight to identify, explain and understand particular unknowns" (Dykes et al., 2005: 4). At the last decades, the shift from the communication-oriented cartographic research (which had been sustaining the static maps design for 'public consumption'), towards to the complementary facet of geo-visualization – exploratory-oriented cartography supporting interactive maps in individual – is endorsed by the ICA Commission on Visualization (MacEachren and Kraak, 1997) in an attempt to 'push' cartographic visualization research to its new frontiers. In other words, from the corner of the cube that entails: map use in public, communicative presentation of 'knowns' and low interactivity, cartographic research is 'advancing' to the map use in the "private, revealing unknowns and high interaction" corner of the cube (MacEachren, 1994a: 7) (this trend is portrayed in Fig. 21b); nonetheless, according to MacEachren, visualization itself is defined by this corner of the cube. In such a way, he detaches visualization from the rigid and obsolete analogue cartographic processes of the past, suggesting that geo-visualization is just one of the identifiable extremes of the three continua of this 'cartography cubed'[15]; what is more, as Van Elzakker (2004) notices, it occurs that MacEachren (1994a) stresses out that the very existence of this new discipline is prompted by the ongoing technological advances and the versatile environments of GISystems.

Since this field clings to the enabling potential from computer technology, it follows that the process of creating interactive, dynamic maps is facilitated by this technology, along with the process of visualizing in real time (Taylor, 1994). Adopting the view that the medium is the message, with computer being now the medium (Peterson, 1995; Kay, 2001), and as the interest of geoscientists has been placed to complex and dynamic phenomena, it is inferred that the nature of the respective maps require adaptation (Harrower, 2001). According to Campbell and Egbert (1990) *animation* is inherently linked to the majority of the problems which visualization is meant to address, whereas Peterson (1995) suggests that a viable solution (to such problems) seems to lie in *metaphors*[16], which, in cartography, imply the notions of interactivity and animation through the function of user interface. In a more practical manner, Cartwright and Peterson (2006) assume cartographic visualization to stand for the process of converting (geo)spatial data (stored in databases) into kinds of maps that refer to/ invoke multimedia and animation – providing distributed information and 'wireless' access to it.

According to all the aforementioned both in this and in the previous section, the necessity of dynamic and interactive mapping which incorporates animation seems to be the common ground. Efforts to incorporate the temporal/ change dimension in maps on the one hand, and the multi-purpose map-use aspect governing cartographic visualization on the other, intersect at the premise of what Dorling and Openshaw (1992: 640) has connoted, that is, rendering "visible complex dynamic processes that previously were invisible" via animation.

4.2.2. The Role of Animation in GeoVisualization

'To animate' literally means 'to bring to life' and 'animation' is, respectively, 'the act of bringing to life'. It can be considered, as well, as a graphic art taking place in time (Baecker and Small, 1990), or as "a dynamic visual statement that evolves through movement or change in the display" (Peterson, 1995: 48). In essence, animation prompts a visual illusion of change based on a series of single *frames*[17] that are swiftly displayed (Roncarelli, 1988). This illusion is achieved by a procedure that comprises the 'computer-simulated' creation of in-between frames ('tweening') between significant frames which have been actually captured (key

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[15] Or *(Cartography)*^{3}.

[16] Peterson (1995: 200) elaborates that the usage of the word metaphor is: "to describe a correspondence between what the computer does and how we should think about what it is doing. [In other words,] a metaphor relates our understanding of the computer to something with which we are already familiar".

[17] i.e. static (map) displays.

frames), resulting in a relatively smooth transitional changes of several features (Peterson, 1995) included in some/ all of the frames/scenes when the latter are viewed in a sequenced display.

From a (spatiotemporal) database perspective, a sequent set (series) of states (see § 4.1.) that links pertinent data creating 'snapshot sequences' stands for the very "intuitive spatiotemporal model" (Langran and Chrisman, 1988) for dynamic spatial pattern representation and cartographic visualization. Conceptually, cartographic animation ranges from the simplest metaphor of 'slideshow' to the more sophisticated and demanding metaphors of 'metamorphosis' (*'morphing'*) and 'model and camera' (Gersmehl, 1990). So, according to MacEachren (1994b), the slideshow metaphor comprises the lowest level of map animation, since it is about "sequencing of spatially and temporally independent scenes" (MacEachren, 1994b: 119). As shown before, states and situations are used interchangeably to manifest instances in world time. Herein, it is vital that the interrelation between real world instances and their cartographic counterparts in the context of animation be promoted. Quoting Langran and Chrisman (1988: 5) who allege that "the temporal parallel of map is state", and DiBiase et al. (1992: 206) who declare that "the representation of a situation is called a 'scene' in animation terms and may take the form of a static map", we can infer that the graphic representation analogue of an instance in world time is a scene or a static map itself. Thus, the act of creating a proper sequence of scenes, frames or static maps appears to be the keystone for animation.

More specifically, for this act to be considered animation, MacEachren (1994b) contends that such sequences may involve either temporally independent but spatially linked scenes or temporally dependent, spatially linked scenes; the first case corresponds to animation of static maps, whereas the second to animation of dynamic maps. As an effect, from this point of view, the slideshow metaphor does not befall in the category of animation. For the two former cases, and especially for animating dynamic maps, Dorling and Openshaw (1992) set the fundamental algorithm which provides the basic steps for a pre-rendered frame-based map-movie tape; these steps are: i) development of a temporal data set with a multitude of time-intervals, ii) election of proper time periods, typical of the 'phenomenon' to manifest, iii) production of one map for each typical time period and storage of it in one or more frames (scenes), and iv) reproduction of the previously stored frames of static maps at a 'normal' speed. What is more, (for the animated map) the potential of manipulating geographic data through methods such as interpolation (Peterson, 1995) should not be neglected, since the scenes produced from this kind of data are (at least) spatially correlated/ linked.

However, apart from the deviation from interactivity (see below) that this algorithm demonstrates, it is crucial to examine the 'meaning' of the scenes or frames – whether temporally dependent or independent: it should be noted once more that events – punctuating word time (and not merely instances) – relate with changes; unfortunately, Langran and Chrisman (1988) warn us that the scenes (snapshots) tend to represent states rather than events which 'carry' the transitional effects from a state to the next. Therefore, a proper cartographic animation should contribute to cartographically represent events, thence change.

Intuitively, cartographic animation is used to map time, and this is considered a 'good idea' because "time is mapped with time" (Harrower, 2001: 33). As described in the previous section, there are three concepts of cartographic time. Blok et al. (1999) and Kraak and Ormeling (2010) accentuate the direct link that develops between display time and world time – the changes of characteristics in the first and their representation in the second – when harnessing a (temporal) animation. Since there is such an explicit interconnection, and change can be represented and visualized with animation – allowing "a person to see the data in a spatial as well as a temporal context" (Blok et al., 1999: 140) – geographic processes could be visualized as well through animation. Still, not all changes or processes entail time in its conventional sense of chronological order: they may encapsulate temporality as a means of displacement or movement (fly-bys). As MacEachren (1994b) puts it, processes that lack ('sheer') dynamic character can be as well facilitated by animating static maps. In any case, animation does play a significant role in the transition from depicting static phenomena with still maps towards visualizing dynamic process with digital animated maps. This notion is insinuated by Dorling and Openshaw (1992: 643), who, in their attempt to expose the incapability of static maps to 'unveil' changes, note:

> "*It is self-evident that two-dimensional still images are a very good way (if not the only way) of showing two-dimensional still information. However, when the underlying patterns (and processes) start to change dynamically, these images rapidly begin to fail to show the changes taking place*."

The same notion emerges – this time at a manifest form – from Ogao and Kraak (2002: 23), asserting that:

> *"[Animations] play an intuitive role when used to view geospatial transitions as they happen in time as opposed to simply viewing the end states. Thus, they enable one to deal with real world processes as a whole rather than as instances of time. This ability, therefore, makes them intuitively effective in conveying dynamic environment phenomena."*

The strength of animated maps to convey 'change within continuity' of the flow of a process appears to be undisputed. Yet, is it all about communicating the temporal variation of studied spatial patterns, or can it be that this new means of making visible is endowed with the potential to unravel 'dynamic unknowns' in geographic patterns? Moreover, is this so-called potency of animation proper to visualize cartographically (either to present or explore) the effects of time and change with reference to our biological 'sensors' and 'processors'? The latter question, being more generic, and concerning perceptual and cognitive aspects of human-medium interaction is addressed in the following section.

With reference to the first one, as one could expect, animation utilization rather expands to the whole continuum of map-uses in cartographic visualization. When Peterson (1995) promotes the essentiality of animation in rendering apparent a phenomenon or a trend not being visible otherwise – in a series/ multiple of (ostensibly) unrelated individual static (display) maps –, we doubt that he emphasizes the communicative over the 'insight-deriving' aspect. Neither his condensed but meaningful explanation: "what happens between each frame [(static display)] is more important than what exists on each frame" (Peterson, 1995: 48) seems to account only for presentation or synthesis map-functions. On the contrary, it turns out that animation is equally exploratory-oriented as presentation-oriented – if not more exploratory-oriented. This assumption is fueled by Kraak' s (2006: 317) pertinent thesis, who eloquently notices: "Animations not only tell a story or explain a process, they also have the capability to reveal patterns, relationships or show trends which would not be clear if one would look only at the individual maps only". Confirmation of this full-ranged capacity of animation within the map-use cube emanates from Ogao and Blok (2001), when they adduce cases both for presentation and exploratory tasks in environmental studies: on the one hand, presentation tasks can be facilitated by dynamic maps which visually portray numerical projections that result from historical observatory geographic data (e.g. relating to aspects of global climate change); on the other hand, exploration rises in cases where the animation and its respective interface 'intrigues' adepts of specific phenomena or process to obtain profound insight from the inquiry into the shift of the respective spatial patterns. In any case, and especially when it is about the exploratory extreme of the map-use spectrum, the recognition and understanding of spatial distributions (patterns) require a 'motion-embedding', dynamic sequencing process of visualization. Towards this direction, Openshaw et al. (1994) claim that no matter how perplex these time-dependent spatial patterns may show, animation, under the disguise of a linked sequence of scenes (i.e. when viewed on film), can expose their fundamental simplicity under a certain level of abstraction.

4.2.3. Abstraction, Symbols and Variables in Cartography

The concepts of abstraction and generalization have always been the underlying facilitator in map-making. Muehrcke (1980 – cited in DiBiase et al., 1992) has long ago designated maps as 'forms of abstract thinking'. Robinson et al. (1995) describe generalization as a necessary procedure in order to infer reality to cartographic scale, while they point out that maps owe their very existence to the generalization; else, these abstracted forms of thinking which serve in standardizing and simplifying reality by reducing overwhelming detail and emphasizing certain aspects of interest (i.e. map's theme) would have been simply substituted by images. As a consequence, maps are not identical reflections of reality, but selective representations of it (DiBiase et al., 1992), depending on the theme they are meant to represent. Generalization and cartographic generalization[18] in particular, though, includes several functions, one of which is *symbolization* (Robinson et al., 1995). Symbolization, or "the general characteristics of the graphic cues used", along with some kind of convention ascribe maps their influential character (Kraak and Ormeling, 2010: 64). As one would expect, the appropriateness of these graphic characteristics is far from being random: in effect, their proper selection constitutes a major challenge in visualization (DiBiase et al., 1992). With reference to static maps – depicting static distributions and static phenomena –, the pertinent abstraction required to depict a *specific theme* (e.g. land-cover or poverty spatial distribution) calls for a qualitative and/ or quantitative differentiation. In such cases, information transfer can be optimized by harnessing the intrinsic potential that emanates from "the *variation* in graphic characteristics" of the selected symbols (Kraak and Ormeling, 2010). In essence, cartographic symbolization for conventional maps has been traditionally facilitated by what Bertin (1983) has called the *visual variables*: the differentiation of certain graphic attributes and their interrelation to the measurement level of geographic data is presented in Figure 22.

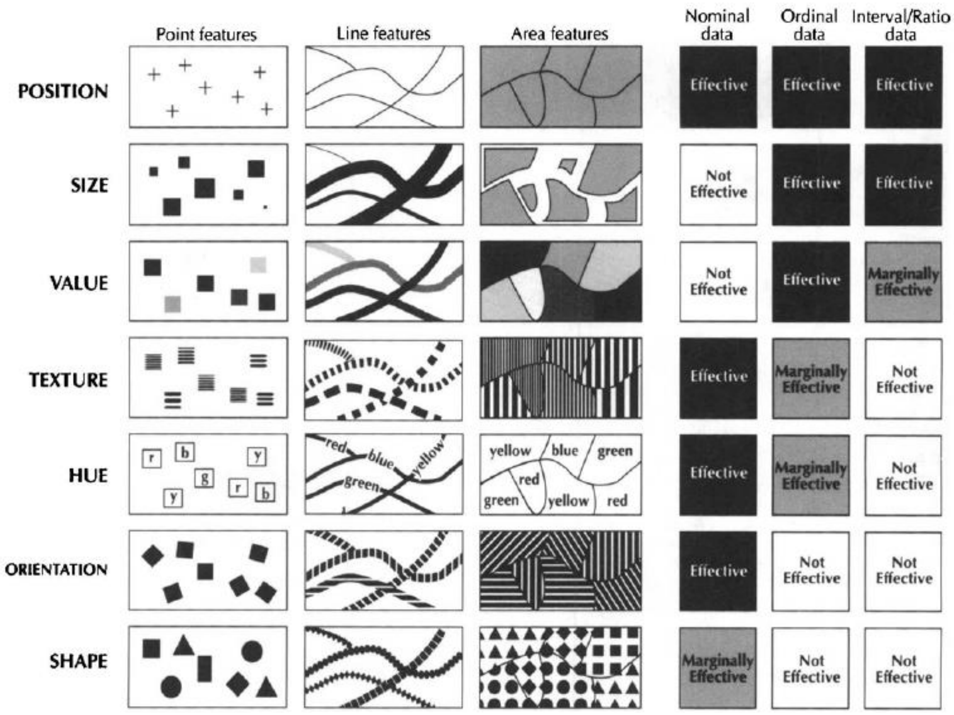

Figure 22: The visual variables and their appropriateness/ effectiveness in signifying the level of measurement for data linked to point, line and areal features (geographic entities).
After Bertin, 1983.

[18] Muller et al. (1995) discern model-oriented generalization from cartographic generalization; whereas the former engages with the apprehension and interpretation leading to "a higher level view" of some phenomena at "smaller scales", the latter addresses the issue of spatial data/ information graphical representation resulting in the legibility improvement of the cartographic end product.

4.2.4. Dynamic Variables and Cartographic Visualization

Bertin (1967/ 1983: 42) has stated that: “although movement introduces only one additional variable, it is an overwhelming one; it so dominates perception that it severely limits attention which can be given to the meaning of the other variables”. Even though, several researchers have attempted to introduce some kind of motion so as to encompass dynamism in map communication or in cartographic visualization. From Tobler’s (1970) computer model for urban growth stimulation to Gersmehl’s (1990) nine metaphors of varying degree of animation, the awareness of this motion-entailed potential of animation to extend the limits of traditional ‘graficacy’ was growing. However, it was not until 1992, when David DiBiase, Alan MacEachren, John Krygier and Catherine Reeves, in their seminal publication, readdressed the issue “of appropriately and creatively signifying geographic data” (DiBiase et al., 1992: 203) with visual variables in still maps, presenting ‘fresh’ implications on the means that new, *dynamic visual variables* could be incorporated to the old, static ones, prompting an analysis harnessing “time in abstract ways that complement spatially abstract maps in enhancing visual thinking in geography” (DiBiase et al., 1992: 202). In essence, they figured out that movement, instead of distracting attention from the traditional visual variables, would reinforce them. These so-called dynamic variables are: *Duration, Rate of Change* and *Order.* In the context of representing situations with scenes or frames – a group of ‘unchangeable’ frames can be considered a scene – and events or series of events with sequences of frames that entail changes, these variables are elucidated below:

- **Duration**: Refers to the time that a frame/ scene (static map) is displayed within an animation. In practice, the *pace* of an animation varies according to the duration of a frame; thence, the shorter the scene, the faster the pace of the sequence, and vice-versa. Since duration is measured in quantitative (time) units, it can be utilized for ordinal- and interval/ ratio-scaled, and generally, quantitative data representation.
- **Rate of Change**: Refers to the quantitative representation of the variance of events, that is the variance of coherent sequences of situations; it ensues from the division m/d, where m is the intensity or magnitude of change in positions or attributes of entities (or patterns in field-based world-views) of frames or scenes and d is the duration of each scene. Magnitude relates both i) to the inherent propensity of a phenomenon or process to evolve and ii) to the time intervals at which data is available (through initial collection or manipulation, e.g. interpolation). The character of an animation with relation to its smoothness/ abruptness is a derivative of rate of change: either decreasing m (while holding d constant) or increasing d (while holding m constant) will result in reduced rate of change yielding a smoother animation result, whereas a more abrupt animation will arise by increasing m or decreasing d.

- **Order**: It is defined as the sequence in which frames or scenes are displayed within an animation. By default, animations are presented in chronological order; yet, reordering frames or scenes metrically (e.g.) rather than chronologically can be proven fruitful for geo-visualization, and, in particular, for geographic (data) analysis and exploration.

Somewhat later on, MacEachren (1995) extended these dynamic variables to encompass:

- **Display date/ time:** Represents the time at which display changes are initiated; in case it is linked to chronological date, then a 'temporal location' is defined.
- **Frequency**: Determines the number of identifiable states per unit time; even though it is linked with duration, it is worth perceiving it as a separate variable, because, in a sense, it provides the "temporal texture" of a phenomenon (see its effect on *color cycling*).
- **Synchronization**: Signifies the temporal "coincidence" for two or more time sequences; in effect, two phenomena or processes display such a coincidence when their respective patterns correspond (– i.e. peaks and troughs of these sequences correspond), and, therefore, they are considered to be 'in phase' or synchronized. As a consequence, two time series will be 'in sync' in cases where the pattern of a time series that constitutes the main cause has an immediate impact on the pattern of another time series that 'receives' the effect; in the case where a temporal pattern affects another one, but with a time delay (lag), then this pattern is 'out of sync' exposing shifts in the respective peaks and troughs; in any other case, where the patterns have no explicit correlation, this variable has no particular value.

4.2.5. Animated Maps' Classifications Schemes

Having described these dynamic variables that serve the whole map-use continuum, it follows that efforts to put some kind of order to the vastness of maps that are enabled by these variables are vital. To elucidate, maps of this 'type' – the so-called animated maps – are distinct in that they shift from the static display paradigm and comprehend an amount of dynamism. From a point of view, the abovementioned efforts can flourish by probing into the pertinent classification schemes according to which these maps are grouped.

A fundamental categorization has been made by DiBiase et al. (1992), distinguishing between animated maps that 'promote': a) **location**: the presence of a phenomenon in a particular location is punctuated by the assistance of animation, particularly when dealing with complex distributions (e.g. the use of flashing-point symbols to stress out the specific location of major earthquakes only); b) **attributes**: the spatial distributions or patterns of phenomena are emphasized (duration) with relevance to their value attributes – usually classified –, either providing an animated sequence of (spatial distributions of) *choropleth* *units* within the same class, or producing an animation based on different classification schemes sequencing (or based on two different patterns of different phenomena seeking interaction); when not classified, the (single) attribute values (magnitude) are linked to symbol duration; c) **change**: unlike the two previous cases where animation is utilized ('in excess') to put stress on static representations (e.g. hot spots of criminal events within a pertinent geographic distribution), this category of animation is dedicated to convey or explore a changing aspect of geographic phenomena or processes. The change may be i) *chronological* (time-series), ii) *spatial* ('fly-bys', 'fly-overs', or 'fly-throughs') or iii) *thematic*/ with respect to *attribute* (re-expressions):

i) ***Time-series*** are the most straightforward types of animations, expressing change of location or attribute (or, as Harrower (2001) adds, spatial extent) through time. Sequences are made of scenes or frames (corresponding to this location, attribute or geometry) sampled at equal intervals along the spectrum of series, reproduced in a chronological order of a constant rate.

ii) ***Fly-bys*** (fly-overs or fly-throughs) are animations the respective sequence of which is made of scenes that 'capture' and represent (changing) views of static surfaces or volumes. This can be attained if the viewpoint of a supposed observer is changing gradually and properly. In essence, the reproduction of the respective animation sequence enables the harnessing of multiple views (from different viewpoints) with the purpose of providing the sense of flying over a 3-d surface (virtual or augmented reality effect).

iii) ***Re-expressions*** embody an active change in positions and patterns occurring to the structure (of the thematic dimension) of the initial data owing to some transformations. The selection of strategically proper segments or subsets of a time-series original data (brushing) – mostly based on similar thematic characteristics (e.g. similar earthquake magnitude) –, the re-ordering of these data, and the final reproduction of sequences in which pacing (the variation of the duration of scenes or frames) is contingent to the numerical (or ordinal) variation of the values of these subsets signifies this type of animation.

The matter of animation referring to change is further elucidated by DiBiase et al. (1992) and MacEachren (1994b): time series animation is considered to take place in geographic space implicating both location and attribute change of an object; fly-bys occur in geographical space concerning varying locations (differing positions of observer); while re-expressions involve position changes of objects with respect to the attribute space. Therefore, MacEachren (1994b) infers that the use of the dynamic variables for the first case entails the most apparent applications, and the scenes of the animation sequence are both temporally and spatially dependent; as for the second case, because the movement of the observer (that is change of viewpoint positions) does not require any temporally sequential order, but it does require a spatially one, the animation is temporally independent but spatially dependent; finally, the changes occurring at attribute space are linked neither temporally nor spatially: it is rather the thematic relevance that denotes the ordering of the sequence. In a similar vein, Lobben (2003) reviewing the literature relevant to the categorization of cartographic animation identifies ***time-series, areal, thematic, and process*** animation. In a scheme (Fig. 23), she further presents the concerns/ criteria included and the decisions needed to be made so as to opt the proper type of animation according to the purpose of the application, on the basis of the (static *vs.* dynamic) nature of: space, time and variables.

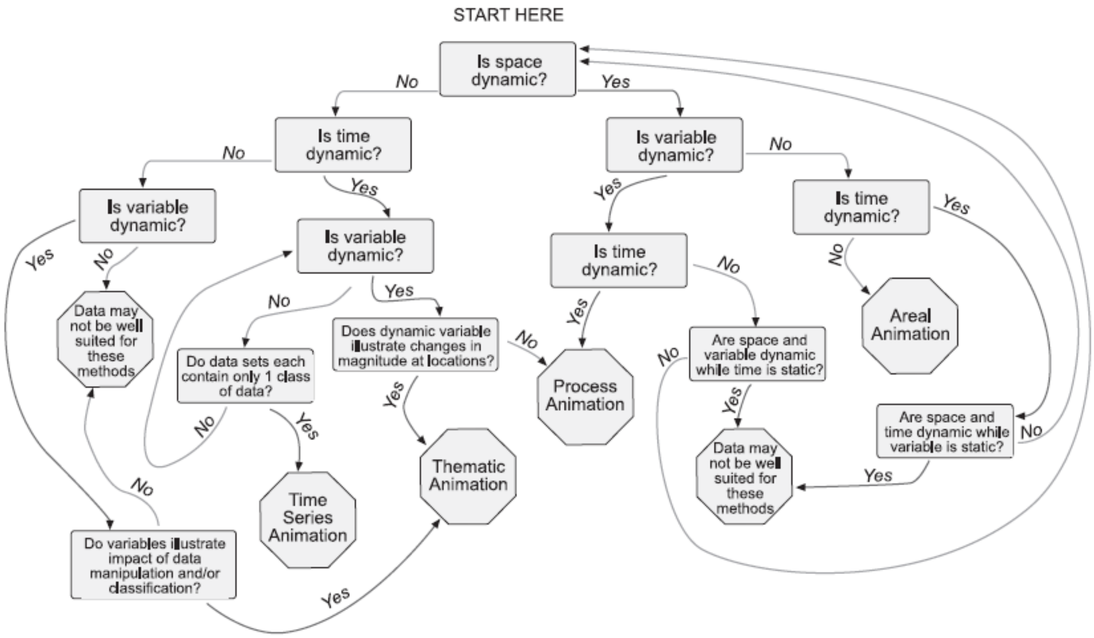

Figure 23: The decision-tree for cartographic animation types. After Lobben, 2003.

4.2.6. Interactivity and GeoVisualization

Apart from these classifications that scrutinize temporal, spatial and attribute aspects and dependencies, the "highest order classification may be based on interactivity, which separates animations into two categories, *presentation* and *interactive*" (Lobben, 2003: 319). A parallel of this phrase is expressed by Slocum et al. (2009: 389) who distinguish animations "characterized by substantial interaction" from those having "little or no interaction". No matter how these animations are organized with respect to the abovementioned criteria, they can diverge from, or converge towards interactivity. Besides, MacEachren et al. (1994b) includes, in their "four dimensions of visualization techniques for spatial data", amongst others (see MacEachren et al., 1994b), "the degree of interactivity (low-high)". Therefore, interactivity gains a substantial attention in the visualization process that entails animation and dynamism – on conceptual grounds.

On more practical grounds, interactivity is related to the *two-way* effect occurring between two or more objects, subjects, phenomena etc. In the realm of modern cartographic visualization and geovisualization, the *user-interface* (more specifically the *geospatial visualization interface*) comprises the facilitator for the interaction between humans and computers, while the interactive map is a form of map presentation assisted from this interface to mimic the display of mental maps (Peterson, 1995; Cartwright et al., 2001). For spatially-related sciences such as geography and architecture, the representations of phenomena themselves (representational structures) are as well utilized for navigation (interfaces); nevertheless, geography in particular, apart from using space to represent space, it implicates representations across a range of scales and entities/ phenomena to be represented (visible, non-visible, concrete, abstract), rendering representations of geography a distinct area of scientific research (Cartwright et al., 2001). Given that geographical processes are scale dependent, requiring varying degrees of detail and generalization/ abstraction, geovisualization (presentation-synthesis-analysis-exploration) should come about at this level of resolution where: geographical variance is maximized or insight about spatial processes tends to be optimized (Moellering and Tobler, 1972; Woodcock and Strahler, 1987; Muller et al., 1995).

Increasing levels of interaction/ interactivity not only succeed to enhance the attractiveness/ interest of maps, but also augment their functionality, providing the potential for people/ users to delve at a 'deeper level' of spatial information interrelation/ exploration, putting "the pieces of information together themselves" (Cartwright and Peterson, 2006: 2). Shneiderman's "visual information seeking mantra" by generating varying representations with respect to over-viewing, zooming, filtering data and requesting details on demand (Shneiderman, 1996: 336) suits the explication for map interactivity – as opposed from presentation – from Lobben (2003: 319): *The viewer may direct the animation in several ways—panning, zooming, and rotating—as well as engaging in discourse with the computer through inputting data or responding to questions*, while Dykes (2005) further extends such "high levels of interaction and user control" to the whole spectrum of visualization. He explicitly states that:

> *"interaction helps us when using a computer to see relationships in complex multi-variate data sets, to learn about places we have never visited through an online interactive atlas […and, whereas] fluidity in interaction supports discovery through visualization, impediments to interaction obstruct it"* (Dykes, 2005: 266).

As an overall assessment of interaction, on the one hand, the quantitative – varying cartographic 'products' can be made faster and less expensively – and the qualitative – interaction with map displays in near real-time – technological changes that both cartography and computer graphics have undergone have induced a new 'cartographic practice' which has shifted the emphasis from static to dynamic map use (Taylor, 1994); in other words, computer technological advances have made possible that map interaction and visual thinking can co-occur in real time (simultaneously), in a manner that dynamic analysis (and exploration) can be attainable (MacEachren and Monmonier, 1992), meaningful and fruitful. On the other hand, static 'epidermic' map displays are no longer considered sufficient for the map users who wish to be able to 'submerge' into the map both spatially and conceptually (Cartwright and Peterson, 2006). Thus, interaction appears to be the quintessence towards (geospatial) knowledge formation and (geo)visualization (Dykes, 2005; Cartwright and Peterson, 2006). Furthermore, borrowing the exact words of MacEachren (1994a: 8) who states that:

> *"GVIS can be to cartography what GIS has been to geography – a reinvigoration of an old, often taken for granted discipline whose relevance is recognized outside the discipline because it can help tackle important interdisciplinary issues",*

it can be deduced that interactivity lies at the epicentre for modern cartography rejuvenation.

4.2.7. Synopsis and Further Consideration

In this section we have treated with recent cartographic advancement, geovisualization (or cartographic visualization) and mostly with the dynamic aspect of the latter. Until the present point, in particular, the focus has been driven towards the purpose in geovisualization (map-use cube), the dynamic variables and the main typologies for cartographic animation – implicating interactivity as a major factor in the 'top right corner of the cube' –, considering, in a general sense, the technical directives for employing cartographic visualization to unravel 'dynamic unknowns'. However, now matter how technological development has been a *sine qua non* for implementing dynamic and interactive cartography, the very origins of cartographic visualization are hardly technological. In fact, as DiBiase et al. (1992) and MacEachren et al. (1992) conceive visualization, it does not adhere to computation methods but rather to cognitive abilities and processes with which the development of mental representations provide pattern identification and insight gaining.

It should be noted that this argumentation does not exalt the biological/ cognitive factors and debases the technological/ computational ones; on the contrary, it promotes the reasoning that technology and technical issues should 'walk hand-in-hand' with biological evolution and human cognition. The fact that technological advance changes the medium (which represents the message) of cartography and that the map cube (in its wholeness of uses) owes its very existence to computer technology, cannot just be overridden. As a consequence, scientific community has endorsed an approach that converges towards the acceptance that these technological advancements should/ can be adjusted in an optimal way so as to reach a compromise for human skills and needs within the whole spectrum of cartographic visualization research. This mentality is illustrated through Taylor's (1994) scheme (Fig. 24), and verbalized (among others) by MacEachren and Kraak (1997) who direct the focus of geo-information technologies pertaining to interactive and dynamic maps towards their cognitive and decision-support implications (map functions).

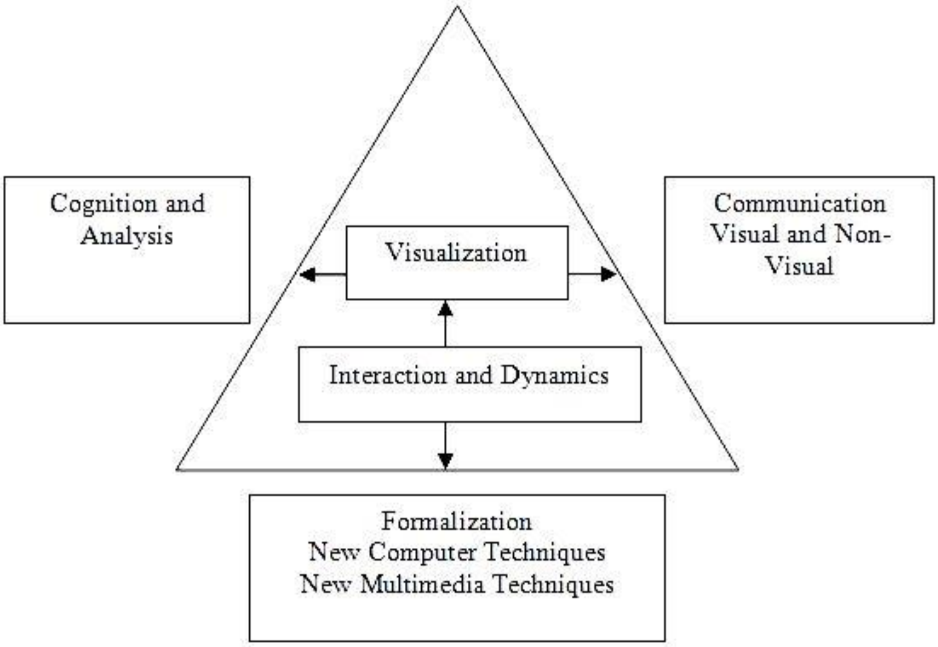

Figure 24: Conceptual basis for cartography.
After Taylor, 1994.

4.3. CARTOGRAPHIC VISUALIZATION OF CHANGE: COGNITIVE AND IMPLEMENTATION ASPECTS

From the argumentation of the previous section, the objective value of cartographic exploration for the 'revealing of unknowns' with reference to spatial patterns dynamics of geographic phenomena and processes through animation is beyond doubt. Expanding this argumentation to its extremity, it appears that the usage of animation or/ and interaction under the aegis of cartographic exploration is a one-way option towards approximating evolving processes. Nevertheless, a major contemporary question has been already posed in the previous section with relation to the factual effects of animation at the interface level between humans and dynamic maps. As Blok (2005b: 71) succinctly puts it:

> *"Animations are believed to be useful for the representation of spatial dynamics because they can mimic real-world dynamics and show processes. The question, however, is whether they are also effective. Are users able to extract useful information and acquire knowledge from them?"*

Thence, a major concern is the efficacy of animated maps towards map-users'/ readers' knowledge gaining and learning affordance. In this thesis, this neuralgic parameter is discussed in this section, albeit not in an exhaustive manner; for the scope of the thesis is not to explicitly assess the effects of dynamic maps. It is rather an attempt to provide a conceptual framework and a means to detect the crucial pitfalls and promote the strengths and suitability (relative advantages) in several cases and into several map-types (e.g. animated choropleth maps), while simultaneously to 'prescribe some regulations' for theoretically and practically effective dynamic maps. Such issues fill the pages of this thesis, not only for their theoretical importance, but also for their pragmatic prompt – towards our venture to create non-poorly designed animated maps adjusted to the scope of the thesis (Chapter 6).

4.3.1. Cognitive Aptitude for Coping with Animated Graphics and Maps: Theoretical Notions and Concerns

In the last two decades, technical/ technological advancements in several domains, including the domain of animation and (geographic) visualization, and the availability of (geographic) digital data have met with an unprecedented growth, giving the impression that the potential to visualize (present, synthesize, analyze, explore) the changing (geographic) reality or its abstracted environmental processes is compelling. This misleading impression is 'dispelled' by Harrower (2007a) who emphasizes that the capabilities of the users whom technological innovations used to facilitate are often eventually outpaced notwithstanding the mounting maturity of the respective technology. In a similar vein, Fabrikant (2005), referring to these technological developments, asserts that "the theory and understanding of novel graphics technology and applications has lagged behind". This means that the technology applied in an experiential manner intends to justifying/ corroborating itself without appearing to be concerned with procuring or developing the appropriate theoretical conceptualization and understanding to be entrenched upon; as a consequence, there is a fundamental deficiency in the principles that can render animations and geovisualization cognitively effective (i.e. compatible to effortless human understanding). This deficiency has been only recently realized and has been attempted to be addressed. The following are a synopsis of the notions and principles related to the cognitive aspects for animation and dynamic visualization and research ventures towards their clarification.

Both the conceptual background and the empirical studies have been arisen from the fields of cognitive science and cognitive psychology; cognitive scientists and psychologists have dedicated their efforts to unravel the 'mystery' of how externalized visual representations (e.g. statistical graphs, remotely sensed data, maps, animations etc.) interrelate and interwork with internal human visualization capacity (Tversky, 1981; Hegarty, 1992; Barkowski et al., 2005 – cited in Fabrikant and Goldsberry, 2005). The pertinent research on static graphics has demonstrated their capabilities as facilitators of perplex process in various functions (understanding, learning, memorization, communication). Yet, "the human mind can visualize not only mental static maps but also dynamic mental map animations" (Peterson, 1995: 43). Nonetheless, a step further towards animated displays does not necessary hold the same potential. Despite the widespread and popular presumption that because animations can explicitly represent and portray dynamic processes and changes they can as well successfully cope with enabling people's (scientific) understanding and learning of such processes (Griffin et al., 2006), evidence from the studies of cognitive psychologists (see Betrancourt et al., 2000; Morrisson et al., 2000; Morrison and Tversky, 2001; Tversky et al., 2002) suggests otherwise. Although according to the ***Congruence Principle*** for effective graphics – that is the natural cognitive correspondence between "the structure and content of the external representation" and "the desired structure and content of the internal representation" (Tversky et al., 2002: 249) – it seems a rational eventuality that people tend to form mental representations of dynamic processes in the form of animations, however, as they suggest, in animated events and graphics, it is the ***Apprehension Principle*** – according to which this externalized representation "should be (also) readily and accurately perceived and comprehended" – that is violated (Tversky et al., 2002: 256).

Within a research framework where the superiority in efficacy of animation is only attributed to the lack of equivalence between animated and static graphics in content or experimental procedures (e.g. interactivity) (Morrisson, 2000; Morrisson et al., 2000; Morrison and Tversky, 2001; Tversky et al., 2002), in combination with cases promoting small-multiple snapshots as the most appropriate mental representations for dynamic processes (Hegarty et al., 2003; Lee et al., 2003), it ensues that more scrutiny is required. The experimentation carried out by Fabrikant (2005), Fabrikant and Goldsberry (2005) and Griffin et al. (2006) are some of the research works addressing these issues.

Fabrikant (2005) has raised the issues of *perceptual salience* (i.e. where the attention is focused according to *where* the most dominant (pre-attentive/ cognitive) characteristics are located), *thematic relevance* (i.e. where the attention is directed according to *what* (semantic characteristics) *is* intended to be presented), and their interrelationship in the context of geo-visualization in an empirical research. Her research has been fuelled from the scepticism about Lowe's (1999) experiments on complex weather map animations and the failure of the participants to entrench their understanding upon thematic relevance (rather than perceptual salience – as it did happen), and the cognitive scientists/ psychologists reluctance to promote the benefits stemming from animation when it relates to perplex processes (see Betrancourt et al., 2000; Betrancourt and Tversky, 2000; Morrisson et al., 2000; Morrison and Tversky, 2001). More specifically, her efforts have concentrated on stimulating the differences between the kinds of objects (constrained by physical properties, e.g. compartments of a complex mechanism in motion) in which studies/ experiments of cognitive psychologists are conducted upon, and the abstracted, non-tangible geographic processes of geo-visualization; in addition, she has emphasized the fact that the cartographic visual variables are meticulously selected on the basis of rendering "thematically relevant information perceptually salient" (Fabrikant, 2005). So, abutting on a pre-attentive (bottom-up) saliency-based visual attention model[19] developed by Itti et al. (1998) and Itti and Koch (2001) and applying Bertin's variables in order to systematically evaluate static maps matching thematic relevance to visual saliency, it has been proven that the appropriate manipulation of cartographic variables and the adherence to cartographic design principles[20] do play a decisive role. Moreover, Fabrikant and Goldsberry (2005) have expanded the experimentation on dynamic scene designs, relying on the Itti-model applied on dynamic scenes (Itti, 2005). Under these experiments, the hypothesis (provided by Tversky and colleagues) that *small multiple displays* are less advantageous than *stop-and-play animations* because they convey less information has been falsified, at least for cartographic geo-visualizations created by adepts. In fact, these deviations in information content emerge as the most salient locations in the animation frames are detected where the most significant changes occur at the transition[21], and due to the gradual nature of this transition in animation (Fabrikant and Goldsberry, 2005).

In the research paper of Griffin et al. (2006), animated maps are compared in effectiveness with the small-multiple maps. The latter ones (also called small-multiple snapshots, small-multiple displays, small-multiple maps, or small-multiple map displays) being popularized by Tufte (1983) are a type of data representation which, in cartographic terms, present an ordered map sequence of the same region portraying changes of it (this region) (Fish, 2010). These multiples can be accessed in an internally (mentally) interactive means by users, i.e. by viewing them at the pace and in the order they wish (Fabrikant et al., 2008). So, in this comparison, Griffin et al. (2006) scrutinize the participants' (map readers') capability to correctly identify clusters moving over space and through time within a controlled experiment with concern on factors such as: animation pace, cluster coherence, and gender. According to their findings, animated maps contribute to quicker responses and to the correct identification of greater number of patterns; moreover, pace and cluster are proven to be interlocked in a manner that certain animation paces reveal different types of clusters.

The studies having attempted to answer '*whether* animations are effective' have infused a theoretical support for creating animations and animated maps. Nonetheless, they are only preliminary stages towards dealing with the challenge of understanding '*how* they differ, under which conditions and in what ways – for: what kind of data, which map functions, which users, what strategies and

[19] This model operates as a baseline against which collected data from actual maps with the eye-movement method from several subjects are compared.

[20] The establishment of a visual hierarchy congruent with thematic levels of relevance lies at the core of cartographic design (Dent, 1999; Dent et al., 2009).

[21] "…what happens between each frame is more important than what exists in each frame" (Peterson, 1995: 48).

techniques – they are particularly effective' (Edsall et al., 1997; Fabrikant and Goldsberry, 2005; Harrower, 2007a). Given that theory limps in content and rigor, there is a dire necessity for:

> *"[…] an overarching theory (or theories) of how animation functions on a cognitive level […] – as separate from, yet adding to, our existing theories of how static maps function – so that ongoing research on map animation can be placed in context and seen as either adding to or modifying a larger, evolving intellectual framework"* (Harrower, 2007a: 350).

In an attempt to remediate this shortcoming on theory, *Cognitive Load Theory (CLT)* is herein cited, based mainly on the paper of Harrower (2007a). According to CLT, two types of cognitive structures (in the form of memories) are involved in the procedure of information processing and learning: the long-term memory (LTM), in which knowledge and skills are stored, placed on a permanent basis, and the working memory (WM) which pertains to conscious-driven tasks implicating actively processing incoming stimuli (Sweller 1988; 1994; Chandler and Sweller 1991; Drommi et al., 2001 – all cited in Harrower, 2007a). The former is considered as the essential, dominant structure of the cognition (Ayers, 2005), in which knowledge is embedded in the fabric of knowledge schemata – condensed mental shortcuts useful for the representation of certain knowledge-based views of the reality and the organization of current knowledge in a manner that they can also facilitate future understanding (acting as frameworks) –, while the latter only processes small pieces of information/ knowledge – a function very limited, both in duration and capacity, especially when it applies to novel information (Harrower, 2007a). Referring to visual media, a series of studies leaded by Sweller and colleagues reveal that the specification of the role and the restrained capacity of WM can prompt the quality of instructional design.

In cartographic/ geo-visualization terms, this interplay evokes MacEachren's (1995) assertion about how maps (and generally visual displays) function: every piece of novel visual incoming information (stimulus) is linked to the interrelated knowledge acquired and disposed at knowledge schemata, and by this interaction learning and understanding emerges. From a semiotics perspective, Charles Peirce and Ferdinand de Saussure have suggested that the derivation of meaning is based upon linking *signs* (e.g. the symbol of a road on a map) to *referents* (e.g. the road as an object): Ogden's and Richards' (1923) *semiotic triangle* (*semantic triangle or triangle of meaning*) (Fig. 25) uses the *concept* (interpretant) as mediator, and therefore the concept acts as a direct link both to *referent* and to *sign-vehicles*, while the link between sign-vehicle and referent – with sign-vehicle standing for referent – is not direct, but 'passes through' the concept (see also Kavouras and Kokla, 2008). From the point of view that maps refer to concepts about the world rather than to its objects (MacEachren, 1995) the semiotic triangle with concepts as mediators carries the proper interrelations. Therefore, what is contained in a map does not merely exist a priori in a map; in contrary, it is actively constructed by the mental schemata of the map-reader (Harrower, 2007a). As an effect, the potential of comprehending a map or obtaining knowledge from it is determined by the interplay between the conscious processing of novel stimuli with already learned material; and if enough and perplex schemata are possessed on the LTM, the limitations of WM can be diminished by accessing this material (schemata) from LTM and restoring it back to WM[22] (Harrower, 2007a).

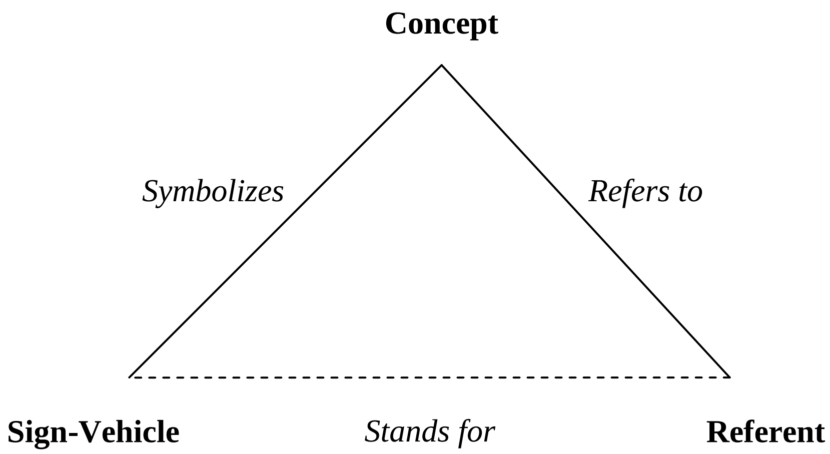

Figure 25: Depiction of the semiotic/ semantic triangle with the concept as mediator between the referent and the sign-vehicle.
From Ogden and Richards, 1923 and Kavouras and Kokla, 2008: Modified.

Nonetheless, maps as mediums entail by nature multiple elements of information which interact and thus producing a burdensome *cognitive load*, aggravating the tasks of comprehension and learning (Wilson and Cole 1996), irrespectively of the quantity and quality of schemata existing on the LTM. According to Chandler and Sweller (1991) and Sweller et al. (1998) to the previous type of cognitive load – (i) *intrinsic cognitive load* (the intrinsic load of a map is augmented by the degree of its complexity – two other types of such load are involved when reading maps: (ii) *extraneous cognitive load* (the avoidable load relating to ineffectual cartographic design and other (extrinsic) distractions), and *(iii) germane cognitive load*, (the load resulting from map-reader's learning potential from the interplay between LTM and WM). So, the challenge lies in the investment on augmenting learners' active engagement with the material (i.e. facilitating germane load), while simultaneously minimizing unnecessary extraneous factors (extraneous load) and mitigating map complexity (intrinsic

[22] See below for *germane cognitive load*.

load) – which both account for precious cognitive resources consumption (Sweller, 1994; Van Merrienboer, 2006).

More specifically, when it comes to animated graphics and maps, they entail two major barriers that need to be overcome. As Ayers (2005) explains, animated graphics are more prone to saturate the limited WM because:

- They constantly change and their information is transitory, so it lingers in the memory for no more than a few seconds unless it is rehearsed; thus, an extraneous cognitive load is added on animated graphics, in comparison to their static counterparts.
- The effectiveness of an animated sequence of elements/ scenes is built upon apprehension and remembering of the latter ones in terms of succession – i.e. previously viewed scenes have to be remembered in order for those who come next to provide understanding; this calls for an optimization of the interplay between LTM and WM, and the quick transfer of the earlier material (previously viewed scenes) to LTM to free up WM. In the case, though, that there is not enough time for this shuttle to be fulfilled, then a 'cognitive traffic jam' arises, known as *retroactive inhibition*.[23]

While from a practical perspective Harrower (2003) has demonstrated that map-readers need to see an animation loop several times, it is only through this theoretical (cognitive) approach that it is interpreted why this replay is at least useful: "repetition gives readers time i) to revisit material, thus refreshing WM, and ii) for material from WM to be integrated into LTM" (Harrower, 2007a: 352).

4.3.2. Animation in Dynamic Maps and Considerations for Visual Exploration

After citing and commenting on basic notions, principles and cases towards the formation of a theoretical background for the generic cognitive functioning of animated maps, this sub-section examines several types of animated maps. As Harrower (2007a: 349) posits: "When it comes to designing animated maps, the bottleneck is no longer the hardware, the software, or the data – it is the limited visual and cognitive processing capabilities of the map reader", it ensues as a dire necessity to "investigate how different types of animated maps operate and how they challenge the visual and cognitive processing capabilities of map readers" since, after all, "different thematic maps rely on different visual variables [and] when they are animated […] they signify change in different ways" (Goldsberry and Battersby, 2009: 202). In this sense, in the following we deal with both *animated choropleth maps* – and their classified (classed) and unclassed sub-categories –, and *animated maps for explorative tasks*, raising questions about interactivity.

[23] So, to a certain degree, the facilitation of germane cognitive load can contribute to the halt of this inhibition.

4.3.2.1. Classed/ Unclassed Animated Choropleth and Dynamic Raster Maps

Since choropleth mapping has been the most popularized and common method in thematic mapping[24] (Armstrong et al., 2003; Slocum et al., 2009), the focus on their animated counterparts and, moreover, on their notable sub-class of classed and unclassed animated choropleth maps emerges as a logical consequence. Choropleth maps symbolize the magnitudes of statistical variables as they come about within the boundaries of enumeration units (Robinson et al., 1995; Goldsberry and Battersby, 2009).

To this direction, Goldsberry's and Battersby's (2009) research paper is an attempt to characterize change in choropleth map animations by detecting and identifying the elements of this (choroplethic) change, emphasizing factors that restraint the perceptual facility and effectiveness of these animations. In general, animated choropleth maps symbolize change by a dynamically modified visual variable that occupies an enumeration unit. In this research work, they have depicted the changes that occur on temporal choropleth pairs by presenting two techniques to quantify the magnitude of change between these pairs (on animated choropleth maps). In practical terms, by initially specifying a group of elements of change:

- enumeration units: administrative areas partitioning the choropleth map;
- origin state – initial state in the choropleth pair; the earlier timestamp in a temporal transition;
- destination state, ending state in the choropleth pair; the later timestamp in a temporal transition;
- class rank – determines the class value of each class;
- rank distance – the difference between origin and destination state in class rank;

they derive: i) the *Basic Magnitude of Change* (*BMOC*): the (absolute) number of enumeration units which transit between the origin and the destination state, and ii) the *Magnitude of Rank Change (MORC)*: the cumulative rank (quantified at an ordinal level) of distance between the origin and destination states. These object-based Magnitude of Change (MOC) measures can be applied as well to pixel-based approaches, where pixels themselves are manipulated as enumeration units.

Since interpretation of animated choropleth maps relies on the assessment of evolving patterns over time, the ability to detect their change in spatial (*where?*) and in quantitative (*how much?*) terms, is a prerequisite. This ability, however, is undermined by *Change Blindness*. The latter is a phenomenon inducing individuals to fail to notice change pertaining to a visual stimulus (Simons and Rensink, 2005), thus "disrupting the retinal transient normally accompanying a change" (Simons, 2000: 2).[25] In a choropleth map animation, this phenomenon can

[24] In comparison with other kinds of thematic mapping, e.g. proportional-symbol mapping.

[25] Typically, it can occur in cases where a blank scene or frame is inserted between two successive scenes in an animated sequence, or because of eye-flickering.

drive map readers to elude even crucial shifts in the value or class of several enumeration units across temporal states (Goldsberry and Battersby, 2009). Up to a certain degree, change blindness can be surpassed adhering to the notion of the *focused attention* (see Rensink et al., 1997). In order to enhance the latter, a moving/ changing signal adequately distinguishable against the background noise in animation is required (Klein et al., 1992). With reference to animated choropleth maps:

> *"[…] this means that a change in class for any specific enumeration unit must be substantial enough that the map reader can tell the difference between the classes and that the change must be more perceptually salient than other changes in the map's background information"* (Goldsberry and Battersby, 2009: 205).

Summarizing, they propose a three-level transition detection approach in which they comment on the differentiated difficulty of detecting certain transitional behaviors (Fig. 26). Moreover, they stress out the increasingly augmenting demand for the change detection task as the number of class rises (Fig. 27), and the method used to divide data into classes according to which, as Goldsberry (2004) has stated, frequency and types of change would vary considerably. They refer as well to the size and number of enumeration units (with less and larger being more appropriate) as determinants of the effectiveness of the animation. Lastly, they suggest the smoothening procedures for the animations, along with the suitable selection of classification schemes, number and size of enumeration units and the manner (i.e. the appropriate level of change detection) as a remedy for change blindness.

Despite the popularity of choropleth maps, their capability to visualize change implicates several considerations as demonstrated above. Monmonier (1994), being aware of the tremendous implications of the class breaks placement has attempted to promote a robust method for meaningful class break identification by mitigating trivial, 'non-genuine' changes across time-series data. Harrower (2007b: 313), seeking an alternative, suggests "to simply avoid classification altogether". The pivot of this research attempt (Harrower, 2007b) is instigated by the deficiency of classified animated choropleths to portray changes that are essentially linked to the underlying spatio-temporal processes at work, which, in turn, end up rendering the map readers to: i) elude the few transitions occurring, since only some enumeration units 'flicker' while the rest stay unchanged, and ii) misinterpret the evolving patterns, providing them the impression that the changes – being abrupt – have been instantaneously emerged, when, in reality, it may be about (gradual) transitions potentially been initialized even from the very beginning (i.e. from the first frame) of the animation.

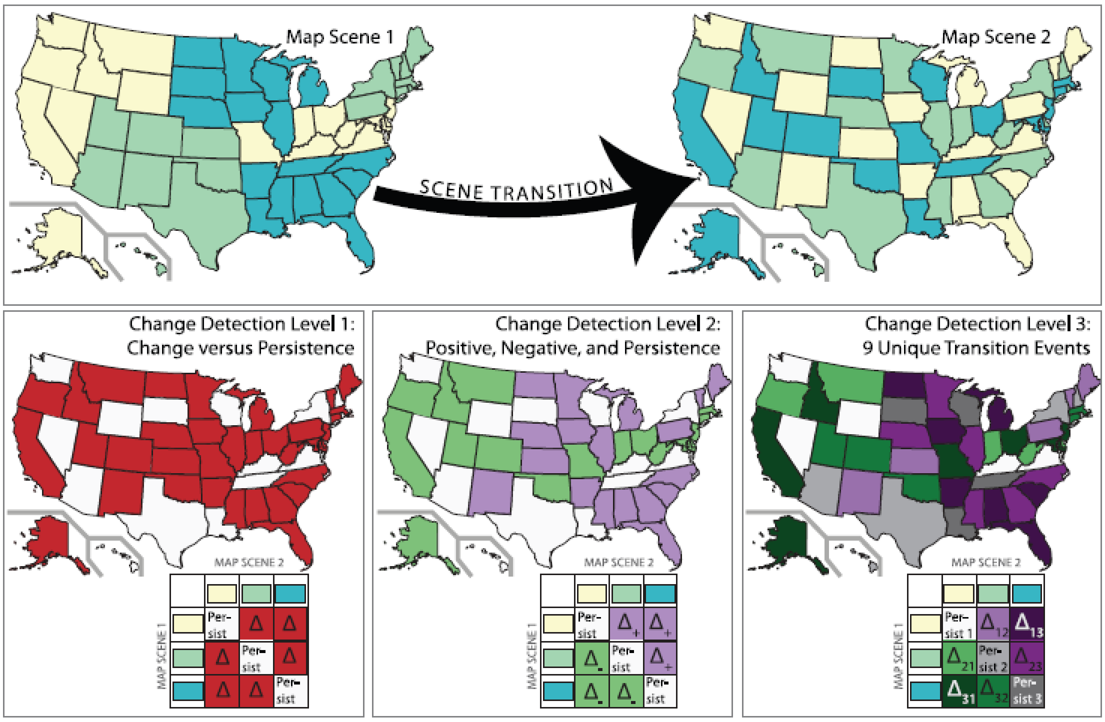

Figure 26: Levels of change detection in choropleth map animations: In a three-class animated sequence, map readers simply notice presence/ absence of simple changes (Level 1), while the full meaning of each enumeration's unit transition behavior (Level 3) may not be comprehended, since there are nine qualitatively (ordinal) different transition behaviors.
After Goldsberry and Buttersby, 2009.

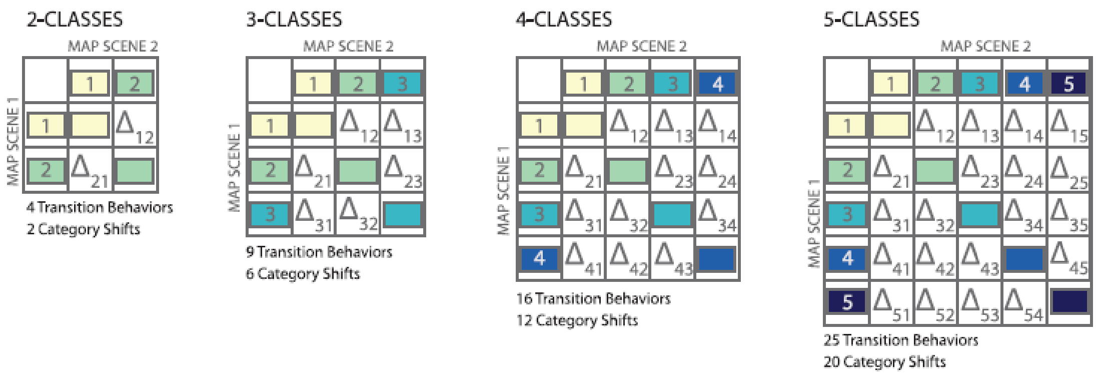

Figure 27: Classification and transition behaviors: The number of transition behaviors rises exponentially as the number of classes on each map frame increases.
After Goldsberry and Buttersby, 2009.

Given that animated maps are useful "for examining general trends and providing a 'sense of change' over time" (Slocum et al., 2004: 63) and not for emphasizing specific rates of change for specific locations, the experimentation of Harrower (2007b) focuses on the way map readers conceive and comprehend spatial patterns of change and not on their capability to retrieve the respective rates. The results from this research with reference to the comparison between classed and unclassed animated choropleths show that even though contribution of unclassed ones to the change perception of map readers is neutral (they neither help nor impair their perceptual ability), they posses two assets:

i) classed maps 'look busier' and appear 'more jumpy' (unclassed maps 'look smoother') and are perceived to be playing more quickly
ii) unclassed maps facilitate the visualization of subtle geographic transitions (e.g. seasonal unemployment cycles).

Consequently, the change depiction with more and more gradual color variations (in unclassed map), in contrast to the large, intense color shifts (in classed maps) may account for the first finding; the explanation for the second finding arises as a logical aftermath of the different thematic data organization, since the onset of the underlying evolution of the geographic pattern has been depicted synchronously in unclassed maps, whereas these changes are only portrayed with temporal lag in classed maps, if and only if the magnitude of change and the class range allow for a shift to occur.

Another option for map animation is to abandon enumeration units which are imbued with anthropogenic meaning (e.g. administrative divisions). Instead, these units can have a regular configuration. Rana and Dykes (2003) have promoted the visualization of dynamic raster surfaces, proposing five techniques for the optimization of animated sequence of raster images. Such sequences representing constantly altering surfaces (e.g. a temporal series of an evolving landform) can be useful "to gain insight from ordered raster spatial data" (Rana and Dykes, 2003: 126). The five techniques are: i) smoothing of 'small-scale' spatial and attribute variations, ii) exaggeration – augmentation of temporal continuity through (temporal) interpolation[26], iii) raster surface transformation (simplification) through the use of morphometric (topographic) feature networks to highlight the information content, iv) enhancement of the graphic representation – assisting the working memory for visualization to aid interpretation by the use of graphic lag or fading[27] and v) implementation of a proper design through appropriate controls for animated, sequential and conditional interactivity support for visualization (Fig. 28).

[26] Blending (warping and morphing) is used widely in the computer graphics field for transforming one particular shape or object into another (see Gomes et al., 1998).

[27] Symbol persistence and decay or graphic lag between successive events may assist the observer's own persistence of vision, that is the visual (working) memory and so enhance the interpretation of maps which convey visual information that varies over time (Shepherd, 1995; Ware, 2004).

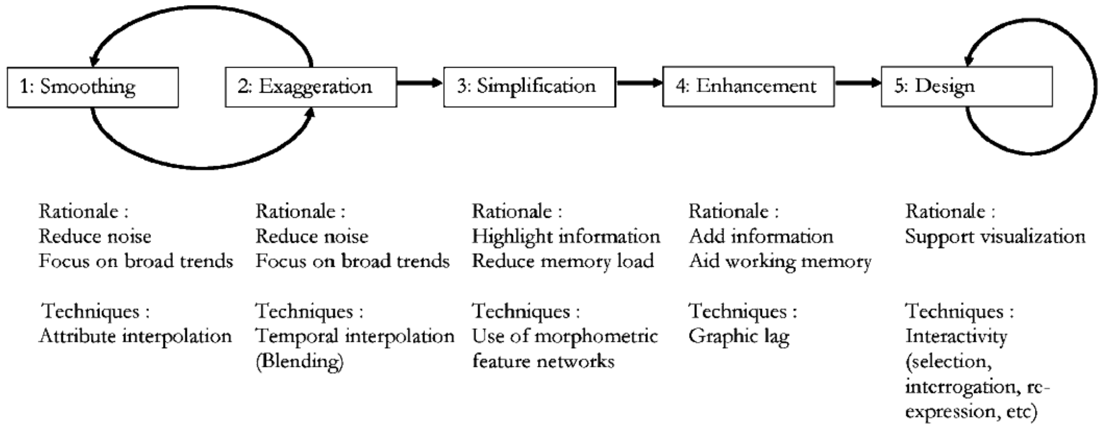

Figure 28: Implementation framework for the augmentation of dynamic raster surfaces visualization: This framework can operate as part of a continual iterative re-design process. After Rana and Dykes, 2003.

4.3.2.2. Animated maps as Exploratory Tools – Dynamic Visual Exploration

As it has been analyzed on previous sections, the (geo)visualization or explorative corner of the (Cartography)[3] differs significantly from its 'communication corner' (MacEachren, 1994a). In particular, cartographic exploration enables technological innovations and techniques "for revealing new, previously unknown information about spatio-temporal phenomena" (Adrienko et al., 2003: 505). Dynamic displaying, animated sequencing and interactive controlling are some of the distinct elements the cartographic exploration entails; moreover, the element of private examination is included – instead of public presentation. Besides, DiBiase et al. (1992) have connoted that explorative tasks (through animations) could be more beneficial to the expertises of a domain.

In fact, the whole map cube, and especially its explorative corner requires to be investigated with reference to its effectiveness upon different 'audiences'/ map-readers – in addition to its utility and potency for various scopes and applications. Although these issues have been acknowledged by several authors, they have not been comprehensively addressed and tackled. For instance, Harrower (2003) has proposed a series of tactics to reduce change blindness for animations facilitating communicative presentation, but it has not been rendered lucid either to what extent, or even whether they assist data exploration. Fabrikant and Goldsberry (2005) wonder whether novice viewers' attention is directed to thematic relevant information through perceptual salient elements (even in dynamic displays), while they are equally interested in comparing the viewing patterns of novices and those of experts of the domain. Goldsberry and Buttersby (2009) are aware that different tasks of change detection (in animated choropleth maps) from different map-readers may entail varying approaches of the way that variables, classification schemes and animation techniques should be implemented. From a more theoretic perspective, Harrower (2007a) points out the cautiousness in which the implications of Cognitive Load Theory should be treated with for animated maps in cases of different map-readers; he suggests that the notions emanating from this theory afford an initial background, yet it has to be empirically tested if and what kind of differences emerge between novices' and experts' interplay with animated maps. A more recent, empirical study – unfortunately not pertaining to dynamic maps – has given answers to the questions posed by Fabrikant and Goldsberry (2005). Within a two-phased experiment pertaining to the evaluation of wind direction in weather maps – with the first phase predicting eye-fixation patterns based on bottom-up, stimulus factors alone (bottom-up saliency model), and the second relying on the effect of top-down, cognitive factors by comparing the performance of map-readers with varying levels of domain knowledge – provided strong evidence that perceptual saliency does not affect the accuracy of the responses, but does affect the viewing behavior and the response time, especially for the naïve (novice) map-users (Fabrikant et al., 2010). Thence, it ensues that "the predictions of solely bottom-up-based models seem to be promising for cartographers" (Fabrikant et al., 2010: 15), meaning that perceptually salient design can mobilize to a significant degree the attention towards thematic relevant elements, irrespectively of the domain knowledge level. Even so, it remains unanswered if this is as well the case for animated maps, and especially for explorative ones.

Despite the inconvenience to give valid responses to these core matters, there are several salutary results that can be yielded through exploratory spatio-temporal visualization. In any case, the challenge of the effective and efficient detection and understanding of the underlying dynamic behavior of geospatial phenomena and processes is indeed huge for analysts (in geosciences) (Guo et al., 2005; Kraak and van de Vlag, 2007). And, since the representation of real-world geospatial phenomena and processes entail large and complex (multivariate and multi-temporal) data sets, acquiring knowledge out of the latter ones in the form of studying their trends, trajectories, space-time patterns and correlations require explorative alternatives (Kraak and van de Vlag, 2007). Therefore, a fundamental prerequisite is the registration and understanding of the available and suitable options of exploration with relation to the types of data and geospatial phenomena and processes under study. As an effect, spatio-temporal data exploration has been considered and evaluated by Adrienko et al. (2003) under two perspectives, and namely according to: i) the techniques and tools that are applicable to different types of data and, subsequently to types of change, and ii) the exploratory tasks that can potentially be buttressed with this exploration. Summarizing this research attempt:

- Table 4 presents the appropriate techniques according to the data under exploration;
- Figure 29 condenses the research from Bertin (1983), Koussoulakou and Kraak (1992), Peuquet (1994) and Blok (2000) into a cube that reveals the possible combinations of operational tasks in spatio-temporal exploratory visualization analogously to the *search level* ([28]), *search target* (when → where + what/

[28] There are four categories according to the search level:

where + what → when) and *cognitive operations* (i.e. comparison/ identification) (see Adrienko et al., 2003);

- Table 5 demonstrates the supporting techniques for the two cognitive operations for one out of the four specific cases (see Adrienko et al., 2003) which refers to the general (with respect to time) data analysis search level tasks (that is general "when" and elementary "what + where", and general "when" and general "what + where"), where search target is of "where + what → when" kind.

Table 4: Types of data/ change and suitable exploration techniques in geo-visualization. From Peuquet, 1994, Adrienko et al., 2003 and Kraak and van de Vlag, 2007: Modified.

Type of Data/ Data About: *Components*:	Techniques
'Universal'/ All Cases	querying (lookup and filtering), map animation and map iteration.
Existential Changes When?	time labels, representation of the age by color, aggregation of data about events and space–time cube
Location Changes Where?	trajectory lines, arrows, "tracing", time labels, space–time cube and different animation modes, i.e. snapshot in time, movement history and time window
Attribute Changes What?	change map, time-series graph and aggregation of attribute values

- "elementary "when" and elementary "what + where": describe characteristics of this object (location) at the given time moment;
- elementary "when" and general "what + where": describe the situation at the given time moment;
- general "when" and elementary "what + where": describe the dynamics of characteristics of this object (at this location) over time;
- general "when" and general "what + where": describe the evolution of the overall situation over time." (Adrienko et al., 2003: 510).

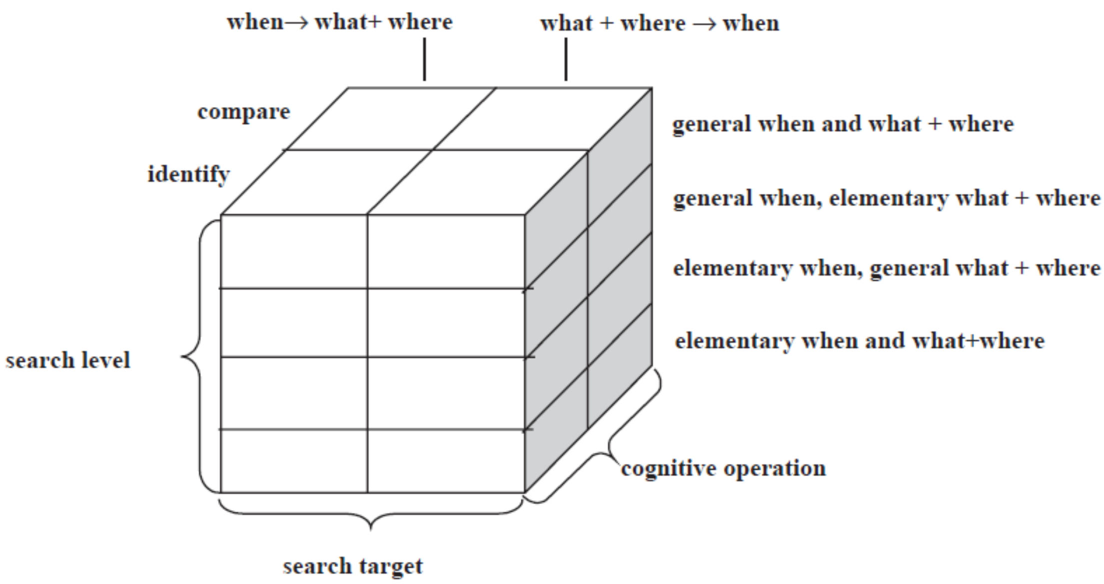

Figure 29: Operational task typology towards summarizing geo-visualization (exploration) techniques and tools for spatio-temporal data.
After Adrienko et al., 2003.

Table 5: Summary of the suitable techniques for general (with respect to time) data analysis tasks of the type "what+where →when".
After Adrienko et al., 2003.

Cognitive operation	Search Level (regarding space and objects)	
	Elementary	*General*
Identify	Map iteration Map animation (time stepping) *Events and moving objects*: space–time cube *Numeric attributes*: time-series graph cube	Map iteration Map animation (time stepping) *Numeric attributes*: change maps+time stepping; iteration of change maps *Events and numeric attributes*: data aggregation; provides only a summary for a set in whole
Compare	Map iteration *Events and moving objects*: space–time cube *Numeric attributes*: time-series graph	Map iteration *Numeric attributes*: iteration of change maps *Events and numeric attributes*: data aggregation; provides only a summary for a set in whole

After this meaningful and useful categorization and typology of explorative geo-visualization, there is growing concern to seek how it works in practice. In this vein, Blok (2005b: 72) contends that:

> *"visual exploration is a creative process to derive meaning and construct knowledge [...] from maps and images [and it] is centered around identification and comparison of patterns, their spatial and temporal characteristics, relationships and trends",*

while the dynamic (animating and interactive) geovisualization techniques may be potent tools to fulfil these tasks (Kraak and van de Vlag, 2007), even under the shadow of cognitive psychologists' warnings with relation the Apprehension Principle.

In practical terms, according to Blok (2005a; 2005b), the procedure of exploration begins without prior hypotheses about the data. In fact, it is this exploration of (a representation of) data that enables hypotheses regarding patterns, trends and relationships, and these hypotheses are subsequently assessed to decide if they are meaningful and congruent "into a coherent pattern of cognitive representations" (Blok, 2005b: 72). Furthermore, visual exploration pertains to manipulating, that is refining and restructuring of maps and geospatial elements created in a manner that learning and understanding of space-time patterns is prompted not only *from the creation*, but also *through creating* (Dorling and Openshaw, 1991; Openshaw et al., 1994). Therefore, exploration can act like a gradual knowledge facilitator that initially puts some order into the vastness of spatio-temporal data in order to provide a general perspective and instigate human cognition, while afterwards it can, by repeated 'runs', yield more refined dynamic outputs. This process has been viewed by MacEachren (1995) to entail iterative 'seeing that' and 'reasoning why' phases in which the derived patterns are imbued with meaning within a cycle.

No matter how visual exploration can indeed function as a bottom-up, data-driven process, not having established a hypothesis at all (i.e. not being 'cognitively predisposed') is not always the case. As the cyclic notion implies, there is no antecedent between the two phases. A dynamic display (animation, interactive small multiple displays etc.) certainly adds, from its first run a portion of understanding, but the conceptualization of the geospatial research problem/ perspective can have occurred in a prior stage. Besides, "because of how we are in fact constructed biologically and socially, we do not start inquiry utterly ignorant"; contrariwise, we tend "to favor certain behaviors and to organize our sensations in particular ways" (Glymour, 1999: 122).

Irrespectively of the extent at which an anterior hypothesis/ speculation can hold a stand-alone role of initial conceptualization, it is important to figure out in what ways the knowledge constructing is facilitated by spatio-temporal data exploration. Given that dynamic pictorial representations yield compact qualitative impressions and no predefined queries including analytical operations (i.e. computational algorithms) are requisite, then the (suitable?) external representation mitigates the memory/ cognitive load (Blok, 2005b). So, by depending on animation and interactivity and the provided capability of demonstrating ‘micro-steps’, a ‘simple’ examination of the evolving spatially structured information – e.g. how patterns appear or disappear, are dilated or are eroded, what are the principal directions and the relative speed or frequency of their change – can induce an effective understanding of the phenomenon/ process under study (Blok, 2005a). However, this ‘simply seeing’ at an explorative level refers to experts of a domain; thence, it is an (inter)active, intuitive and creative procedure which is theory-laden (even subliminally) – since domain adepts[29] attempt to explain patterns and their evolution/ interrelations imbuing them with meaning successively and, sometimes, up to a certain degree, cumulatively.

Spatio-temporal pattern geovisualization and exploration is founded on the ground of animation and interaction. As Harrower (2007a: 352) contends: “user control is one of the foundational tenets of geovisualization because it facilitates exploration”. Yet, whereas interactivity entails user-control (Dorling, 1992), animation typically implicates a pre-ordered sequence of scenes in which these controls are minimized. In § 4.2.6. interactivity has been exalted to a keystone in geovisualization, while in parallel Tversky and associate researchers in the late 90’s and the early 00’s have concluded that the supremacy of animated graphics over static ones lies in interactivity. In the geospatial realm, Koussoulakou and Kraak (1992) isolate the aspect of *control* in animation and argue that only due to it faster responses on animated maps emerge in comparison to static maps. In corroboration of the previous findings, Monmonier and Gluck (1994) remark that a single animation pace in perplex changing maps with no available controls is bewildering for the map-readers/ users – for some of them the map plays too quickly, for some others too slowly.

On the other hand, animations are designed to accomplish more than merely a ‘successive summation’ of their display pieces (i.e. small multiples) (Harrower and Fabrikant, 2008). As an effect, in the field of user control provision lurks the pitfall for the dynamic potential of an animation to be bypassed. This kind of detour and neglect is indicated by the research of Lowe (2004) in which the majority of the participants-users either have examined still frames by stopping the animation, or have investigated them one at a time (step-wisely) by successively stopping and playing the animation. As a consequence, he further infers that availability of user control to an animation does not always procure enhancement in learning (Lowe, 2004), and thence in knowledge/ insight gaining. Given that the empirical study with regard to animation interaction in geosciences is insufficient and with miscellaneous (if not contradictory) results (Blok, 2005a), the research direction of Harrower and Fabrikant (2008: 61) remains unaltered: “What kind of interactive controls are needed for dynamic map displays, and how these controls should be designed such that they are more efficiently used”?

[29] …in the ‘private realm’.

4.3.3. Practical Aspects for Effective Animations and Dynamic Geovisualization

After having delved into crucial theoretical matters about perception, cognition and animation, and discussed their implications on some kinds of animated maps with relevance to their usage/ map-readers, at this sub-section the pragmatic dimensions of effectual animated maps are distilled. So, the focus lies on the practical considerations and tips of how to make dynamic, animated maps that are both appropriate for their purpose and easy-to-conceive/ manipulate – in accordance with the underlying theory (principally CLT).

As Campbell and Egbert (1990) have claimed, several maps involving animations owe their existence merely to their attribute of "looking cool", while being insufficient both in conception and in execution. Because animation can inflict a grave burden upon the human WM, before being involved in the 'channel' of the creation or of creating a dynamic sequence, it is vital to wonder whether animation is capable of adding an indispensable 'something' that it would be for other means (i.e. for a static map) impossible to convey (Harrower, 2003).

It has been alleged that the potency of dynamic displays (maps) encompassing animations lies – in addition to their aptitude for interactivity – to their capacity to "convey more information" than the static ones (Tversky and Morrison, 2002). In other words, this 'superiority' of information on animated scenes which induces their improved effectiveness, relies on the enhanced potential to visualize 'micro-steps' between larger changes (Morrison et al., 2000; Blok, 2005a; Blok, 2005b). These small steps constitute intermediary scenes that can facilitate successful information and knowledge elicitation from animated maps (Slocum et al. 1990; Patton and Cammack, 1996). Nonetheless, this kind of learning cannot accrue from a disordered, fully interactive animated map, but rather from an ordered, pre-arranged succession of scenes. Thence, adhering to this strategy/ tactic called ***'sequencing'***, "the cartographer can increase the likelihood that the reader will notice important features or events in the animation" through displaying the spatio-temporal data or information display "in a logic and pre-defined sequence" (Harrower, 2003: 63-64).

A pre-determined animation is not technically difficult to be achieved – it includes several (spatio-temporal) data realizations strung together, the transitions between which have to be smoothened in some way; however, the fundamental theoretical issues that emerge pertain to the appropriate calibration of the frame sequencing (and towards the development of the proper interpolation method in some cases) (Ehlschlaeger et al., 1997), and thence the manner with which these transitions are implemented is essential. MacEachren and DiBiase (1991) have claimed that the smoothness of animation is the key to a gentle and cohesive transition between images/ frames, a requirement that can be (partially) assured through intermediate frames generation (these intervening frames constitute interpolations between original data realizations (Ehlschlaeger et al., 1997)). Techniques that can approximate such transitions are those involved in portraying graphical representation of change such as *fade*, *morph*, *"tween"*, *wipe* etc. between frames (Battersby and Goldsberry, 2010).

Yet, changes related to geographic phenomena or processes can be either smooth or abrupt (Graf and Gober 1992); as an effect, it would be rational to assume that different techniques could be useful to depict the differing transitions of (intrinsically) smoothly or abruptly changing phenomena or processes (Battersby and Goldsberry, 2010). Nonetheless, attaining congruence between transitions and the inherent spatio-temporal behaviour of phenomena/ processes or achieving statistical correspondence between the mapped phenomena and their external representations does not ensure the proper and accurate internal representation of these phenomena, even if (particularly complex) dynamic (animated) displays emulate in a realistic manner (particularly perplex) the evolution of the phenomena/ processes (Hegarty et al., 2003; Battersby and Goldsberry, 2010). Moreover, the map type or the spatial enumeration unit can induce significant alterations. For instance, unclassed animated maps – compared to classified animated maps – in addition to their capability to visualize more refined temporal changes, they appear to be less 'jumpy' (smoother) even when demonstrating abrupt transitions (see Harrower, 2007b).

Regardless of the level of congruence required, it has been proposed that ***gradual transitions (smoothing)*** are possibly of assist to map-readers since these smooth transitions render (spatial and/ or thematic information) changes more salient by cueing the map-readers to anticipate such changes (Lasseter, 1987; Fabrikant et al., 2008). Inversely, smoothing the transitions can lead to de-emphasizing of non-informative (i.e. non-relevant) changes (Rensink, 2002). Harrower (2003) views data smoothing as a means to mitigate complexity on an animated map so that it becomes highly generalized, allowing only the most prominent-significant features, trends or relationships to emerge. However, this generalization strategy can erroneously beget de-emphasizing of informative changes as well, especially when subtle but important modifications are hard to be detected in 'visually congested' background. Therefore, attention should be paid so as to find the 'happy medium' for creating animated maps; so, the latter ones should be simultaneously: not so abrupt as to conceal the general trend, and not so smooth as to miss slight or infrequent but significant changes. In practical terms, as been described in § 4.2.4., the smoothness of an animated map is controlled by the constituents of rate of change[30]; so, by either decreasing *magnitude of change* or increasing *duration* between adjacent key frames, an animation with more gradual transitions comes about. In any case, it should be noticed that within sequencing, smoothing is a method occurring amidst discrete steps:

> *"While it is possible to incorporate smooth transitions in any dynamic map, the overall appearance and implications of how a transition may be interpreted by a reader depend on the behavior of the visual*

[30] Rate of change is a dynamic variable.

> *variables in the static map key frames that bookend the transition."* (Battersby and Goldsberry, 2010: 19).

So, the interpretation of transmutations is facilitated by new, interpolated values delivering congruence and, thence, the uncertainty associated with these transitional values raises several questions about how map-readers recognize and asses these values (Battersby and Goldsberry, 2010). In any case, though, the dynamic variables' behaviour is not only contained to the display of changes between frames, but it can further expand towards prompting the human-map interaction (Fabrikant and Goldsberry, 2005).

As argued above, the effect of gradual transition in (pre-ordered) sequencing is of great importance. Along with sequencing, ***segmenting*** (or ***data filtering***) has been exhibited as a fruitful means to empower the effectiveness of animated maps (Slocum et al., 1990; Monmonier, 1992 – both cited in Harrower, 2007a). Harrower (2007a) has envisaged segmenting under the aegis of 'imposing more structure' in animated maps, including *intro screens* for reasons of ***pre-training***, with a principal aim to managing the cognitive load. While Mayer et al. (2002) have proven the benefits of pre-training, owing to the extraneous cognitive load diminution, Harrower (2003: 64) notices that the map-readers'/ users' confidence increases in cases where they "first learn what the map can do (the tool), [and] then apply that knowledge to learn about the map (the data)". Furthermore, since the amount of data/ information that can be incorporated in an animation is huge but only a fraction of the former can be derived from the latter because of the limitations of working memory (Sweller, 1988), it is particularly effective (i.e. implicating higher germane cognitive load) for animations to be segmented into parts rather than being played straight through (Mayer and Chandler, 2001; Hasler et al., 2007). So, animated maps rarely hold more than one minute (Harrower and Fabrikant, 2008) – while, before showing the data (playing the animated map), a short (less than half a minute) guided introduction should be provided (Harrower, 2003). Yet, animated maps owe their limited duration – besides the relevant practical importance – to their being temporal abstractions (Harrower and Fabrikant, 2008). This kind of abstraction is supported from a similar point of view by Harrower (2003) who claims that the generalization of animated maps towards exposing the significant trends lies in presenting only subsets of data (i.e. data filtering); such an approach has been championed by DiBiase et al. (1992) referring to the election of strategic data subsets in dynamic sequences (*data brushing*). As a consequence, segmenting a sequence serves two objectives: generalization of spatio-temporal changes and facilitation of human cognition. Nevertheless, for the effectual management of a multitude of sequenced segments, their interrelationship should be established and accompanied by introductory instructions.

Harrower's (2007a) approach to further enhance the structure of animated maps involves the ***management of split attention effect***. The latter has been defined as "any impairment in learning caused by students having to integrate disparate sources of information" (Mayer, 2002: 110). Towards obliterating this disparity, which is both semantic (different types of informative sources) and spatial (uneven spatial arrangements/ configuration of multimedia elements), Mayer (2001; 2002) proposes the proper spatial organization of related material (images, texts etc.) and their interrelations in semantically rich ways. Therefore, proximity and meaningful interconnections of the elements of animated maps are crucial guidelines for the effectiveness of animated maps. Since in animation in general it is shown that suitable instructional designs increase germane cognitive load while decreasing extraneous cognitive load (Kirschner, 2002), there is adequate evidence to hypothesize that proper design of both: i) static displays frames that comprise the sequence and ii) the animated sequence itself play analogous role in animated maps. Indeed, map and human-computer interface design is approached through CLT, aiming at mitigating extraneous cognitive load (Dromni et al., 2001; Mertens et al., 2006). In cartographic literature, split attention has been viewed as a major 'threat' in animated maps (Kraak et al., 1996; Peterson, 1999; Harrower and Sheesley, 2005). Kraak et al. (1996) provide a solution regarding legends in temporal maps: they propose an animated map design in which map and legend are visually integrated (combined) into a single graphic/ symbol whereas the temporal dimension is enabled through sonification (i.e. referring to sound) techniques. Similar approaches, where the dynamic variables' behaviour is not only limited to the display of changes between frames (Fabrikant and Goldsberry, 2005), have been adapted by Mitbo et al. (2007) who promote means to incorporate time visualization in the animation – though they point out the importance for the differentiation between the variable utilized to visualize time from the variable used to visualize the phenomenon/ process itself.

While Harrower (2003) identifies the likelihood that map-readers can elude significant information or cues as an animated map plays, he places this issue under the problematic case of disappearance; his remediation for this problem lies on either looping – i.e. watching the animation several times –, or/ and adjusting the rate of animation, including the potential to stop the animation and proceed at one frame at a time. The latter 'tips' clearly refer to interactivity, and to the options that one should be cautious about (see previous section). However, Harrower (2007a) conceives such alternatives as means to augment the *extent* and *types* of ***user control*** over the human-map interface. In essence, user control in animation and dynamic visualizations stimulates learners (map-users) to invest more mental effort into learning (map-reading) raising, thence, their germane cognitive load, since in such an engaging dynamic visualization interface, the users are prompted to interplay with dynamic visualizations instead of merely and passively watch a sequence (Bodemer et al., 2004; Ayers, 2005; Harrower, 2007a). As an effect, a great level of alertness and self-consciousness in learning or map-reading is potentially imposed on the users of this interactive geo-visualization.

On the other hand, the availability of unbound user control potentially diminishes the added value contained in animated sequences that are pre-determined, as has been demonstrated in the previous section by the experimentations of Lowe (2004); this can be truth since the micro-steps existing in meticulously designed animations are absent in (interactive) small multiple displays (Slocum et al., 2001; Jones et al., 2004), whereas the significant pattern trends and relations derived from a succession of strategically elected spatio-temporal data subsets (DiBiase et al. 1992; Harrower, 2003) cannot emerge in cases of watching an animation 'frame-by-frame'. Besides, several times, even the cognitive cost itself for infusing interactivity to animated maps may be prohibitive from the scope of dynamic map/ interface designing – especially when considering the designers' efforts to maintain a balance for the dual demands of map-users to concentrate their attention on interface and map simultaneously (Cockburn and McKenzie, 2002; Harrower and Sheesley, 2007; Harrower, 2007).

So, it could be alleged that in various cases the active engagement and the raise of germane cognitive load of map-users provided by augmented levels of interactivity could be nullified by the time consumed and the amount of mental activity required for a geo-visualization to be enriched with such (interactivity) levels. Since interactivity is a requisite mostly in the private, revealing unknowns, explorative corner of the map cube, this task appears to apply only to a limited extent to the communication/ presentation corner of the map cube. Therefore, given that the pertinent benefits are not diffused to the whole society (i.e. not to domain experts if not for presentation purposes), but only to a restricted scientific community, then this cognitive cost per user mounts significantly. (Yet, this is not always the case: interactivity has entered the domain of public use, even not for revealing unknowns). Even though the insight that could be potentially gained from a spatio-temporal process visualized with many and diverse user controls can be invaluable, it does not follows that the same controls and interactivity levels are effective for every case; as an effect, dynamic visualizations are not always replicable. Under this perspective, and between the extremes of full and complicated user control and utterly pre-defined sequenced animations, a series of alternative pre-arranged sequences – including varying (but not unbounded) levels of interactivity – could potentially be of use in order to integrate all the merits stemming from both sequencing and interacting, namely:

i) properly approximating the real-world process and rendering them in an effective way (sequencing – use of micro steps);
ii) directing attention and cognition towards essentially prominent trends and relations without missing subtle but significant variations (temporal generalization through strategically segmenting/ data filtering);
iii) providing potential for varying levels of active engagement with interconnected sequences (animated visualizations under different parameters).

Even in the case of data exploration which is a presumed bottom-up (pre-cognitive) approach, we contend that insight gaining of unknowns does not initialize from a *tabula rasa*, and so researchers creating their explorative maps either for their own needs, or for expertises of their scientific domain should cling to some kind of initial hypothesis/ hypotheses. In all, such an approach attempts to bridge the gap between experts and not experts in terms of an integrated design-interface, while still retaining the pertinent differentiation by providing varying levels of user controls according to the map-reader and the position in the map cube (map-use).

Lastly, another practical approach is to utilize *audio-enhanced animations* or the ***Modality Effect***. Sensory modalities in multimedia apply to both visual and auditory senses (Mayer, 2002). So, by adhering to the *Modality Effect*, multimedia learning "transfer from animation and narration than from animation and on-screen text" is improved (Mayer, 2002: 121). The 'engagement of both eyes and ears' has been present in the literature of geo-visualization since Krygier's (1994) seminal research work. This engagement has influenced the dynamic mapping especially through sonification, and more specifically through the use of sounds to provide time cueing. Regardless of its importance and effectiveness in cartography (see Fairbairn et al., 2001), its implementation aspects are not further discussed in this thesis for they do not appertain to its scope.

Table 6 summarizes the general abovementioned strategies/ tactics towards effective multimedia learning expanded to the effective dynamic mapping and geo-visualization[31]. Concluding, an overall empirical comment is cited: "as a rule of thumb, strive to have the time it takes to learn how to use the map be less time than it takes to play the map." (Harrower, 2003: 65); simply put, the animated visualization should be designed in such a manner that the map-reader/ user could gain the most of what this visualization is intended to afford with the least possible effort.

Table 6: Principles and Strategies for animated map design towards the reduction of (extraneous) cognitive load.
From Mayer and Moreno, 2003; Harrower, 2007a: Modified.

Type of Cognitive Overload Reduction	Principles for Animated Map Design	Strategy for Animated Map Design
Off-Loading When One Channel is Overloaded With Essential Processing Demands	When possible, offload work from the eyes to the ears.	Modality Effect Utilization
Segmenting and Pre-training When Both Channels are Overloaded With Essential Processing Demands in Working Memory	Segment content and provide pauses within the animation.	Segmenting-Data Filtering/ Provision of Proper User Controls
	Include pre-training (e.g., a narrated introduction) to familiarize viewers with important terms and ideas.	Pre-Training

[31] … through extraneous cognitive load reduction.

Weeding and Signalling When the System is Overloaded by Incidental Processing Demands Due to Extraneous Material	Weed out extraneous material that detracts from the animation (e.g., needlessly complex transitions).	Management of Split Attention Effect
	Signal to viewers what content is most important (e.g., by placing it highest in the visual hierarchy).	Sequencing-Smoothing
Aligning and Eliminating Redundancy When the System is Overloaded by Incidental Processing Demands Attributable to How the Essential Material is Presented	Eliminate redundancy (e.g., use text or narration, not both).	Proper Modality Effect Utilization
	Put related content as close together as possible spatially.	Management of Split Attention Effect: Careful Interface Design
Synchronizing and Individualizing When the System is Overloaded by the Need to Hold Information in Working Memory	Put related content as close together as possible temporally.	Careful Multimedia Design
	Individualize content for learners of differing abilities.	Imposing Varying Levels of User Control/ Interactivity

4.4. VIRTUAL ENVIRONMENTS AND THE ROLE OF ABSTRACTION IN EXPLORATORY LANDSCAPE/ TERRAIN VISUALIZATION

This chapter has been dedicated to the integration of time/ change in cartography and the potentiality of cartographic visualization for the portrayal of dynamic phenomena or processes. However, until now, the attention has not been explicitly directed to the ‘amount’ of (visual) realism or abstraction required, or to the ways that this amount could be involved in various cases of geo-visualization. In the following, the discussion is steered towards the exploratory visualization through fly-bys/ fly-overs taking into consideration the emergence of virtual environments (VE).

4.4.1. Visual Realism *vs.* Abstraction/ Generalization in Geo-Visualization

As it has been shown above, maps owe their very potency to their not being reality itself, but an abstraction of reality; thence, it is not realism that empowers them in a unique manner (Muehrcke, 1980; MacEachren, 1995). Yet, geo-visualization capabilities and requirements impose new considerations regarding the means of abstraction and the effectiveness of methods and techniques (animation, user-controls etc.) applied. As Monmonier (1996: 96) suggests: "The compression of time as well as space in dynamic cartography poses new problems requiring the recasting, if not rethinking, of the principles of map generalization".

On the other hand, some of the general trends in geo-visualization not only supersede static map forms, but also tend to exploit 3-d "immersive and highly interactive virtual environments to explore and present dynamic geospatial data" (MacEachren and Kraak, 2001: 3). But, since *virtual environments (VE)* invoke the sense of realism in a digital (computer-based) representation (Slocum et al., 2001) and "enable the user to interact with a representation of something familiar, namely a world with familiar objects that he/she can interact with" (Gracanin et al., 2005: 222), newer technologies referring to representation and interaction adopt the 'paradigm' of realism, in direct contrast to the paradigm of geo-visualization – for insight-gaining – which is deeply rooted in abstraction (MacEachren and Kraak, 2001). In a sense, this conflict echoes Tufte's and Shneiderman's notice about the widespread assumption that realism is more powerful than abstraction and that 3-d is better than 2-d – preference of '3-d for 3-d's shake' (Harrower and Sheesley, 2005).

But does the advent of new technologies promote and abet a paradigm that is to displace the existing paradigm in geo-visualization? Even more essentially, is this the proper question to be posed? Proper responses appertain to a shift from dogmatic views towards a critical approach.

"Because a process appears complicated [, there] is […] no reason to assume that it is the result of complicated rules" (Tobler, 1970: 234). Similarly, because a representation can faithfully approximate a (geographic) region, there is no reason to believe that it provides better understanding of the underlying complex spatio-temporal patterns and interrelations. Contrariwise, "a more generalized display may be more effective for interpretive purposes [(regarding spatial/ spatio-temporal data)] than a highly detailed and complex virtual world" (Fairbairn et al., 2001: 22). Empirical research corroborates such an approach (e.g. Vinson, 1999; Bowman et al., 2005) – some of them demonstrating the increased capabilities to apprehend landscape and to accurately locate and recall the relative positions of basic geographic features (mountains, lakes etc.) in standard topographic maps than in 3-d animated maps (Rice, 1999).

Harrower and Sheesley (2005) are aware and emphasize that much of the new technologies and techniques supporting VE and enabling *visual realism* (*VR*) may be merely novel, without really prompting understanding of spatio-temporal data. The basic barriers impeding effectiveness are: i) the immense information present, causing visual saturation to the viewer[32] and ii) the lack of spatial awareness/ orientation cues and the absence of visual hierarchy or symbolization (absence of perceptual saliency), inducing disorientation and uncertainty of where to attend

[32] In relation to visual saturation, Bishop (1994) has exposed the latent danger of the domination of aesthetic appeal and aspects over other, possibly more important variables owing to the use of visual realism (realistic visual stimulation') as a medium of communication.

or what to remember. Notwithstanding to these problematic issues, Harrower and Sheesley (2005; 2007) put forward some guidelines beyond this kind of VR novelty – towards creating more effective 3-d fly-over maps –, and propose several methods for decreasing the disorientation. The next section focus on these problems and solutions in 3-d fly-over animated maps.

4.4.2. Fly-Overs: Visual Realism's Effects and 2-d Abstracted Pre-Sequenced Animations in Geo-Visualization

"In a fly-by (fly-over), the user is given the feeling of flying over a 3-d surface" (Slocum et al., 2009: 391). These types of maps differ from VEs in that there is an animated sequence occurring from a predefined flight path around a 3-d scene that is to be passively watched by a user (Harrower and Sheesley, 2005). So, each scene/ frame of the animation is a 'capture' of static surfaces/ volumes from viewpoints that change positions in a gradual manner, and so the respective captures do – in this pre-sequenced animation. This lack of interactivity raises once again the issue of the optimal amount of user control. So although "personal exploration" in VEs may result into a richer mental representation (map) than in "guided exploration", the "cognitive cost" entailed is much higher with increasing the degrees of freedom in navigation (Elvins, 1997; Cockburn and McKenzie, 2002). Harrower and Sheesley (2005), adopting the pre-determined exploration that enables users to focus on the content of the map, have exposed the four basic caveats affecting the effectiveness of 3-d fly-over animated maps, pertaining to:

i) ***oblique perspective***: since the map scale is not consistent all over each scene, a significant difficulty arises with reference to the estimation of (relative) sizes and distances or directions;
ii) ***information overload***: lack of perceptual salient features/ visual hierarchy due to fixation on realism and abandonment of abstraction;
iii) ***visual occlusion***: since the perspective is oblique, the low viewing angles in combination with a rugged relief cause portions of the surface/ scene to be obscured;
iv) ***user disorientation***: the 'immersive' character of VE dramatically affects the orientation (what is my location/ direction?) and not the navigation of the users, given that the path/ route is predefined.

Their solutions have entailed: grid superimposition to the scene (i), various kinds of cartographic abstraction (generalization) enhancing mental structuring of the landscape, and labels/ landmarks (ii), flight path circles, transition from an static planimetric view – overview – to a 3-d oblique view and combination/ link of 2-d and 3-d views ('overview windows/ maps' or 'detail + context') (iii), and path tracing (behind the present location: *jet contrail*, both behind and ahead the present location: *spotlight path*), *floating compasses* or *directional tick marks* and *heads-up-display (HUD) texts* (e.g. airspeed) employing the sense of augmented reality of a pilot's field of view (iv). The solutions to the fourth problem – disorientation – encompass solutions to other problems as well, namely: gridded background, virtual labels/ landmarks and overview windows/ maps; in Figure 30, five of these orientation aids are harnessed.

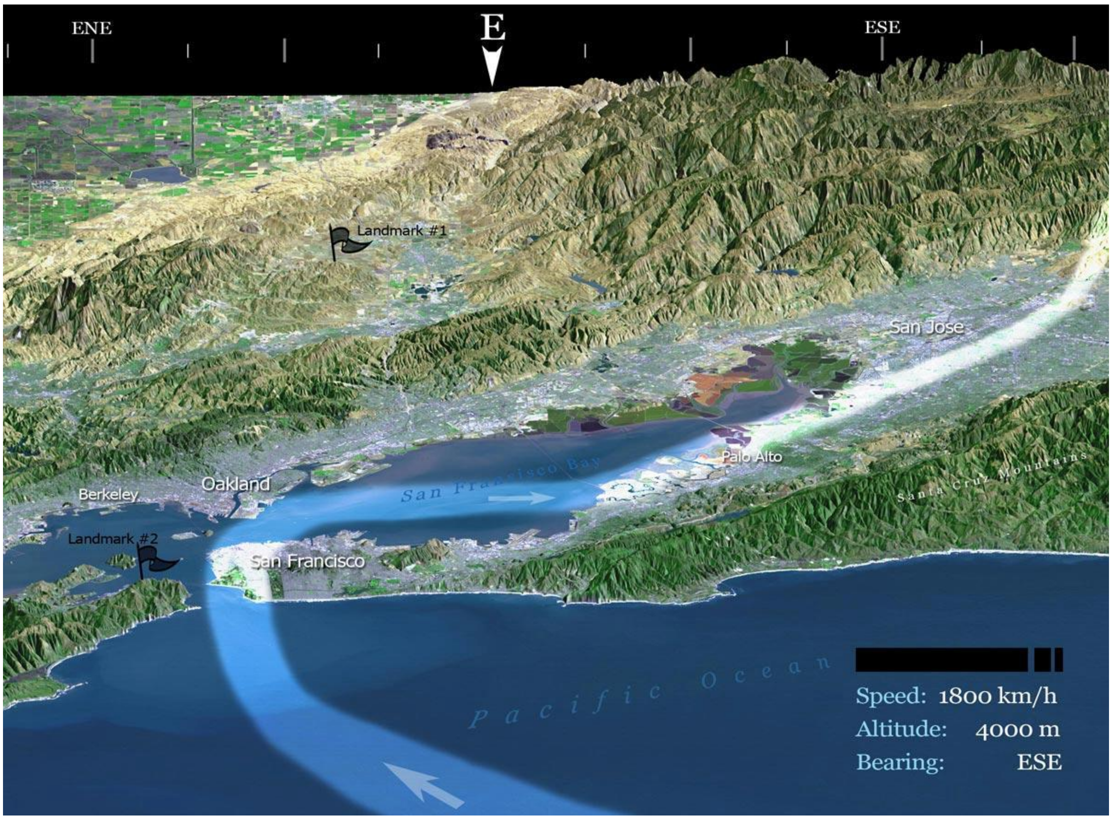

Figure 30: Five cases of orientation aids designed to augment either immediate spatial awareness (e.g., what direction am I facing?) or overall survey knowledge of the landscape (e.g., where was landmark A relatively to B?): 1) spotlight path, 2) embedded virtual landmarks, 3) compass tick marks on the horizon, 4) map labels of orientation (e.g. Oakland), 5) heads-up display text (e.g., altitude).
After Harrower and Sheesley, 2005.

In a more recent research, Harrower and Sheesley (2007) propose four kinds of visual 'orientation cues' to reduce viewer disorientation in 3-d fly-over animated terrain maps. These cues, and namely the presence of: landscape grid, monorail, horizon compass and landmark labels have been tested experimentally (Fig. 31): The first and second cues have reduced at half the directional error, the third one (floating compass) practically has eliminated this error, while the ability to trace the flight-path has been enhanced, though to a lesser degree; in contrast, the presence of landmark labels has been proven to be ineffective in the subjects' performance improvement in relation to these tasks.

From all the previous, it has been inferred that 3-d fly-overs involve a great deal of weakness when there is nothing done to enhance their level of abstraction and generalization or to lift their visual occlusion/ immersion barriers. The imposition of visual hierarchy and the entailment of other means of symbolization – thus increasing the levels of abstraction/ generalization – can associate thematic attributes of a visualization with salient features of each scene (see Fabrikant and Goldsberry, 2005; § 4.3.1.). On the other hand, tackling the problem of visual occlusion with linked 3-d oblique and 2-d planimetric perspectives is equally important. Fuhrmann and MacEachren (2001) and Fuhrmann (2003) have suggested that navigation and way-finding difficulties (or orientation difficulties in a guided exploration) in the 3-d 'egocentric' perspective ('first-person perspective') can be overcome by extending or adding the 'exocentric' 2-d frame of reference ('locator map') (Fig. 32). In fact by creating a live-link between them, the partial view of the 3-d egocentric perspective is further contextualized with the prompt of a locator map by showing its (relative) position within a complete view of the area of interest (Fuhrmann, 2003).

Additionally, the linked 3-d and 2-d perspectives can equally efficiently serve – aside from remediating the visual occlusion problem – at ameliorating navigation and orientation performance (Fukatsu, 1998; Hornbaek et al., 2002; Fuhrmann, 2003). After all, it is now empirically shown that it is the combination of 3-d/ 2-d view displays that enhance orientation and relative position tasks (Tory et al., 2004 – cited in Harrower and Sheesley, 2005). Yet, the attempt to integrate these two different displays – disparate sources of information – simultaneously in such animated maps will eventually raise the split attention effect/ problem (see Mayer, 2002; Harrower, 2003; § 4.3.3). So, means to mitigate the extraneous cognitive load stemming from the disparity of these two displays lies at 'inventing' a proper map/ human-computer interface design (see Dromni et al., 2001; Mertens et al., 2006; § 4.3.3). Harrower and Sheesley (2007) demonstrate how the problem of split attention can be managed by directly embedding all the orientation cues into the scenes/ frames of the animated maps, imitating HUD technology (see Fig. 31).

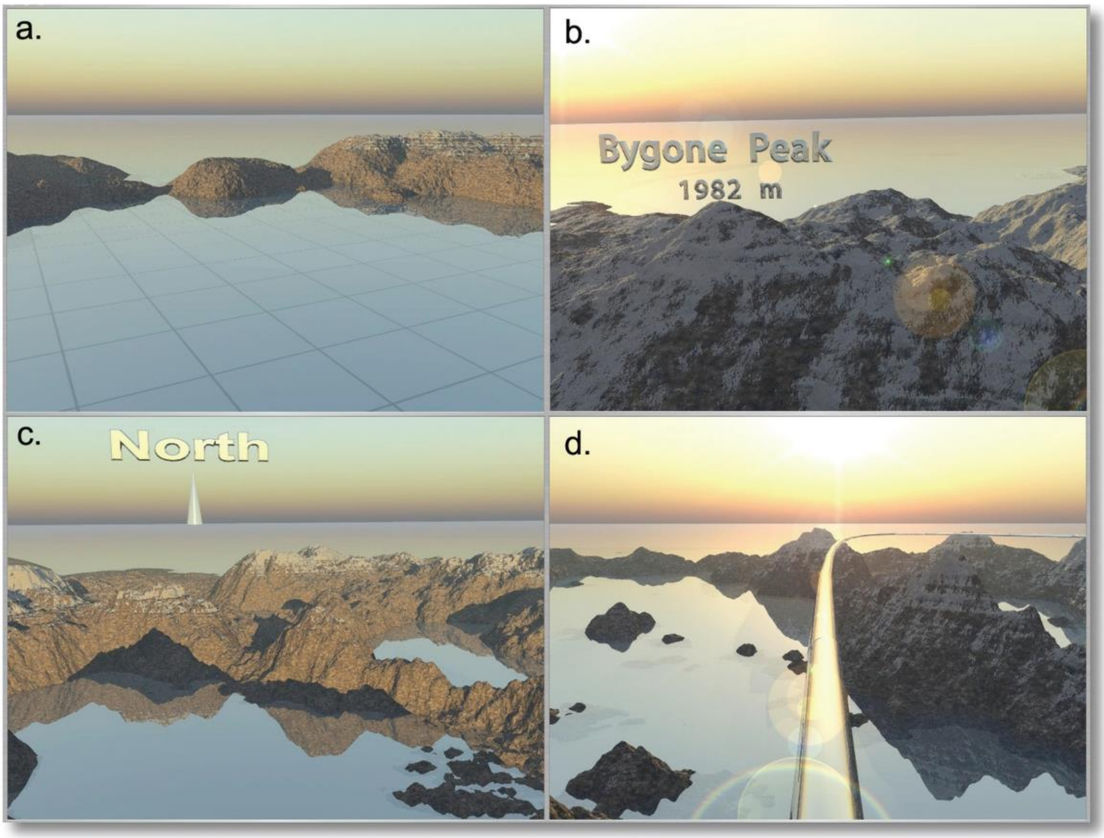

Figure 31: The four tested orientation cues: landscape grid (a), virtual landmarks/ labels (b), horizon compass mark (c), and monorail (d). The problem of split attention is minimized by directly superimposing these cues into the main scene (unlike multiple-window displays) similar to heads-up display (HUD) systems in military aircrafts.
After Harrower and Sheesley, 2007.

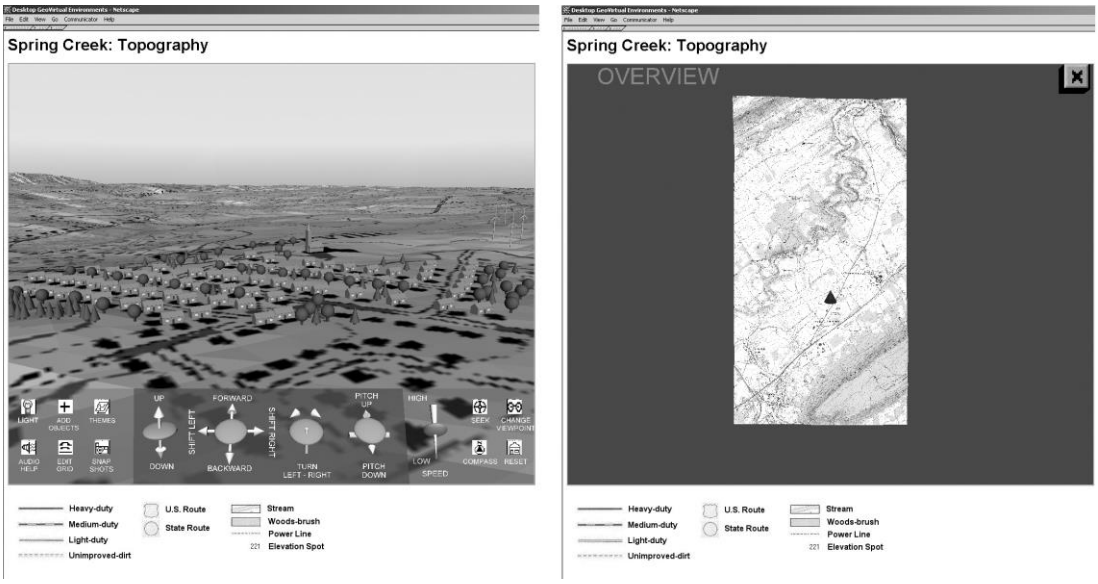

Figure 32: Example of combining 3-d egocentric with linked 2-d exocentric perspectives leading to the enhancement of user navigation and orientation.
After Fuhrmann, 2003.

4.4.3. The Potential of Dynamic Viewshed Mapping in Landscape Exploration

If the real purpose of fly-bys in the domain of cartographic visualization is to portray the landscape's abstract form in a manner that one could observe it while flying or moving over a (flight)path, trail or route, then maybe the 3-d display should be rendered to derogate from its 'sway' and accredit it no other but a secondary role. Even though the orientation aids and cues greatly facilitate users in their respective performance, these cues cannot entail or surmount the powerful effect of the symbolic abstraction (visual hierarchy etc.), whereas the combination of 3-d/ 2-d displays involve the difficulty of how to link them without raising the extraneous cognitive load – inducing the split attention problem.

Yet, an insinuation for an effective visualization has been given by Harrower and Sheesley (2005); in their venture to further mitigate the problem of visual occlusion and user disorientation through linked overview window/ maps, have suggested "to 'paint' on the 2-d map all of the terrain currently visible in the 3-d map (i.e., viewshed analysis in GIS)", an implication which is vital, in our opinion, for a dynamic generalized view of the landscape. To elucidate, the presence of such an overview could be much more than a locator map capable of significantly assist in the 3-d egocentric perspective. Since it (a viewshed overview) reveals the visible portions of a landscape through a planimetric view, it could be, in essence, accounted an abstracted landscape conceptualization in itself; and if this exocentric view is to reveal these visible portions from a predefined route/ path by consecutively computing them from a series of properly selected points of observation, it could constitute a generalized reference map that can at the same fulfil much of the task of landscape visual exploration: in fact, since there is no immersion, visual occlusion or oblique perspective, there will be no need for the orientation cues mentioned above.

In a sense, such an approach evokes the landscape's visual analysis and assessment through the manipulation of (dynamic) viewsheds or visualscapes (see Chapter 3). Despite the copiousness of multimedia tools such as renderings, photomontages, videos, sound/ audio enabling media, or quick time VR that enrich the potentiality of geographical data visualization in tasks such as visual impact assessment (Dransch, 2000), the fact is that other, less attractive and suggestive means of representing reality are to attain the visual evaluation (whether a region is visible or not and/ or from which part of the study area, etc.) in a more objective (or exocentric) analysis based on viewshed computation (Danese et al., 2011). In a similar vein, MacEachren (1994b) has forwarded the usability of the viewpoint change as an extension of GIS analytic operations to asses such visual impacts in a dynamic manner.

Yet, as Bishop (1994) asserts, the degree of VR for spatial change understanding depends on the audience (map users/ readers), with the non-scientific audience ('general' public) preferring abstraction minimized and information content maximized. So, even VR associated with changes in viewpoint or objects can stimulate public understanding beyond aesthetic criteria, the extension of geo-visualization towards its explorative ends implicate processes of creative thinking (Bishop (1994) requiring, thus, more abstracted and connotative means and media that are appropriate to involve the fundamental underlying spatio-temporal patterns and interrelations.

To an extent, we claim that for a venture to handle large geo-spatial data and to depict complex spatio-temporal information that may be otherwise difficult to analyze and provide insight of unknown processes to a scientific community, there is no need to include a considerable degree of realism – one could even avoid 3-d animation altogether. Instead, visual exploration of landscape could emerge as an 'abstracted fly-over', the scenes of which are derived from 2-d viewsheds – and not from 3-d views –, while one or more alternative animations are implemented on pre-ordered routes not randomly, but meaningfully selected.

This venture delves into a multitude of aspects, the overwhelming majority of which is examined in the following chapters and sections. But, since exploration is to occur on the landscape, one of these aspects – a practical one – is considered here. This issue relates to the vital requirement of how to render landscape's terrain along with its visibility (viewshed) in an intuitive manner. To this end, Buckley et al. (2004) and Mitasova (2012) have stated that an elevation model on which several land surface parameters – including viewsheds (see § 5.2.2.) – are overlaid or draped as color maps can be of great use to increase the information content, while conveying the relationship between the surface geometry and surface parameters. Since hillshading or relief shading pertains to a very realistic approximation of the topographic variation of rugged relief areas providing a 2-d planimetric view of the relief at a uniform scale (Buckley et al., 2004; Smith and Clark, 2005), it can be inferred that the optimal case is to overlay viewsheds with an amount of transparency over the DTM's derivative of relief shading/ hillshading – as in Fig. 11).

Thence, the viewshed-hillshading nexus entails a potentially congruent combination to generate the scenes required for this 2-d animated fly-over. Although this conceptualization may be important, several critical matters with regard to representation, geomorphology/ geomorphometry and implementation remain unsolved. The following chapters are dealing with these matters.

5. DYNAMIC VISUAL LANDSCAPE REPRESENTATION AND VISUALIZATION USING DIGITAL TERRAIN ANALYTICAL PROPERTIES

[“But note that information about a world that surrounds a point of observation implies information about the point of observation that is surrounded by a world.”]

James Gibson

[“If there are many, they must be just as many as they are and neither more nor less than that. But if they are as many as they are, they would be limited. If there are many, things that are are unlimited. For there are always others between the things that are, and again others between those, and so the things that are are unlimited.”]

(attributed to) Zeno of Elea

If geovisualization is actually endowed with the potential to transform and rejuvenate modern cartography – as previously mentioned – then all of the discrete situations of the map-use cube and mostly its explorative one should be meticulously approached and linked with suitable representation models. In the previous chapter, designative (dynamic variables), functional (animation classification) and cognitive aspects of cartographic visualization were examined focusing on the ‘time/ change-integrative’ and interactive ends of the mapping continuum, towards enhanced landscape perception/ apprehension and navigation through viewshed utilization. Yet, viewsheds are extracted from the underlying topographic surface (terrain) of a landscape – in fact, viewshed is one of the terrain derivatives –, so their approximation is to be attained in geomorphological terms as well. So, a venture to comprehensively characterize a landscape according to its visual structure and properties is to be approached with various empirical studies and from differing standpoints. In essence, what is required at this stage is to provide a new conceptualization for the notion and cartographic effect of viewshed (i.e. vista) as it ‘transits’ along a route (path), with relation to proper spatial representation schemes and understanding of issues related to geomorphology and terrain analysis.

5.1. GEOGRAPHIC REALITY APPROXIMATION WITH ALTERNATIVE REPRESENTATIONS

5.1.1. Representation Issues

For every geographic object, entity, phenomenon, or process which is to be visualized, a representational scheme is required. MacEachren et al. (1994) has made a four-folded distinction for visualization techniques, including (as one of the four dimensions) the degree of congruence between spatial data and the respective representation in a GIS; this dimension involves the means of manipulating (restructuring and combining) data/ information in order to provide a representational model that is most proper for the spatial information (knowledge) which is intended/ expected to be visualized. In a sense, "the manner in which data are represented is inextricably linked with specific analytic tasks" (Peuquet, 1994: 446), and, since geovisualization is much more than simple presentation of geographic information, representational issues arise to be fundamental to the cartographic visualization domain.

The two major representation perspectives that have prevailed in conceptualizing and modelling geographic reality are: i) the object perspective and ii) the field perspective (Couclelis, 1992; Peuquet, 1994; Worboys, 1995; Cova and Goodchild, 2002). These two representation models imply differing "world views" (Peuquet, 1994), or opposing 'object' and 'field' views of geographic space (Couclelis, 1992). According to Longley et al. (2005: 71, 72) "the discrete object view represents the geographic world as objects with well-defined boundaries in otherwise empty space", while "the continuous field view represents the real world as a finite number of variables, each one defined at every possible position". This opposition can be inferred to the ontological domain – atomic and plenum ontologies opposition in the philosophy of physics (Couclelis, 1992) –, and, as the latter remains unsettled, so does the former: the field and object *conceptual perspectives* should not be regarded as opposites (mutually exclusive) (Couclelis, 1992; Worboys, 1995), "but rather as complementary and interrelated representations that are particularly suited to answering location-based and object-based queries, respectively" (Peuquet, 1994: 447).

It occurs, thence, that a single perspective is too rigid to represent diverse geographic reality – especially for varying geovisualization tasks. First, the nature of the geographic data/ information itself steers the proper model election; in essence, the kinds of boundaries – Smith and Mark (1998), Smith and Varzi (2000) and Varzi (2001) provide the distinction between *fiat* and *bona-fide* boundaries – are crucial in defining geographic objects/ phenomena. In general, the readily perceived, discrete objects with crisp boundaries (land parcels, bridges, rivers) are represented by points, lines, and polygons, while objects/ phenomena with ill-defined boundaries (that vary in a continuous mode across space and are more suited to techniques in fuzzy modeling) are optimally represented by spatial tessellations (regular, irregular, or hybrid) (Cova and Goodchild, 2002). Second, the (analytical) operations[33], or, in a more generic means, the map-use of

[33] Common object-based analysis operations: spatial querying, overlay analysis, distance calculation, buffer generation, point pattern analysis, network analysis, spatial similarity analysis, shape analysis etc. (Longley et al. 1999). Common field-based operations: classification,

cartographic visualization 'shape' the optimal representational models; the shift towards spatio-temporal data manipulation with an aim to revealing unknown spatial patterns with a high degree of interactivity can also determine these models. However, except for effective attempts at integrating these two perspectives and at inventing methods resulting in mutual transformations between them, a crucial matter pertains to whether these and only these perspectives of geographical world can exist (Goodchild et al., 2007).

The act of moving away from a static world and from equally unchanging spatial distributions may give rise to new forms of representations, especially when both the two prevailing views (geo-objects, geo-fields) and their fundamental properties are vital to a proper visualization process. Considering the basic objective of this thesis – which is to create a dynamic cartographic visualization of the viewshed(s) for a track – it is rather apparent that it cannot be attained by means of a static, interactive-free map display. What is more, since this track can be approximated by a multitude of points, i.e. by a moving point of view/ observer, a particular kind of *interaction* begins to appear among the spatial patterns (viewsheds) directly assocciated with this dynamic point of view; as Goodchild et al. (2007: 251) point out: "The processes that modify such distributions [,…,] must often be understood in terms of interactions". Therefore, it is not only appropriate, but as well necessary that a representational model emerge to support so crucial an interaction. Worboys (1995) has implied that for several phenomena, field and object models are required simultaneously at some level, while Goodchild (2004) criticizes the obsession on static *forms* in GIScience and the little prompt from GIS technology towards dynamism, when digital representations of *processes* can add important insight of the evolution of social and physical landscapes.

Predicated on dynamism and interactivity, a general approach (more than just a representational model) is required in which two general concerns should be addressed:

i. The track – a polyline from the object conceptual perspective[34] – should be connected to viewsheds – a distribution befalling to the field conceptual perspective; given that a route is a linear object and that viewsheds are computed from one (or more) points of view, the route should be broken down to points-constituents of this route, further linked to the respective viewshed. At this stage, the necessity of a proper representational model arises emphatically.
ii. The approximation, though, of this polyline and of the connected viewsheds (through a model) could only be realized by an extremely large (infinite?) number of points, rendering, thus, such an approximation neither attainable,

interpolation, convolution, spatial overlay, statistical analysis, map algebra, terrain analysis etc. (Cova and Goodchild, 2002).

[34] Linear entities/ objects (with multiple vertices) the data structure of which corresponds to the vector format are called polylines.

nor practical: therefore, the selection of only a finite (as few as reasonably possible) points-viewsheds under certain criteria could provide a viable solution to this problem.

The requirements of (i) relate to the development of a representational scheme; more specifically, a model in which objects and fields are simultaneously interlinked and manipulated is needed. Cova and Goodchild (2002) have extended the dichotomic object and field conceptual perspectives to include *fields of spatial objects*, introducing the perspective of *object fields* (*OFs*) (Fig. 33). The latter comprise mapping locations from geographic (field) space not to values but to entire geographic objects (Cova and Goodchild, 2002; Goodchild et al., 2007; Liu et al., 2008); in essence, OFs relate "locations in a field-space to objects in an object-space", while they encompass qualities of both fields and object perspectives (Cova and Goodchild, 2002: 512). Given that the object types used to enable this association can be points, lines (polylines), areas (polygons) or other complicated spatial types (networks, graphs), cases where this modelling of reality gains utilitarian value may be: a network-based field, in which every location along a network is linked with a contiguous areal object or terrain exploration occurring from its observation from various locations etc. The second case is particularly relevant to our scope; in a practical manner, it is interpreted as follows: "If a viewshed is identified for every location in an elevation field and associated with the location, this would yield an areal object-field, as each location would be associated with an areal object (not necessarily singly bounded)" (Cova and Goodchild, 2002: 512). Nevertheless, the ubiquitous problem of approximating the continuous geographic space by discrete objects (or even fields) emerges here, a problem related to the second concern which is to be addressed further below.

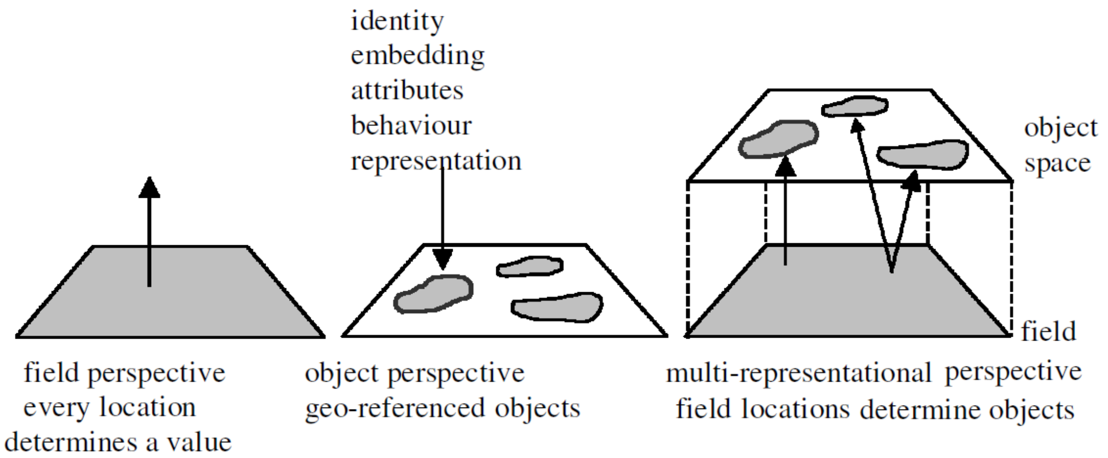

Figure 33: The field, object and multi-representational (OF) perspectives. After Cova and Goodchild, 2002.

At this point, it is essential to distinguish between the three basic stages in constructing an OF (Goodchild, 2002). The first and the second stages refer to the clear definition and representation of i) the underlying field and ii) the related objects. Questions that arise with reference to the field representation are the qualities of the fields such as: extent, unit of discretization and detail (resolution), while questions for object representation are: the object's properties-embeddings and (transitional) behaviours. The third stage is dedicated to establishing the proper relation between the location of the underlying field and the objects. This association may typically refer to the number of points corresponding to each field location (Fig. 34), yet for promoting the appropriate association it is crucial that the fundamental meaning (purpose) of the objects be conceived and assigned to them through their properties (Fig. 35). The latter means that for each application the object's proper conceptualization leads to the relation that fits this application.

OFs are meant to facilitate the integration of properties existing in the geographic field to instances of geographic object class (g). This mapping procedure can be defined as: f: x→g (Liu et al., 2008). In pragmatic terms, OFs can prompt several cases (see Fig. 35). To our scope, the case of viewshed is the desired one. Cova and Goodchild (2002) have examined the prospect where an analyst/ user is to explore the terrain according to viewsheds and their identification from various locations in the elevation field (DTM). However, an exhaustive exploration of the terrain, i.e. a viewshed identified for every location yielding areal-object fields would be not possible since there are infinite locations in the field, yet a discrete representation, i.e. a finite number of geographic objects entailing the associated elevation/ viewshed fields adopting some strategies for minimization of theses locations (objects) could enable this type of field (Cova and Goodchild, 2002; O'Sullivan and Turner 2001).

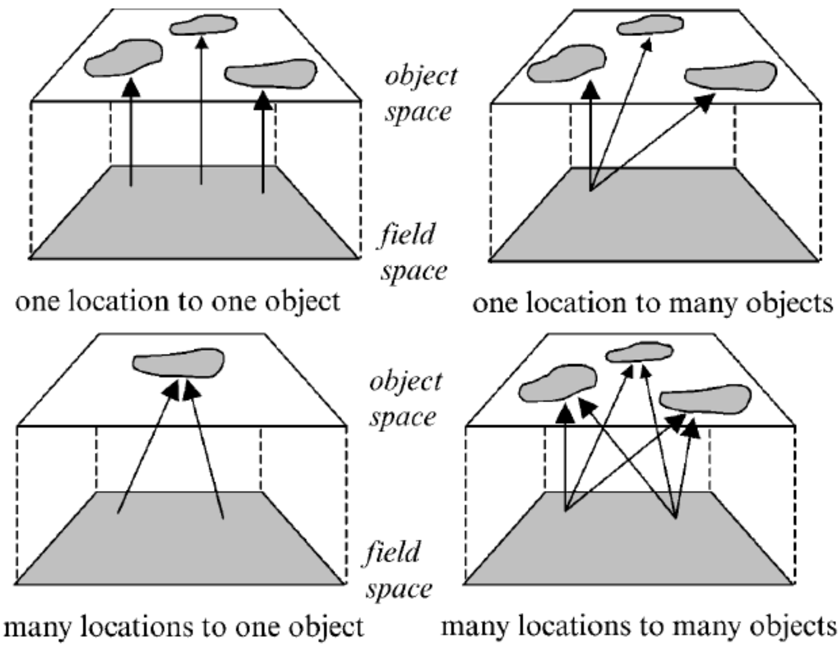

Figure 34: Typical relationships between fields and objects.
After Cova and Goodchild, 2002.

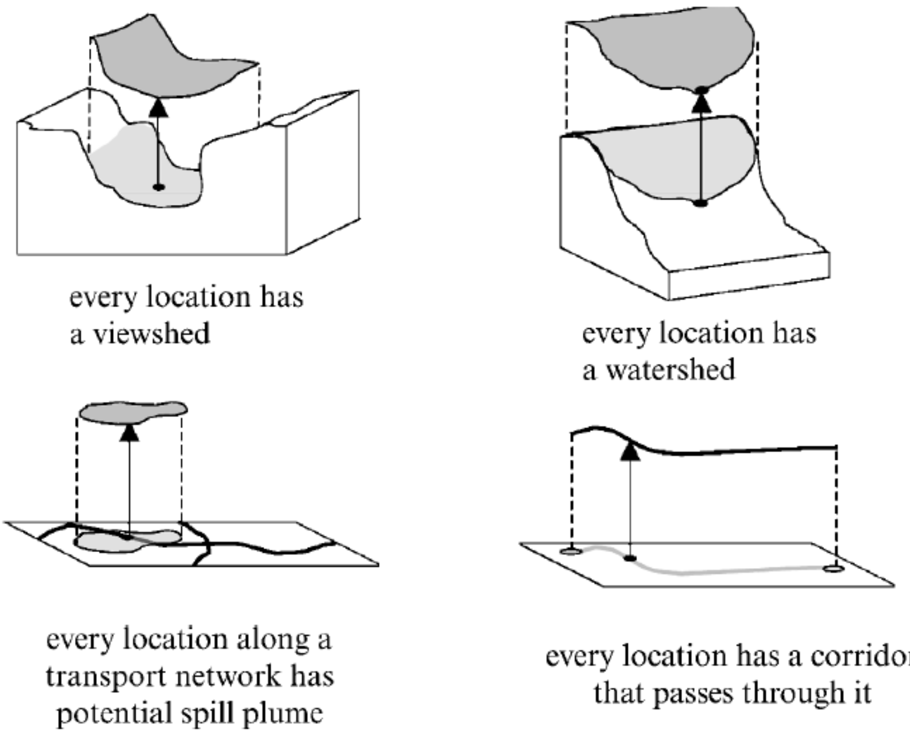

Figure 35: Object-Field types.
After Cova and Goodchild, 2002.

So, the requirements of the second general concern (ii) are as well are exposed in the abovementioned. The OFs are suitable models to condense information about locations in fields (visible regions – aggregation of cells) from discrete locations (objects). Nevertheless, the keystone issues towards apprehending and portraying the visual configuration character of landscapes are the appropriate means (strategies, methods, techniques) to harness the pertinent objects and their contained information. These issues are discussed in § 5.3. and § 5.4.

5.1.2. From Rigid towards Dynamic and Interactive Representations: Landscapes' Forms and Processes

Geographic reality involves a plethora of elements, objects, events, phenomena and processes. Yet, the way in which geographic reality is carved pertains to vagueness (Kavouras and Kokla, 2008); and, regardless whether vagueness is not inherent in the "mind-independent world"[35] (Russell, 1923), it appears certain, at least, that *what* we intend to extract/ derive out of this reality is crucial to our generic approaches of conceptualizations. Since geographic world is 'analogue' ('infinitely separable'), but computer systems are digital (discretized), the associated means of *how* to represent it should pose an abstraction in the vastness

[35] This is about ontic vagueness which is distinguished from ontological vagueness. In fact, the former pertains to the questions like the one posed by Williams (2008: 763): "Might it be that world itself, independently of what we know about it or how we represent it, is metaphysically indeterminate"?

of the information/ relations captured (Longley et al., 2005). In this context, the object fields are to approximate another conceptualization of this reality. From a particular perspective, their generation (including both objects and field-location pairs) occur as i) *analytical functions*, ii) *process-based simulations*, or iii) *exact/ heuristics optimization solutions* (Cova and Goodchild, 2002), depending on the specific problem they are designed to tackle.

Besides, Goodchild et al. (2007) contend that our knowledge about the complexity of geographic world does not postulate equally perplex sets of rules within computer systems so as to represent this world. Such an approach echoes the assertion of Tobler (1970: 234): "Because a process appears complicated is also no reason to assume that it is the result of complicated rules". What is more, it has been rendered clear that the complexity of geographic world applies mostly to phenomena, and, more generally to processes. So, processes (and phenomena) entail enormous amounts of interactions across an overwhelming range of scales, explaining why treating with geographic processes is so challenging a task (Harrower, 2001).

Therefore, there is a requirement for interactive representational models that shift away from the conventional static paradigms, being capable of addressing "situations in which not only the non-spatial attributes, but also the location and form of the objects, change in reaction to the process being modelled" (Wilson and Burrough, 1999: 738). In essence, these models owe their success of producing coherent (series of) patterns to simple computations of multiple local interactions at varying aggregation scales (Burrough, 1998). Yet, it is the proper graphical representation of these interactions making it such a critical endeavour (Harrower, 2001). Towards this direction, the "process of research and discovery" for the model refinement promotion and the communication of complicated geographic phenomena and processes are facilitated through dynamic maps and visualization methods (Wilson and Burrough, 1999).

In other words, dynamic and animated cartography under the aegis of geovisualization can contribute either to the visual exploration, or to the presentation of phenomena (such as estuary formation, drainage network development) or less explicit processes (like erosion progression and landscape character evolution) befalling to landscape morphology simulation. In such landscape investigations, DTMs are widely utilized (Moore et al. 1991 – cited in Florinsky, 1998) in the more generic shape of the underlying geo-fields. In the realm of landscape ecology (less abstracted cases), the composition and spatial configuration of a landscape significantly determine the ensuing ecological processes (Wiens, 1995), while the landscape's morphological expressions occur as responses to such processes (Wilson and Burrough, 1999). More generally, the internal structure and composition of a landscape, that is form (or spatial patterns) interacts with the manifestations of various ecological (natural) functions, that is process (Wilson and Burrough, 1999; Turner et al., 2001b), or as Turner et al. (2001: 2) eloquently has put it: "the causes and consequences of spatial heterogeneity across a range of scales", including the dynamics of such heterogeneity (Risser et al., 1984).

In more abstracted cases, elevation variance (and its derivatives) alone constitute the sole source of spatial heterogeneity, represented by a geo-field. But, along with abstraction which may be highly required to conceptualize and model several situations by segregating and retaining the most fundamental attributes of a field (e.g. the terrain elevation in landscape), a means to infuse dynamism and interactivity is equally important towards real-world processes approximation. The latter is stressed out by Wilson and Burrough (1999: 738):

> *"Most current GIS cannot deal with this aspect of the real world because, once digitized, the basic units are as inflexible as if they were cast in stone. The interactions between an "object," its nonspatial attributes, its location, its neighborhood, and those forces operating on it at a distance may be very important for determining how it may change with time or respond to driving forces."*

In such a manner, a more flexible and interactive perspective is promoted, integrating the spatial and temporal scales of these interactions (Figure 36). Moreover, since these (local-global) interactions refer to objects types, while occurring at the field level, they could be deemed as operating through the representation of OFs within a different context – that of time or change. A situation, thence, that is to harness the viewshed occurrence from a multitude of locations can be approached by a *process-based simulation* which relies on the analytical computation of intervisibility, requesting to optimize some of its spatial/ non-spatial attributes – or just to explore what is dynamically visible. The utilization of animation and interaction in Cartographic Visualization can be of significant assistance towards this end. Thus, problems referring to both representation and geovisualization – and their respective solutions – appear inseparable.

A step further towards the visualization of the changing geospatial patterns of the landscape in the abstracted form of its underlying terrain (topographic surface) would be the proper manipulation of alternative, varying portrayals of its visual properties and configuration. Before demonstrating how viewsheds can be utilized to give prominence to the visual structure of a landscape with relation to a specific map purpose, and how the dynamic dimension can be ingrained, there is need to examine landscape – and, so, terrain – from a geomorphological perspective. So, the following section is dedicated to an overall overview of geomorphological issues of terrain modeling, scale, sampling, interpolation, terrain derivatives/ parameters categorization, concentrating on viewsheds.

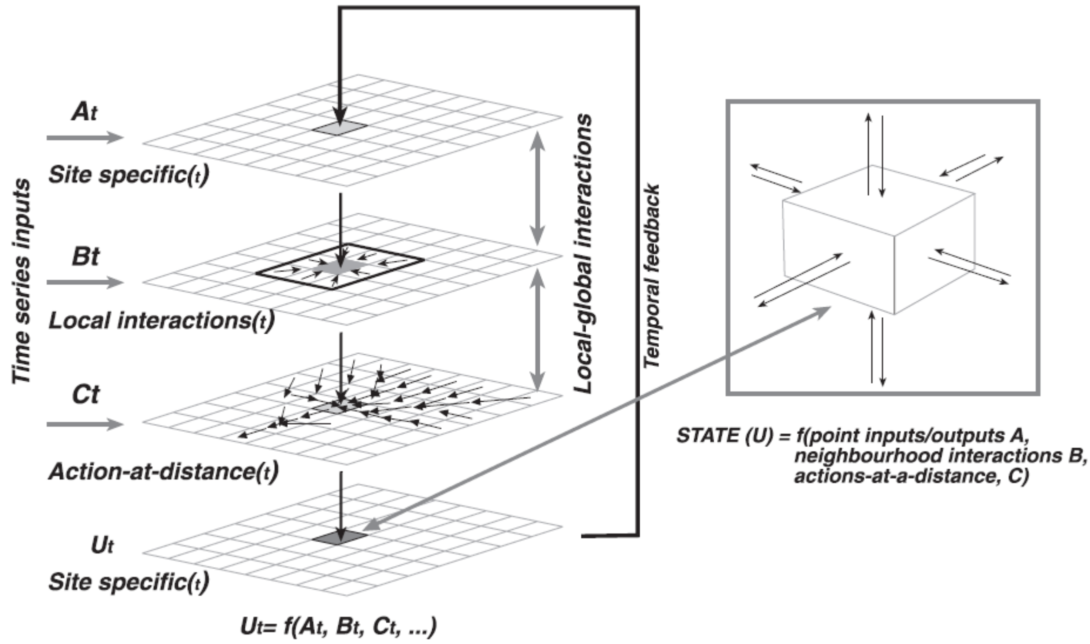

Figure 36: Schematic diagram depicting site-specific, local, and regional interactions as a function of time.
After Wilson and Burrough, 1999.

5.2. GEOMORPHOLOGY AND DIGITAL TERRAIN MODELLING

5.2.1. General Considerations

5.2.1.1. The role of DTMs in Geomorphology and Geomorphometry

In the second Chapter, the mutual visibility principle and the intervisibility notion on real, natural conditions have been reduced to the abstracted and discretized realm of computer systems in the shape of terrain (inter)visibility and viewshed analysis. So, the pertinent algorithms have been developed and implemented in alignment with the digital counterparts of the real surface topography, thus, by manipulating DTMs. However, if we are to achieve a comprehension closer to the natural phenomenon of viewshed (in real conditions) and to approach its representation and visualization in dynamic contexts, then we should regard it within a class of issues associated to the study of the earth's surface formation and classification.

Land's surface (terrain) acts as a major regulator of atmospheric, geomorphic, hydrologic, and ecological processes (Wilson, 2012). *Geomorphology* (from the three Greek words 'γη', 'μορφή', 'λόγος') is a discipline been defined as "the genetic study of topographic forms" (McGee, 1888: 547) destined "to study and interpret landforms and especially the causes that create and modify them" (Panizza, 1996: 1). So, the topographic terrain is sculpted responding to (*endogenetic* and *exogenetic*) forces and processes (see Panizza, 1996; Huggett, 2011). And, the association between both the driving forces and process on the one hand, and the emerging land forms on the other is so close, that our exploring of the distinctive character of the land surface can directly enable our understanding of these processes (Hutchinson and Gallant, 2000).

The efforts towards modulating the aforementioned processes of physical geographic reality[36], along with the representation and modelling of the latter are prerequisites in several tasks and applications – so that DEMs or DTMs[37] serve as mediators in the analysis, interpretation and visualization of the terrain attributes (Fig. 37). Furthermore, modelling of the terrain digitally (i.e. *digital terrain modelling*) is a situation involved in a multitude of tasks, operations and scientific domains in the realm of geosciences (Fig. 38; Table 7). In this sense, geomorphologic knowledge acquisition stems from the land surface analysis based on digital terrain modelling which is a multifarious field.

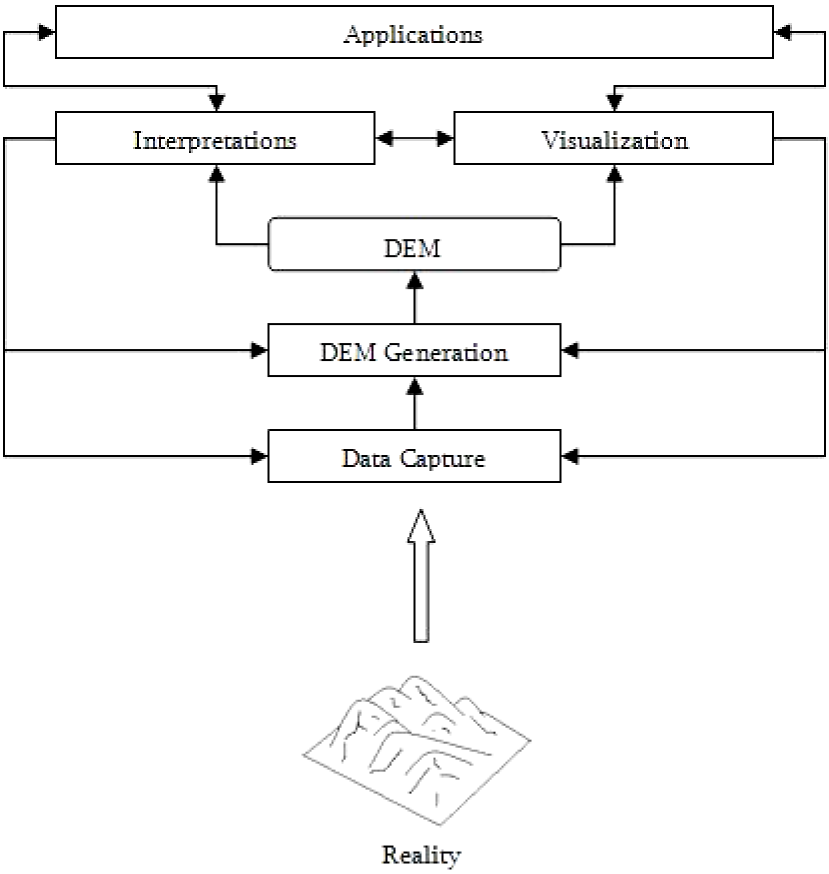

Figure 37: DEM as a link between geographic (topographic) reality and applications: The main tasks associated with digital terrain modelling.
From Hutchinson and Gallant, 2000.

[36] Here, we refer to studies that approximate real world at the *geo-scale*, i.e. a scale in which "real world refers to a world studied by the geosciences" – geography, geology, geo(infor)matics, and geophysics (Li et al., 2005: 192).

[37] The term DTM is more generic in meaning than DGM (Digital Ground Model), DHM (Digital Height Model) or DEM (Digital Elevation Model), tending to incorporate specific terrain features such as rivers, ridge lines, break lines, etc. (Li, 1990).

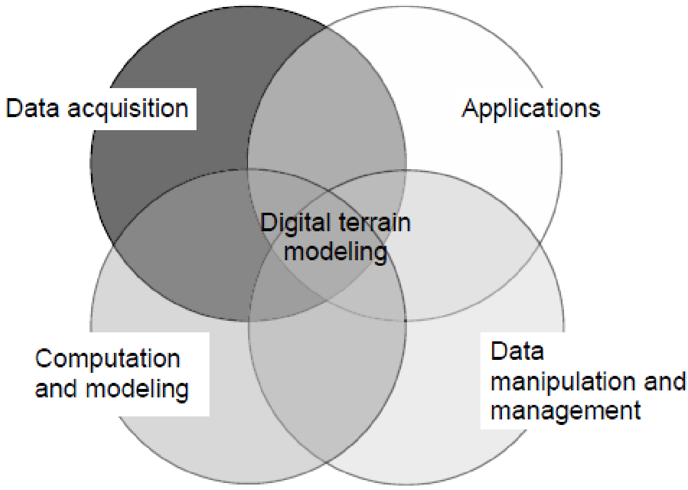

Figure 38: Relationships between digital terrain modelling and other tasks. After Li et al., 2005.

Table 7: Relationships between tasks and disciplines in digital terrain modeling. From Li et al., 2005.

Task	Disciplines/ Scientific Domains
Data Acquisition	photogrammetry, surveying (including GPS surveying), remote sensing, cartography (mainly contour maps digitization)
Computation and Modelling	photogrammetry, surveying, cartography, geography, computational geometry, computer graphics, image processing
Data Management and Manipulation	spatial database technique, data coding and compression techniques, data structuring, computer graphics
Diverse Applications	surveying, photogrammetry, cartography, remote sensing, geography, geomorphology, civil engineering, mining engineering, geological engineering, landscape design, urban planning, environmental management, resources management, facility management etc.

More specifically, this analysis is enabled through *geomorphometry* which quantitatively analyses the Earth's (land) surface by deriving measures (land surface parameters) and spatial features (land surface objects) from DTMs (MacMillan and Shary, 2009; Wilson, 2012). DTMs are models designed to store elevation values, and thence, to digitally represent and portray the distribution of elevations throughout a region. Yet, geomorphometric analysis does not really cling to elevations but rather to the way surface parameters and objects (drainage basins, viewsheds, landforms) are estimated through digital terrain modelling (and the assessment of these estimations in comparison to the respective measurements in the field) (Wilson, 2012). From this standpoint, Reuter et al. (2009) have posed some critical questions pertaining both to the accuracy of surface roughness and hydrological shape presentation and real ridge/ stream detection, and to the consistency of the elevation measurement (over a study area), for a DTM to be applicable for a geomorphometric analysis. These questions are linked with Florinsky's (1998) factors for proper geomorphometric applications (land-surface parameters and object extraction). MacMillan and Shary (2009) stress out the horizontal and vertical resolution of the elevation data, which along with sapling issues, the overall geomorphologic character (i.e. the land surface roughness) and the more general issue of the geomorphometric analysis type are to impose significant influence on the detailed and accurate object portrayal and parameter value assignment (derived from a DTM) (Florinsky, 1998; MacMillan and Shary, 2009)

5.2.1.2. Scale and Resolution

Scale is a core matter in geography (Harvey, 1969; Woodcock and Strahler, 1987). Issues related to scale and resolution are ever-present in analyses related to geosciences because “scale is a fundamental and inescapable dimension of geographic data” (Goodchild and Quattrochi, 1997: 396) and because geoscientists and especially geographers deal with spatial phenomena and spatiotemporal process across various scales (‘geo-scales’). Scale is, in particular, an essential trait in correspondence to which geographic data are depicted, providing “a unique perception of spatial attributes as they relate to form, process, and dimension” (Lam and Quattrochi, 1992: 88). But, it is also a confusing an ambiguous word and concept with different meanings across different disciplines and different contexts (Goodchild and Quattrochi, 1997; Zhilin, 2008). So, it can imply the cartographic ratio (ratio of distance), the degree of abstraction, the degree of detail, and the magnitude of the area of interest (Zhilin, 2008). The latter two are, according to Goodchild and Quattrochi (1997), the *small* and *large linear dimensions*, with the first being defined as the *limiting spatial resolution* (i.e. the size of the smallest discernible object – the cell size or pixel) and the second as the *geographic extent* of the study (i.e. the area over which a project is conducted or data is collected). Another aspect of scale refers to the continuous length increase with increasing accuracy of length, noted by Steinhaus (1960) – generally known as the ‘Steinhaus Paradox’ and being related to fractals. Goodchild and Mark (1987: 266) present this paradox: “as scale increases, more and more detailed irregularity will become apparent, raising the question of whether any finite limit exists for length”.

Phenomena and spatial processes are scale-specific, so their interpretation may differ as the scale of spatial data change (Harvey, 1969; Stone, 1972). As a result, the inference of spatial processes from their ‘underlying’ or ‘reflecting’[38] (equally scale-specific) spatial patterns may be a bewildering endeavour, for different processes may lead to the same spatial pattern[39] (Harvey, 1969; Turner et al., 1989; Lam and Quattrochi, 1992). Furthermore the attempt of solely analyzing independently spatial patterns entails ambiguity. In this sense, while a spatial

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[38] Patterns and processes are interdependent and are dynamically formed, so there are not really pre-structured, underlying patterns determining processes.

[39] We refer to the pertinent “well-known dilemma”.

pattern may appear at one scale clustered, at another it may be characterized random (Lam and Quattrochi, 1992).

Abiding by the definitions of small and large dimensions of scale, and adopting a digital terrain modelling/ analysis approach, both the resolution of the DTM and its extent should be regarded when analyzing the distributions over the lattice. While the cell size variation may modify the characterization of the occurring spatial pattern, the geographic extent expansion/ shrinking can induce a dramatic alteration of the respective pattern (simply because a process operates somewhere and not somewhere else). Another reason why they are to be considered as a pair pertains to their usability for practical reasons; indeed, the ratio of large to small dimension determines data volumes, and the respective storage and (most importantly) processing capacities (Goodchild and Quattrochi, 1997). Therefore, the processing requirements are lowered either by decreasing the area of interest (maintaining the same resolution), or by increasing the cell size of the DTM (maintaining the same geographic extent). Since the study area size is rather generally dependent on the specific phenomenon/ process coming about at a specific region, no generic objective instructions could be suggested for the geographic extent, and so the election of the latter should be approached *ad hoc*. Therefore, the issue of scale is directed to a research of the spatial resolution with reference to the digital terrain modeling as follows.

The selection of the optimal scale is mostly an empirical matter, and it is also dependent on the nature of the raw data (Harrower, 2001). Nevertheless, for cases related to land surface (terrain) analysis, the "concept of land surface starts at the human scale: 1,5 m" (Evans, 2012: 95-96). Several studies with regard to slope and gradient advocate that the measured lengths should not be lesser than 1,5 m and greater than 20 m (Gerrard and Robinson, 1971; Young, 1972). In general, finer-scale variations (lesser than 1,5 m) are treated as micro-relief, whereas the upper limit has not been explicitly established (Evans, 2012). As it will be described below, there are several terrain derivatives and types of surface parameters that are not equally susceptible to scale (i.e. grid resolution) variations. Moreover, in cases where these resolutions vary significantly, the spatio-temporal pattern behaviors are to be drastically altered (see Harrower, 2001). At this point, it should be noticed, though, that grid resolution is not the most appropriate approximation of scale because when sub-sampling a DTM (elevation grid) at a coarser scale, not only the finer scale objects/ features are removed, but the number of cells (samples) are changing (dwindling), further complicating the analysis (Gallant and Hutchinson, 1996).

Notwithstanding their (Gallant's and Hutchinson's) suggestions, the literature on digital terrain modelling and analysis teems with cases where grid resolution is the tangible counterpart of scale (i.e. changes in scale are mostly approximated by changes in DTM grid resolution/ cell size). In a similar vein, another notion related to the scale election is that of multi-scale representation. This notion has been considered and utilized in several digital terrain modelling conceptualizations and applications. As Zhilin et al. (2008) claim, for multiple representations, two main parameters that need to be considered are the cartographic ratio and the degree of detail (resolution) (Fig. 39). This notion is not further analyzed for it will not be explicitly addressed in this thesis.

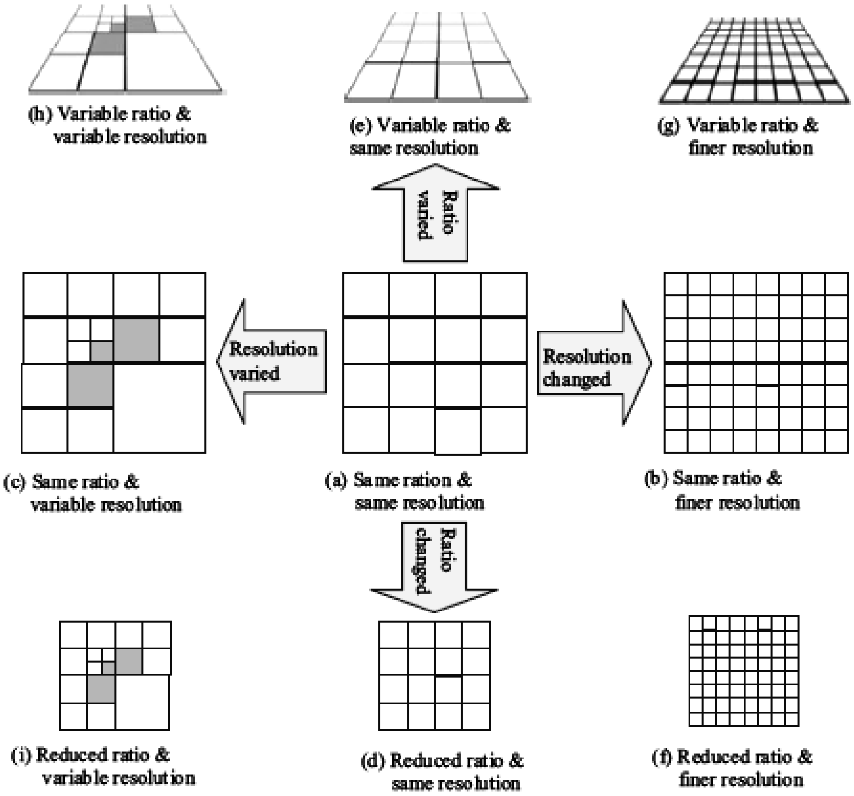


Figure 39: Types of representation depending on nine possible types of scale changes. After Zihlin, 2008.

5.2.1.3. Data (Capture) Advancements

Provided that the aim of this research is not to generate a DTM, but rather to analyze, visualize and interpret its land surface features and (mainly) parameters, no rigorous inquiry is to be carried out regarding the specific attributes and techniques for a proper DTM to occur. However, the task of DTM generation incorporates, among others, the sampling of the terrain surface – by capturing elevation measurements (Hengl and Evans, 2009). While the sampling procedure is described in the next section for reasons other than simple DTM generation – serving some other aims of this thesis –, given that elevation data (capture) characteristics greatly affect all the tasks pertaining to digital terrain modeling, a succinct overview of the data capture recent advancements in is required.

Beyond topographic maps and the derivation of DTMs by digitally manipulating contours or other elevation/ hydrologic features of the former (e.g. GIS routines like ANUDEM/ Topo to Raster: see Hutchinson, 1988; 1989; Hutchinson and Dowling, 1991; Hutchinson, 1993; ESRI, 2010) – with medium horizontal and vertical accuracy –, or ground survey – which is expensive and time consuming, usually referring to small areas –, contemporary mapping technologies have facilitated the capability for landform analysis at unprecedented scales, i.e. very fine levels of detail and large geographic extents. Technologies such as the Interferometric Synthetic Aperture Radar (InSAR/ IFSAR) and Airborne Light Detection and Ranging (LiDAR/ LIDAR) have strikingly increased the level of detail captured in DTMs (Mitasova et al., 2012), while their geographic extent of elevation data collection has been greatly expanded. A comprehensive overview of several modern DTM data sources is provided by Wilson (2012), while a tabular representation of the key characteristics of these sources is presented by Nelson et al. (2009) (Table 8).

Table 8: Key characteristics of (elevation) data sources: synoptic presentation. From Nelson et al., 2009: Modified.

Source	Resolution (m)	Accuracy	Footprint (km^2)	Post-processing requirements	Elevation /surface
Ground survey	Variable but usually < 5	Very high vertical and horizontal	Variable, but usually small	Low	Elevation
GPS	Variable but usually < 5	Medium vertical and horizontal	Variable, but usually small	Low	Elevation
Table digitizing	Depends on map scale and contour interval	Medium vertical and horizontal	Depends on map footprint	Medium	Elevation
On-screen digitizing	Depends on map scale and contour interval	Medium vertical and horizontal	Depends on map footprint	Medium	Elevation
Scanned topo-map	Depends on map scale and contour interval	Medium vertical and horizontal	Depends on map footprint	High	Elevation
Ortho-photography	<1	Very high vertical and horizontal	–	High	Surface
InSAR/IfSAR	2,5-5	1–2 m vertical, 2.5–10 m horizontal	Depends on method of acquisition	High	Surface
SRTM, Band C	90 (30)	16 m vertical, 20 m horizontal	Almost global, 60° N to 58° S	Potentially High	Surface
SRTM, Band X	30	16 m vertical, 6 m horizontal	Similar to B and C, but only every second path is available	Potentially High	Surface
ASTER	30	7–50 m vertical, 7–50 m horizontal	3600	Medium	Surface
SPOT	30	10 m vertical, 15 m horizontal	72,000 per swath	Medium	Surface

LiDAR	1-3	0.15–1 m vertical, 1 m horizontal	30–50/ h	High	Surface

LiDAR or laser scanning technology refers to an airborne active sensor (active remote sensing system) emitting near-infrared laser pulses at a high rate (10.000 – 100.000/ second) and recording their reflection from the vegetation canopy, or through it, resulting in the acquisition of a 3-d 'point-cloud' from vegetation and terrain over areas, the extent of which depends on the flight of the aircraft (Reutebuch et al., 2005) (Fig. 40). The most typical LiDAR terrain mapping system consists of several hardware components (a laser emitter-receiver scanning unit, differential GPSs, a sensitive IMU[40], and a computer to control the system and store data), entailing discrete-return pulses for relatively small footprints (typical laser beam diameter at ground level: 0.2–1.0 m) (Reutebuch et al., 2005). Generally, this multiple return (pulses) technology offers the unique opportunity to study the multiplicity of terrain at its various forms: from bare Earth/ ground (underlying topography) to anthropogenic structures, understory plant cover and vegetation canopy (Mitasova et al., 2012). In fact, the 'first pulse return' pertains to elevation points of vegetation canopy or building roofs, whereas the 'last pulse return' pertains to bare Earth (Fig. 41).

3-d point cloud data is now available to the public for several regions. The Open Topography portal which is supported by the National Science Foundation (NSF) is an example providing browsing access to such data through Google Earth relief shaded images (Prentice et al., 2009). The data – virtually exclusively referring to North America regions – comes into 'raw' or other further processed shapes (DTMs derived by different interpolation techniques, hillshading raster files etc.) (Open Topography, 2013).

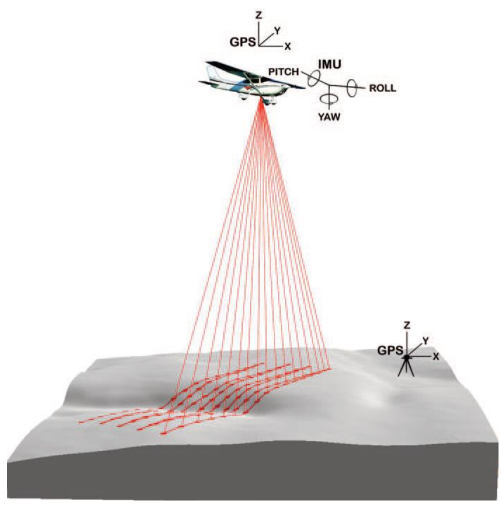
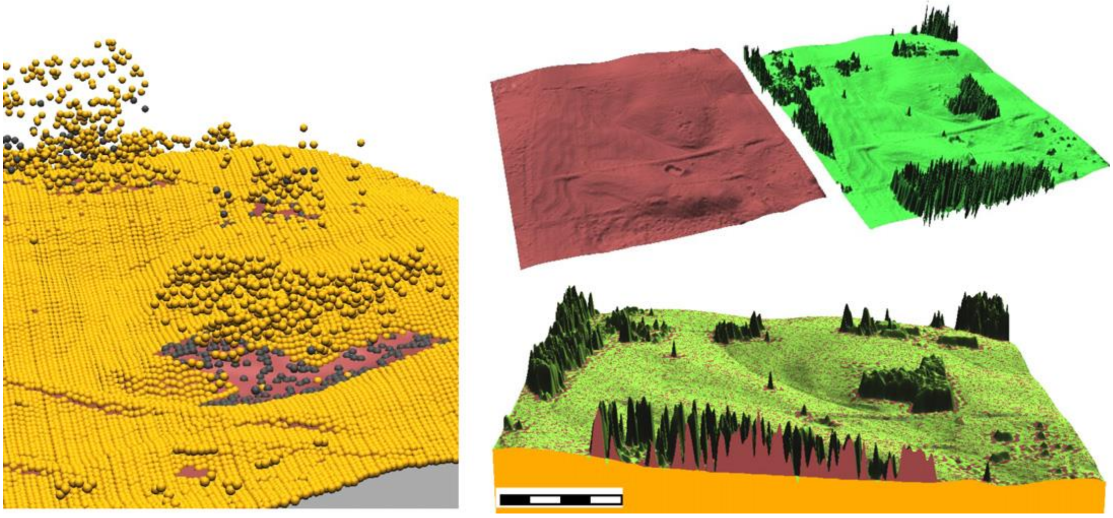


Figure 40: LiDAR (point cloud) data collection from bare ground. After Reutebuch et al., 2005

[40] Inertial Measurement Unit



a b

Figure 41: Visualization based on multiple return LiDAR data: (a) point cloud; (b) bare Earth and first return surfaces side-by-side and overlain with a cross-section.
After Netemer an Mitasova, 2008 – cited in Mitasova et al., 2012.

5.2.1.4. Sampling

As it implicitly ensues, the sampling concept is a very critical one. Since 2-dimensional space, i.e. the land surface, is not inherently partitioned in 'quanta', an attempt to comprehensively describe the geometry of the former would require defining an infinite number of points and conducting infinite measurements. In practice, though, a measurement of a finite number of points over areas of certain size usually suffices for terrain representation. This is also true about digital terrain modelling. But the fundamental "problem a DTM specialist is concerned with is how to adequately represent the terrain surface by a limited number of elevation points, that is, what sampling interval to use with a known surface (or profile)" (Li et al., 2005: 21). Some approaches profess that the level of detail in DTMs – pertaining to their spatial/ grid resolution (cell size) – should depend on the general variability of the landscape of interest by optimally capturing, representing and describing its elevation surface and the majority of its geomorphic features for the application of interest, without, at the same time, introducing disturbing local artifacts or excessively 'burdening' the computation of terrain parameters (see below for such parameters) (Borkowski and Meier, 1994 – cited in Hengl, 2006; Kienzle, 2004; Hengl, 2006; MacMillan and Shary, 2009).

From a theoretical perspective, by extending the *sampling theorem*[41] in DTMs, Peucker (1972) has proposed that the latter ones cannot portray data variations with a wavelength less than twice the sampling interval. Alternatively, for a terrain profile which is sampled at a given interval (d), the terrain information variations being able to be depicted are those with wavelengths of 2d or more (Li

[41] ...or Nyquist–Shannon sampling theorem. Shannon's version state: If a function x(t) contains no frequencies higher than B hertz, it is completely determined by giving its ordinates at a series of points spaced 1/(2B) seconds apart (see Shannon, 1949).

et al., 2005). Schematically, the suitability of the grid resolution with regard to landscape/ terrain complexity and the sampling theorem in a one-dimensional (profile) version is rendered in a way that "the grid resolution should be at least half the average spacing between inflection points"[42] (Hengl, 2006: 1291) (Fig. 42).

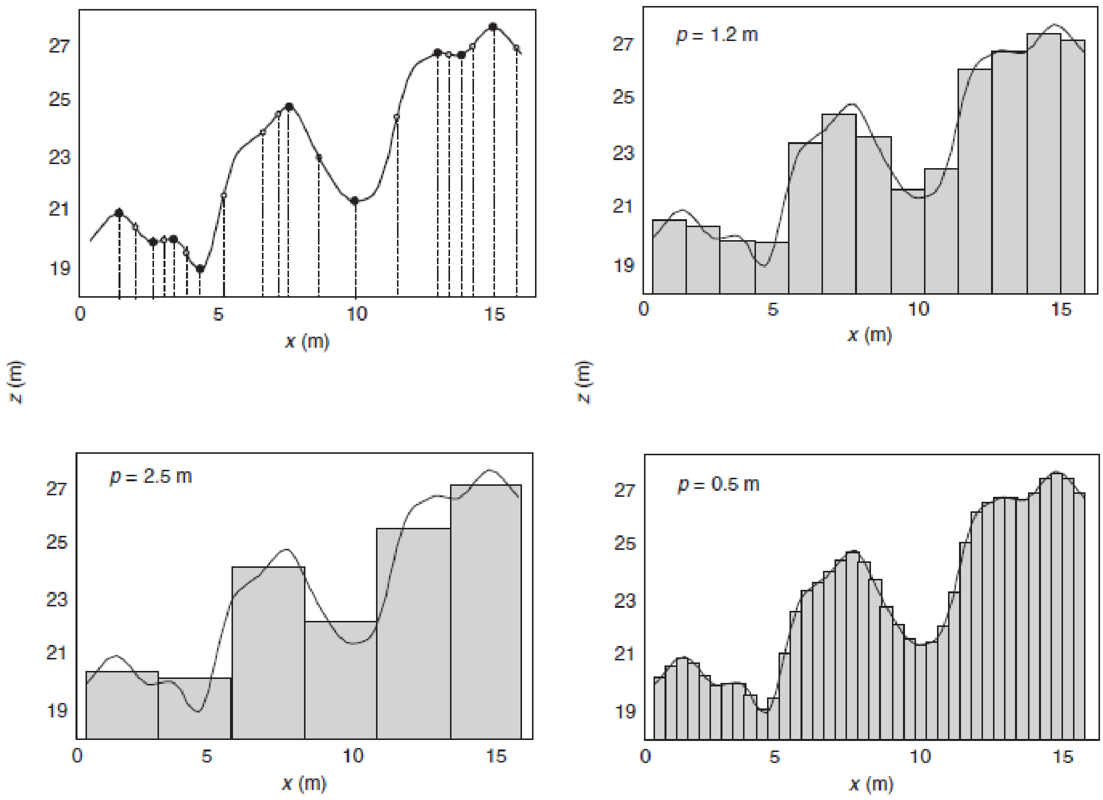
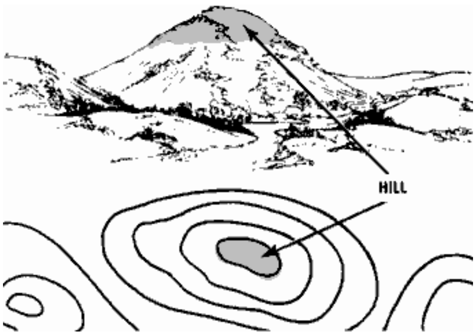


Figure 42: The effect of grid resolution on terrain profile representation: For twenty inflection points and a 16-m length profile (transect) the terrain would be mis-represented for a resolution not close to 0,4 m; here, a resolution of 0,5 m appears to more effectively represent topographic features of the terrain like peaks or pits in comparison to coarser resolutions (2,5 m and 1,2 m). After Hengl, 2006.

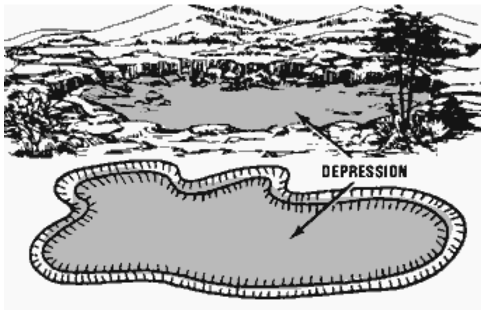
Aside from the abovementioned principle according to which the variations of information can be concealed/ revealed, there are several methods for describing a terrain. Li (1990) has proposed three such methods: i) statistics-based sampling, ii) geometry-based sampling and iii) feature-based sampling. The statistics-based sampling, as its name implies, considers a terrain surface as a population (a sample space) and the sampling is carried out in suitable for terrain modelling strategies: either randomly (simple random sampling) or systematically (systematic sampling). In the second method, different geometric patterns – regular or irregular, 1-d or 2-d – represent the terrain surface (TINs, RSGs, series of contiguous hexagons, contours etc.).

[42] Mathematically, it is expressed as: $p \leq \frac{l}{2 \cdot n(\delta z)}$, where p is the cell size (grid resolution), l is the length of a profile (transect) and $n(\delta z)$ is the number of inflection points observed.

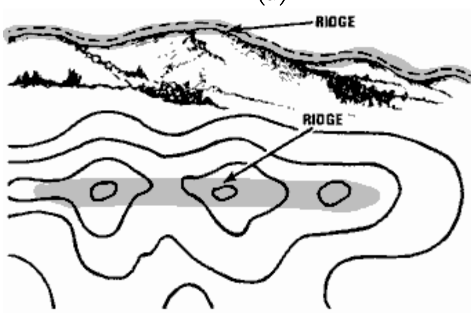
The third method is based on the assumption that information content on 'singular' specific points of the topographic surface may vary significantly (Li, 1990). Indeed, feature-specific (F-S) points, i.e. points corresponding to topographic features such as peaks, pits or passes posses such properties. The first ones – *peaks* – are surrounded by a set of points (land surface) exhibiting only lower elevation values than them, while the second ones – *pits* (*depressions*) – are surrounded by a set of points (land surface) exhibiting solely higher elevation values than them (Li et al., 2005). So, such feature specific points are local extrema points on the terrain surface which aside from carrying locational information, they also represent information about their surroundings in an implicit manner. The linear connection of such F-S points result in linear topographic features such as *ridge-lines* (*ridges*) and *course-lines* (*valleys*); the points on (also defined by) these lines are local maxima or local minima respectively – in elevation terms (Li et al., 2005). *Passes* (*saddles/ cols*) emerge at the crossing points of ridgelines and course lines – between peaks: they share simultaneously the attributes of both local maxima elevation (in one direction) and minima elevation (in the other) (Figs. 43, 44) – while *pales* are another type of 'singular' points sharing analogous attributes with passes, but are located between pits instead of peaks (Warnz, 1966).



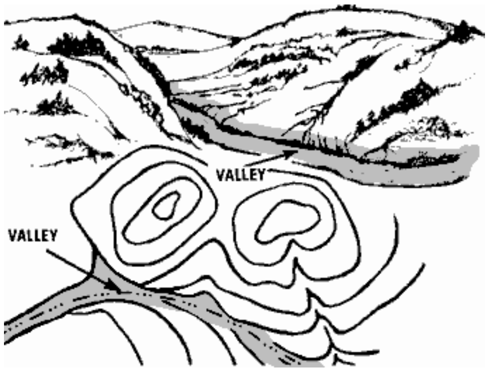
(a)



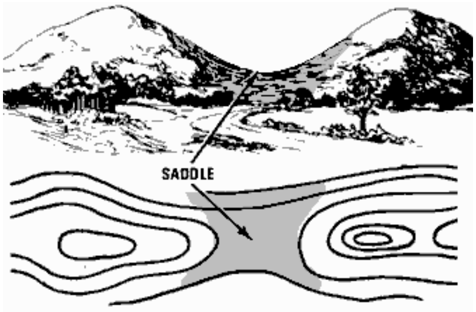
(b)



(c)



(d)



(e)

Figure 43: Feature specific points for peaks (hill) (a) and pits (depression) (b), and their respective linear counterparts (c), (d); passes (saddles, cols) (e) refer only to point, typically not having linear counterparts, but, in practice, within a certain range, lines running perpendicularly to the direction formed between the consecutive peaks could be treated as 'pass-lines'.
After Army Study Guide, 2013.

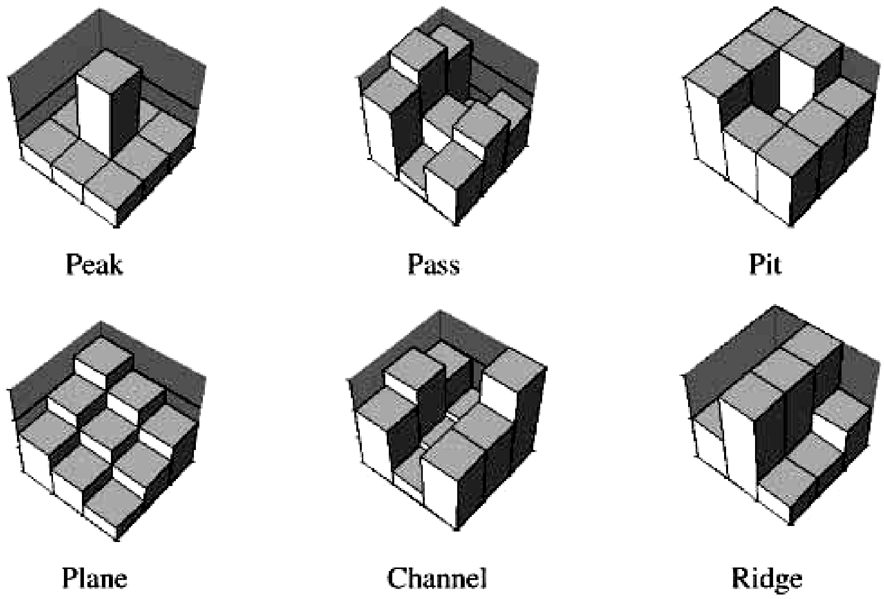


Figure 44: The six morphometric classes as represented by a gridded DTM in which a location is typically assigned
After Fisher et al., 2004.

Therefore, sampling methods and strategies are critical for the appropriate approximation and accuracy of the resulting continuous geo-field (DTM), along with the respective interpolation methods. Although it is outside of this thesis' scope to discuss interpolation methods and techniques, it should be noticed that the interpolation method is a major determinant of the resulting digital surfaces when the interpolation procedure is relying upon widely spaced (i.e. randomly and sparsely distributed) observations (elevation measurements) (Burrough and McDonnell, 1998). But, this is not the case either for densely spaced observations, or for sampling strategies enabling topographic features. When the sampling points include peak and characteristic elevation values ('break-lines'), even typical deterministic GIS interpolation functions such as Inverse Distance Weighting (IDW) are not problematic, for even extreme values can be predicted since being within the range of observations (Meng et al., 2013). Given that feature specific points are more important than others (slopes, planes etc.) in rendering a description of a surface and thence, the solitary points (if for peaks, pits, passes) or contiguous points (for ridges, valleys, pass-lines) representing them are of particular significance. This means, in a sense, that when sampling an area in order to take elevation measurements for digital terrain modelling, such points should be explicitly involved in the procedure, or else the digital surface will not be geomorphologically correct (see Hutchinson, 1988; 1989; Wahba, 1990). In another sense, these points (objects) are potential candidates for storing and conveying compact surface information.

5.2.2. Land Surface Parameters in Digital Terrain Modelling: Viewshed's Particularity

5.2.2.1. Land Surface Objects and Parameters: Local and Non-Local Parameters

After creating a proper DTM, the phase of geomorphometric analysis can take place. Geomorphometric analysis in DTMs (digital terrain analysis) entails the calculation/ extraction of land surface parameters or objects. While Pike et al. (2009) have imposed a somewhat crisp boundary between the former – considered as a descriptive measure of surface (e.g. slope or aspect) – and the latter – deemed as a discrete surface feature (e.g. watersheds or alluvial fans) – (Fig. 45), other approaches tend to reveal the tight linkages between these two facets, insinuating the arbitrariness of such a dichotomy and the fuzziness and ambiguity of multi-scale geomorphometry (e.g. Gallant and Dowling, 2003; Fisher, 2004; 2005; Deng and Wilson, 2008; Wang et al., 2010). Nonetheless, a means of classifying the various terrain derivatives is of great assistance – while keeping in mind the vagueness of these class (conceptual) boundaries across multiple scales and resolutions.

In this context, Wilson (2012) has categorized land surface parameters into primary and secondary, with the former ones being able to be derived directly from a DTM. Olaya's (2009) *basic land-surface parameters* are closely related with Wilson's primary parameters. Their particularity lies in the claim that: "although all geomorphometric parameters relate to the morphology of the land surface, a number of them can be derived directly from a DEM without further knowledge of the area represented" (Olaya, 2009: 141). These parameters are further sub-categorized in *local* and *regional (non-local)* parameters, with the latter differing from the former in that they need to consider, in addition, other (or even all) parts of the DTM than just the specific points that local parameters require (Table 9).

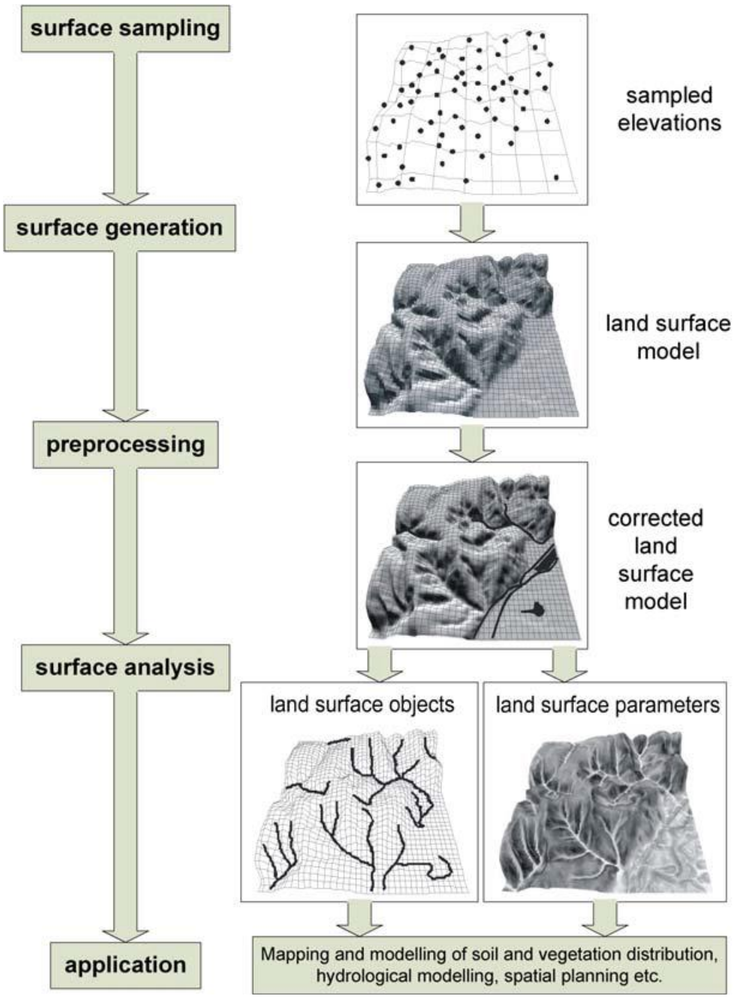


Figure 45: The extraction of land surface parameters and objects as the operational focus of geomorphometry and digital terrain analysis.
After Pike et al., 2009.

Table 9: Some basic land-surface parameters.
After Olaya, 2009.

Land-Surface Parameter	Type	What does it describe
Slope	Local	Flow rate
Aspect	Local	Flow-line direction
Tangential curvature	Local	1st accumulation mechanism
Profile curvature	Local	2nd accumulation mechanism
Catchment area	Regional	Flow magnitude
Hypsometry	Regional	Distribution of height values
Catchment height/slope	Regional	Flow characteristics
Insolation	Regional/ Local	Intensity of direct solar irradiation
Visual exposure	Regional	Extent of visible area
Roughness	Local	Terrain complexity

In essence, this classification has originated from Florinsky's (1998) distinction between local (primary) topographic variables (gradient, aspect, horizontal, and vertical land surface curvatures) – calculated as various functions of the elevation within the vicinity (surrounding cells) of each point of the land surface –, and the non-local variables (watershed delimitation, hydrographical network 'tracing') – the computation of which require the analysis of non-local land surfaces (Florinsky, 1998; Wilson, 2012).[43] In the following, the focus is on local variables or parameters.

As Evans (1981) has asserted, the land surface and land form can be described at any point by the altitude and the surface (terrain) derivatives, i.e. slope and curvature. ***Slope*** is specified by a plane which is tangent to the surface at a given point, expressing the elevation rate of change with distance; it is considered to be the first derivative of the elevation land surface, being fully defined by both its vertical component (first vertical (profile) derivative), that is *gradient,* and by its horizontal component (first horizontal (plane) derivative), that is *aspect* (Evans, 1981; Li et al., 2005). Land surface is further specified by its second derivative – ***curvature*** (convexity-concavity); *profile* (vertical) and *plane* (horizontal) *curvature* are the two second derivatives of elevation (Evans, 1972; Li et al., 2005). The calculation of first and second derivatives of altitudes has been approximated by a variety of equations (see Evans, 1972; Zevenbergen and Thorne, 1987; Moore et al., 1993a; Florinsky, 1998; Shary et al., 2002).

In general, altitude (elevation) and its four derivatives (local topographic variables/ parameters) mainly specify land surface/ form – with slope, as Strahler (1956) and Evans (1972) suggest, being its most fundamental aspect, for land surface can be completely 'reconstructed' by slope angles. Both elevation and these local parameters can be digitally represented collectively by DTMs, and more specifically by digital elevation models and other digital models of gradient, aspect, horizontal and vertical curvatures (Miller and Laflamme, 1958; Burrough, 1986; Shary, 1995; Florinsky, 1998). In digital terrain modelling (referring to grids), local parameters are represented by values assigned to every (target) cell: these values result by the calculation of a function utilizing a moving (local analysis) window (typically 3x3) (Olaya, 2009). In practice, as this window moves across the DTM, all of the cells of the locations-targets are assigned a value for the local parameter of concern – in correspondence to the pertinent function (Fig. 46).

[43] Schmidt and Dikau (1999) distinguish between simple primary and complex/ combined primary geomorphometric parameters instead of local and non-local parameters – attributing to them commensurate meanings.

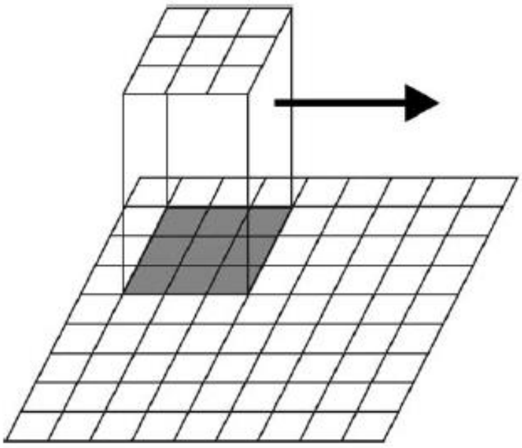


Figure 46: A complete analysis of a DEM normally obtained by moving a 3x3 rowing window across it.
After Olaya, 2009.

Non-local or regional surface parameters, as previously mentioned, cannot be derived by simply being calculated as a function of their surrounding cells. In fact, these regional parameters entail "action-at-distance forces" instead of local interactions between adjacent points (cells) (see Fig. 36; Wilson and Burrough, 1999). Their particularity lies in the fact that they "rely on the terrain shape of a larger, non-neighbour area and need to be defined with reference to other non-local points" (Wilson, 2012: 114)

So, these parameters are concerned with the more generic (or global) *climatic*, *geomorphic/ hydrological* and *visual* properties of landscapes: the first two are roughly about the delineation of *shadowing* and the *reflective* character of the terrain, and the hydrological parameters related to the *watershed* delineation and to the formation/ spatial configuration of *hydrological networks* (Wilson, 2012). Especially with regard to hydrological properties, it should be mentioned that a watershed (or a drainage basin) is the region of the land surface higher than the river bed and the (water) course-lines where all the run-off (water) flows towards a defined point, the *outlet point* of the watershed (Bloom, 1998; Olaya, 2009). In other words, the outlet drains all the run-off generated within a region that is delineated by drainage divides (ridge-lines or other break-lines). Various methods and techniques have been proposed for the (semi-) automated calculation of hydrological properties and their digital modelling (see Hutchinson, 1988; Wahba, 1990; DeMers, 2002; Chang, 2003).

As for the visual properties of a landscape, they arise from the computation of visibility and *viewshed* on DTMs (see second Chapter). No matter how watersheds and viewsheds appear to be somehow similar from a geomorphological perspective – view points are deemed to be equivalent to outlet points and visible regions are considered as counterparts of drainage basins –, in essence, their properties significantly diverge since visible regions may be not continuous/ contiguous but fragmented (depending on the different/ disjointed locations in view), whereas the cells comprising these regions do not entail any direct relation among each other, but are rather associated with the initial point of view from which lines of sight emanate (Olaya, 2009). In contrast, watersheds are contiguous regions, their cells are spatially correlated, there can be several distinct basins (sub-basins), and their boundaries (drainage divides) are rather 'sharp' – they are typically ridge lines or other break lines. Moreover, they partition an area (land surface) into a fixed number[44] of such basins/ sub-basins (including inter-basin surfaces), where the outlet points are determined by the topography and the drainage network of the area, whereas, according to Olaya (2009), visual exposure and viewshed are relative measures derived through geometric principles (mutual visibility principle) that can be applied either for the whole area, or for specific locations. So, a land surface or a landscape can be characterized by several indexes of visual exposure (e.g. the number of cells observed from each cell) and from various or from all the existing points of view, which in a DTM coincide with the existing cells.

5.2.2.2. Viewshed's Peculiarity for a Complete Terrain Description: Sampling and Scaling

Viewshed is a local-specific parameter from a standpoint, since the point of observation is a determinant in shaping the visible/ not visible cells, but it is also a regional parameter in the sense that it requires to involve the whole topographic surface, that is every cell of the gridded DTM (this appertains to the *global operations* on raster data[45]) each time (or from each point of view) that it is computed; in this perspective, it is a unique parameter because the 'vistas' yielded rely both to the view point and to the underlying geomorphology of the study area.[46] This means that, even it is not impossible for two different locations of viewpoints on the same landscape/ terrain represented by a DTM, or for one location of viewpoint on two modified landscapes to yield exactly the same viewshed, it is highly unlikely – particularly when the region of concern exhibits a rough/ rugged topographic relief[47] (see § 5.3.3.). In any case, though, regardless of 'how much local or non-local' this surface parameter is (Olaya (2009) assigns it to the local parameters, while Wilson (2012) to the non-local ones), one matter is certain: In contrast to the parameters that are undoubtedly classified as local and

[44] Scale and resolution affect this 'fixed' number.

[45] See Tomlin (1990) for a thorough classification of GIS transformation of rasters (grids) into four generic types of *operations – local, focal, zonal, global* – imposed on raster-based GISs, collectively known under the label of *cartographic modelling* or *map algebra*.

[46] Deng (2007) promotes a distinction between *topographic position* (typically entailing environmental meanings with reference to some pertinent feature or process) and *terrain shape* (often characterized by local parameters), in that the former can be considered as "primarily point-based, but its characterization has to employ a non-local, perhaps irregular-shaped area that should be determined according to the underlying biophysical processes (Deng, 2007: 408). Viewshed can be viewed as a parameter integrating both topographic position and terrain shape.

[47] The effect of discreteness imposed by binary viewsheds could be of concern for this hypothesis.

which are calculated with *focal operations*, i.e. within a neighbourhood of each cell, a comprehensive description of a landscape based on its viewshed (from every location on a DTM) is clearly far more computationally demanding. This stems from literature as well (e.g. Desmet and Govers, 1996; Gallant and Wilson, 2000) according to which parameters referring to non-local aspects of a landscape entail accessional efforts accompanied by constructing point-to-point relations and interactions over the landscape, a matter that rather augments the complexity of algorithms, perplexing the considerations for scale issues (Wilson, 2012).

In short, the appropriate functions for slope and curvature calculation are implemented by a moving window, harnessing focal operations and resulting in a single new slope/ curvature digital model. Watershed calculation, however, emerges by enabling both focal and global operations and by utilizing the intermediate *flow-direction* and *flow-accumulation* grids (see Chang, 2003); thus, it corresponds to a single output as well. A complete viewshed computation is subjected to the application of global operations resulting in as many outputs, as many are the DTM's cells; for other visibility indexes (see § 5.3.3.) to be conveyed in single output grids, further local operations are required. In any case, a landscape should be sampled based on some of its inherent properties in order to reduce the pertinent computation complexity. Another reason appertains to the fact that visibility is destined to visualize what is seen of a landscape/ terrain from one or more viewpoints: so, a geo-visualization both meaningful and abstracted requires a strategy to include only the most inherently significant, but also cohesive 'vistas' of a landscape (see following sections).

In the abovementioned, one of the sampling strategies has been presented to depend on characteristic morphological features on the terrain surface (e.g. peaks, ridges, valleys etc) (Lee, 1990). In a more emphatic manner, Wilson et al. (1998) and Deng et al. (2007) argue that sample point locations on such features are accounted to influence the DTM accuracy more 'crucially' than sampling density. The importance of these topographic features in rendering the land surface is not surprising, given that a terrain surface is entirely characterized by its slope angles – and it is at F-S points that slope changes at least in direction, if not in magnitude/ sign (Strahler, 1956; Evans, 1972 Li et al., 2005) (Fig. 47). Peak, pit, pass, convex and concave[48] sets of points connected to constitute linear features, and other *break lines* – whose slope changes are severely abrupt due to several reasons – are all invariably F-S lines (Li et al., 2005) that can comprehensively describe the landscape and should be included so as to properly approximate and characterize it.

But are these F-S points/ lines suitable only for sampling measurements in the context of a survey to generate proper DTMs, or are they equally capable of further supporting a viewshed computation and visualization? Moreover, does the sampling theorem apply only to the suggestion of the most congruent grid

[48] When slope is viewed at a bottom-up transition, it changes from gentle to steep at concave and from steep to gentle at convex points.

resolution for proper landscape representation, or can it be of use in defining inflection points (i.e. viewpoints) intervals along a cross-section generated by such F-S lines? The following sections are dedicated to the way that these prominent topographic features can be manipulated so as to provide appropriate sets of view points to properly analyze and visualize a landscape from the perspective of a parameter/ phenomenon that is so dependent on the election of the viewpoint location.

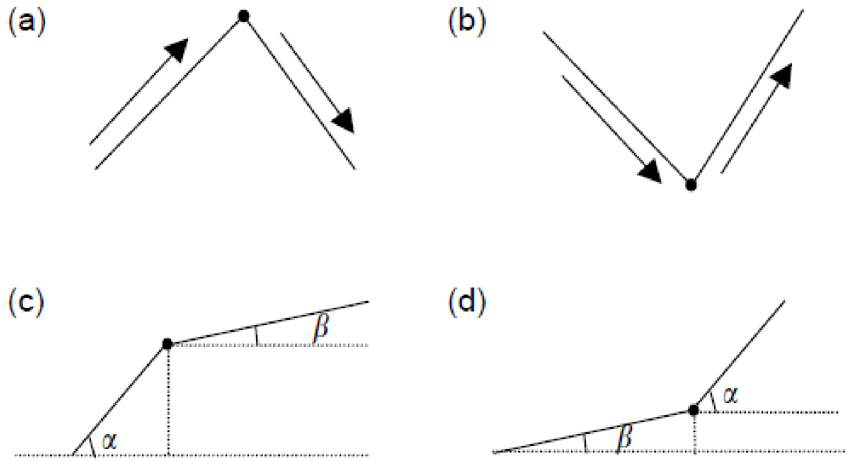


Figure 47: Slope changes at F-S points: Peaks (+ → -) (a), Pits (- → +) (b), Convex points (α ≠ β) (c) and Concave points (β ≠ α) (d).
After Li et al., 2005.

Before proceeding to these issues, some aspects of scale and resolution are to be examined with reference to local and non-local parameters. In general, DTMs portray the terrain as a function of scale integrating terrain complexity, data resolution and land surface spatial scale of observation (Deng et al., 2007; Deng and Wilson, 2008; Wilson, 2012). As MacMillan and Shary (2009: 231) pose it:

> *"What one perceives in observing and classifying terrain is […] dependant upon a combination of the size or extent of the area viewed and the level of detail of the displayed surface as controlled by the horizontal and vertical resolution of the elevation data used to portray it."*

The issue of scale has been widely reduced (mainly) to the one aspect of the level of detail, namely the (horizontal) DTM resolution. Thence, research has been directed towards the examination of the influence of land surface parameters elicited from DTM with varying grid resolutions (e.g. Zhang and Montgomery, 1994; Florinsky, 1998; Kienzle, 2004; Schmidt and Hewitt, 2004; Deng et al., 2007). As Wang et al. (2010) state, this type of multi-scale analysis corresponds to the proper election of scale, and, as it ensues from the previous, to the proper grid resolution election.

With reference to local land-surface parameters in particular, while Hengl (2006) contends that there is no single optimal resolution for their computation because the important information about the land surface is often captured and contained at more than a single scale (i.e. extent and resolution) (Gallant 2006 - cited in Wang et al., 2010), it has been shown that a range of suitable scales does exist. Zhang and Montgomery (1994) have suggested that a grid resolution finer than 30 m, and about 10 m comprises a rational option; similarly, Kienzle (2004) has proposed a range of 5 m – 20 m resolution to optimally estimate the fundamental local parameters depending on the area of interest terrain complexity and the calculated parameter. In general, there is consensus in that the analysis of such terrain parameters is to be conducted in the human-scale context (see Evans, 2012). More specifically, as the DTM resolution becomes coarser, the slope (gradient) values tend to be underestimated in general, while maximum gradient decreases rapidly (Evans, 1972; Kienzle, 2004; Deng et al., 2007). In addition, as the cell size reduces, values for curvature (both profile and plan) vary greatly, with the convexity/ concavity rising even more sharply and the mean/ median values remaining practically unchanged – a result meaning that convexity/ concavity occur at the same 'amount' across several resolutions (Kienzle, 2004; Deng et al., 2007; Evans, 2012). On the other hand, aspect (the horizontal first derivative of elevation) values present a rather uncorrelated, erratic response as cell size varies, since for coarse DTMs (100-m cell size) their spatial distributions are much less realistic than those of finer DTMs (10-m cells); this finding can have severe implications on hydrological properties of the terrain, given that the aspect – in the shape of flow direction – eventually determines the boundaries of drainage basins/ watersheds (Kienzle, 2004; Deng et al., 2007) – the latter being non-local parameters.

Given the previous considerations relating resolution with local surface parameters, the generic manner for overall terrain characterization that has been proposed lies in the summarization of the local land surface parameters (or other terrain indices) across a range of scales (resolutions) implementing a weighted method (e.g. Fisher et al. 2004; 2005; Deng et al., 2007) (Wang et al., 2010). Yet, the manner of computation of several surface parameters should be as well differentiated across scales; the typical 3x3 window should be varied (expanded), since: the sensitivity to local DTM errors is decreased at coarser scales and according to the 'contextuality' of the specific parameter (Macmillan et al., 2000; Van Niel et al., 2004; Deng and Wilson, 2008; Wang et al., 2010).

The issue of scale and resolution cannot be and has not been addressed in so direct a manner for non-local terrain parameters. The "action-at-distance forces" and the "point-to-point connections" over the landscape entail a further complexity in scale concerns (Wilson and Burrough, 1999; Wilson, 2012). Some authors have introduced the 'scale-free' concept and have theoretically and practically demonstrated that properly harnessed regional land surface parameters may be insensitive to scale (Shary et al., 2002; Shary et al. 2005). In essence, landscape classification in terms of regional land surface parameters tends to be terrain-specific (Shary et al. 2005; MacMillan and Shary, 2009); as an effect, the overall terrain character (rugged/ mild, mountainous/ coastal etc.) contributes even more drastically to the derivation of regional parameters and, thence, global interactions from the entirety of the landscape chiefly influence these parameters, in contrast to the more restricted, focal operations involving moving analysis windows for the local parameter extraction. Nevertheless, regional parameters can implicitly embody the effects of resolution and of neighborhood relations: watersheds, for instance, are calculated based on flow accumulation grids which are derivatives of flow direction grids; but, aspect calculation – being severely afflicted by the influence of coarse resolutions as mentioned before – is crucial for the derivation of flow direction).

Viewsheds cannot be affected by scale in the manner that watersheds do. Both the very nature of the parameter and the means of digitally approximating it at conceptual and implementation levels have steered its research towards other considerations than scale effects. Such considerations are: the structure of the DTM utilized (RSG/ TIN), the algorithmic strategy/ procedure implemented, the inclusion of the probabilistic nature (Boolean/ fuzzy viewsheds), the vegetative interference etc. (e.g. Fisher, 1991; 1992; 1993; Sorensen and Lanter, 1993; Dean, 1997; Maloy and Dean, 2001; De Floriani and Magillo, 2003). Regardless of these issues mostly dealt with in the second Chapter, Riggs and Dean (2007) have segregated the matter of spatial resolution. So, the limited/ improper spatial resolution causing a DTM to omit "some terrain feature that profoundly impacts a viewshed" can by itself introduce spatial significant errors in predicted viewshed (Riggs and Dean, 2007: 177). In their empirical research they compute viewsheds at different resolutions (1, 4, 8, 10, 12, 16, 20 m) and with the aid of different GIS software packages (i.e. quite different viewshed algorithms), and then compare all of these combinations to the field delineated viewshed. Of all the combinations no one results in agreement greater than 85%, while for all the GIS algorithms implemented, the 4-m resolution DTM demonstrates the highest agreement (always greater than 83%). Although this resolution is not to be deemed as the optimal for every case of viewshed delineation, since it is an *ad hoc* approach valid for a specific landscape or type of land surfaces, it can be deduced, though, that the most refined available resolution is not by all means the one approximating in more realistic terms the actual visible region.

Furthermore, since viewshed depends largely on the terrain attributes all over an area of interest, another concern is related exactly to this area, that is the geographic extent (the other crucial dimension of scale). The spatial patterns of viewshed are prone to exhibit even dramatic alterations at the variations of the magnitude of the study area. Both intuitively and empirically it could be deduced/ induced that the visible region from a specific viewpoint could be significantly expanded and increase in relative terms (i.e. ratio of visible to not visible cells) in the case that the study area extends annexing mainly land portions that do not impede the view (e.g. if an immense plain lies, say, north of a given area of a generally rugged relief being secluded by a ridge at its northern borders and the geographic extension occurs northerly, then, from a vantage point which is able to see beyond this ridge, the visible region will rise significantly owing to this annexing). Similarly, the visible regions from two peaks (typically 'carrying' the same visible cells) may eventually dramatically differ due to their position within the DTM and the spatial dispersion of the respective viewshed patterns in relation to the viewpoint location (e.g. all of the visible cells are contained within the DTM for the first peak surrounding it, while for the second peak being near the edge of the DTM, many of the visible cells lie (far away) out of the DTM (Caldwell et al., 2003). Such *edge effects*, even though do not invalidate the results, pose a severe restriction or limitation that should be always borne in mind (Caldwell et al., 2003).

To conclude, the issue of scale in digital terrain analysis is vital. The reduction of the cell size serves the more accurate resolution of landscape features (parameters and objects), but not their more faithful representation which is liable to the density and sampling strategy of the original survey data for the DTM generation (Zhang and Montgomery, 1994). The proper resolution is not in alignment with a universal optimum, but it rather depends on the parameter which is to be captured and analyzed/ described for each specific application (MacMillan and Shary, 2009). Even more articulately, the most appropriate means for the derivation of many (usually local) surface parameters often relies on multiple resolutions' combinations. Nonetheless, local parameters describe a landscape in terms of neighbouring conditions of the land surface, rendering its *terrain shape* (see Deng, 2007). Yet, since the scale effect (both limiting spatial resolution and geographic extent) in terrain analysis is non-uniform across space and potentially anisotropic (Schmidt and Andrew, 2005), the factor of scale cannot apply homogenously for local and regional parameters. Viewshed is a representative (to our opinion) regional parameter that contains the (general) terrain shape but from a point-based topographic position; so the uniformity of scale is afflicted by the global interactions innate to its computation. A complete description of a landscape is not as convenient for a viewshed as for a local parameter, owing to these global interactions and the respective computational load. From another standpoint, describing the topographic context (more general terrain shape) without at the same time losing local variability has been deemed to be a persistent challenge (MacMillan et al., 2004). By calculating and by properly depicting viewsheds from 'contiguous' point-based topographic positions for segments of a land surface that are inherently connected in geomorphologic terms might yield a relatively comprehensive description of a landscape.

In the following, the scale factor neither is so directly approached, nor is probed thoroughly via a rigorous experiment, but it emerges as a prerequisite for the congruent description and visualization of the visual structure of a landscape. In fact, the scale issue arises by the literature and by empirical experimentations both as a compromise between accuracy and volumes/ computational load (i.e. suitable cell size) – aspect essential to our application –, and as an unavoidable constraint/ limitation (i.e. the inevitability of the edge effect). So, our attention is steered towards the election of the appropriate segments within the landscape/ terrain and the 'sampling positions' – i.e. election of proper viewpoint intervals.

Since it is not a research that approaches viewsheds solely in geomorphologic, but principally in geo-visualization terms (a '2-d exocentric fly-over' for landscape exploration – see § 4.4.), prominence is given to issues related to latter terms.

5.3. METHODS AND TECHNIQUES FOR 'CONDENSED' VISIBILITY ANALYSIS AND EXPLORATION: VISUALIZATION PARTICULARITIES OF DIGITAL TERRAIN MODELS USING TOPOGRAPHIC FEATURES

5.3.1. Basic Concerns

While the particularity of viewshed in geomorphometric terms (with regard to local and non-local land surface parameters and in comparison with watershed) has been described and discussed in the previous sections of this chapter, another important issue remains when someone is to provide the visible/ not visible regions for large areas or/ and from a multitude of observation locations – an issue associated with the data structures and algorithms utilized. More specifically, when it comes to the viewshed implementation on a raster/ gridded DTM, it becomes apparent that the pertinent function is time-exigent and relates heavily on the number of observers (viewpoints) and the DTM size (extent/ resolution, i.e. number of cells = matrix rows * matrix columns). The time required for viewshed computation for a set of selected viewpoints (v) and for another set of target regions (r)[49] is proportional to O (r^v).

In the second Chapter, it has been shown that the request for visibility analyses has been fueled mainly from a need to render what is seen of a 3-d scene or a set of 3-d objects – the hidden-surface-removal problem. Thence, viewshed implementation accounts not only for the analytical functions transforming the data so as to bring about added value information and understanding but, visualization of the terrain itself (De Berg, 1997) as well. On the other hand, the sampling methods focusing on the DTMs configuration are not irrelevant at any aspect with that kind of visualization; in fact, for a multitude of observation points, they may be crucial under the perspective of algorithmic complexity/ time reduction, as it will be described below. So, in the following, a rationale is put forward *interweaving visualization* with terrain data and one of its derivatives, visibility information, through the citation of several relevant research studies. Beginning with studies dealing with the issues and the importance of (DTM) data structures and volumes, that is: the usefulness and the limits of sampling from prominent sets of location and the effect of discreteness in the digital forms, we proceed to those focusing on visibility analysis and identification/ investigation of landscapes' visual configuration (visualscape), while integrating the previous issues. After all, their methods, techniques and conclusions serve as prerequisites in order to encapsulate them in a more dynamic context of visual landscape

[49] Generally, the target regions coincide with the set including all of the cells of the DTM grid.

exploration demonstrated in the next section below, which constitutes the methodological framework for our case study application.

5.3.2. Discreteness in Geographic Space and DTMs

Space in geography is not commonly perceived in its pure geometric, mathematic or absolute sense; instead, the notions of *relative* or *relativistic* space – implying internal structure and properties – are considered with reference to socio-economic or even physical processes (Couclelis, 1992). As such, the properties of the constituents of an area (points, lines, regions, or other regular or irregular tessellations) neither are negligible, nor are distributed evenly or in an *isotropic* manner. Mathematical models of socio-economic processes of the 60s, like those of *demographic gravitation* have heavily depended on such relativistic perceptions. Borrowing concepts from physical space, the socio-economic spatial distributions were interpreted as terrains: Warnz (1966) ventured to provide topological relations of such distributions with the aid of features of the surface like peaks, pits, passes, pales, ridges and course lines, in an attempt to overcome the pitfall of the lack of continuity (*discreteness*) of isolines representing such distributions. As he has explicitly stated:

> *"In the conventional method of logical contouring, use of a constant contour interval is employed. Of course, we can not be certain that every important feature is shown because no finite constant contour interval can in general be small enough to do this. […] Also, when a finite constant contour interval is employed, the capturing of certain other features becomes coincidental, with the probability of depiction again related inversely to the size of the interval."* (Warnz, 1966: 52).

On the other hand, since the advent of DTMs, introduced by Miller and Laflamme as statistical representations of areas of terrain with known coordinates (x,y,z) in an arbitrary coordinate system rendered in numerical or digital form (Miller and Laflamme, 1952), the topology of the terrain has been adjusted to the new way of representation. As an effect, Peucker and Douglas (1975), adopting the DTM perspective and being aware of the importance of Warnz's topological relations, promoted the harnessing of 'surface-specific points and lines' in order to efficiently encode topographic surfaces – given their large data manipulation exigency; in general, their method is based on the utilization of patterns of changes in elevation between a cell's adjacent cells in an attempt to identify several surface features in a DTM. Similarly to Warnz and the barrier of contours discontinuity, Peucker and Douglas (1975) exposed that the problem of discreteness arises in all three dimensions (x,y,z) generating difficulties in recognizing features that are innately continuous. In the same vein, Pfalz (1976) replaced the term surface-specific points and lines with topographic features expanding their utility to applications ranging from topographic and socio-economic, to potential/ functional surfaces. He demonstrated that the relationships between such features can be represented by a directed graph, a 'surface network' capable of facilitating "selective access and retrieval of information" which can even "guide the data collection or sampling process" (Pfalz, 1976: 81, 92).

5.3.3. Means of Sampling/ 'Condensing' Terrain Visibility Information in Raster DTMs

More recent literature has approached the issue of terrain visibility via the perspective of specific topographic features (similar to those inspected above). While the primary incentives for this strategy/ tactics are the efficiency and the related time minimization in viewshed computation, there appear to emerge some very important implications about the visibility occurrence in relation to morphological/ topographic structure. To begin with, the analysis found on Lee's (1994) research is related to *visibility dominance*, elevation and topographic features – namely: pits, ravines, peaks and ridges. The notion of dominance can be applied in two cases: on pixels i) *dominating* other pixels or ii) *being dominated by* others; as Lee (1994: 451) puts it: "a pixel *dominates* another pixel in visibility if and only if its visible region includes all visible regions of the other pixel" while "a pixel *is dominated by* another pixel in visibility if and only if its visible regions are entirely included in the visible regions of the other pixel". The whole rationale of the research concentrates on how to interrelate each viewpoint on every pixel (cell) of a 50 rows/ 50 columns DTM with the respective viewsheds in terms of: i) elevation (the higher the position of an observer, the greater the visibility?) ii) visibility dominance and elevation (do observers on higher positions exhibit higher dominance?) and iii) visibility dominance and topographic features (do specific topographic features are 'susceptible' to higher dominance values?). The analysis of the results concerning the second research question do not show any dependency between elevation and visibility dominance – except from suggesting the intuitive fact that pits and ravines receive lower mean elevation values than peaks and ridges. Results relating to the first one, display a significant trend between elevations and the number of visible pixels, albeit a weak positive correlation. This weak correlation, which is often accompanied by a very large standard deviation is equally certified by Franklin and Ray (1994) who ascribe it to several not explicitly understood factors, such as the specific cell that is tested, plus the topographic particularities of the neighbouring pixels or of the totality of an area: "from a low, broad valley one can see the whole valley and the fronts of two ranges" whereas "from a peak in a mountainous region one can see only the adjacent small valleys in front of the adjacent peaks" (Franklin and Ray, 1994: 758). However, Lee's (1994) third research attempt displays a more significant relation between visibility dominance and topographic features: it is shown that peaks and ridges tend to dominate and not been dominated by other pixels, whereas the opposite applies for pits and ravines.

Rana and Morley (2002) and Rana (2003), in an attempt to minimize viewshed (visibility index) computation time, adopted a *Reduced Observers Strategy* and

Reduced Targets Strategy respectively. The first strategy is based on the logical assumption that "except in the completely topographic featureless terrains", the (fundamental) topographic features, that is: peaks, pits, passes, ridges, channels can 'house' all the requisite observers in order to yield an optimized coverage for any mountainous terrain (apart from upland plateaus), reducing the computation load from the side of observation or view points (Rana and Morley, 2002); something analogous applies for targets as well (Rana, 2003). More specifically, the results and the uncertainty assessment showed that enabling topographic features for relatively *low* numbers of observers or targets with comparison to random observers/ targets generate better approximations/ estimations of the pertinent distributions (viewshed or visibility dominance); moreover, in the case of topographic features, a decrease in the number of points, alters to a lesser extent these distributions, in comparison with their random counterparts which (distributions) tend to degrade rapidly. As they explicitly mention: "at low numbers, the topographical significance will be a more useful basis for placing targets across the terrain." (Rana, 2003: 886).

Similarly, a multiple viewshed analysis harnessing the abovementioned topographic features was performed by Kim et al. (2004) in a venture for the suitable series of location that satisfy the maximization of visual coverage problem of an area to be emerged. In other words, their work directed towards the identification of that combination of points of observation that would collectively maximize the possible visible area, reducing the observation points to those located on or along topographic features. In their research it is proved once again that no matter how it ensues intuitively that observation from higher elevation will induce larger visible regions, this is not always true. Nevertheless, "while not all peak and ridge pixels have high visibility, all points with high visibility do tend to be located on peaks and ridges" (Kim et al., 2004: 1022). Furthermore, two other significant findings are 'dug out' in their research: i) Adjacent pixels along ridges tend to generate comparable viewsheds in terms of spatial autocorrelation, while even only slight displacements may induce great changes in viewsheds. It is worth noticing that this comparison should always be examined and interpreted not only on terms of figures – visibility index/ value – and estimation of spatial autocorrelation for these values, but also on terms of spatial intersection (as been implemented in this paper. ii) Certain landscape fractions tend to be consistently invisible from ridges such as the slant surfaces (slopes) immediately below the ridge and lower in the valley due to the fact that, according to Carson and Kirkby (1972), erosive processes will shape mountainous areas in a manner that leads to the generation of convex profile hill slopes near the ridge (shoulders), and concave profile slopes lower down (footslope) (Carson and Kirkby, 1972), while in the middle, relatively planar profile hill slopes (backslopes) are formed.[50]

From a slightly different perspective, Lee and Stucky (1998) have focused their efforts on the integration of least-cost-path (LCP) analysis with viewshed

[50] … especially on landscapes where fluvial and mass movement processes prevail.

computation from DTMs, with their results imprint on the extraction of four types of paths: scenic, strategic, hidden and withdrawn, under the effect of different scenarios (and sites). Utilizing visibility grids (general viewgrid and dominance viewgrid) as friction surfaces and selecting origin and destination points, they yielded the optimal viewpaths depending on each case and scenario, implementing different functions according to the requirements of the case (e.g. the hidden path friction surface requires dominance viewgrid to be minimized); for this venture, Euclidean path, the most 'proverbial' LCP referring to Euclidean distance, was used as a general benchmark measurement (Fig. 48). From the critical evaluation of the results we can conclude that both the specification of the selected viewpath type and the geomorphology/ topography of each scenario are crucial determinants for the route generation in each case; it should be noticed, though, that the latter (route generation) relates, to an extent, to the *specific* selection of origin and destination points within each site, i.e. each DTM.

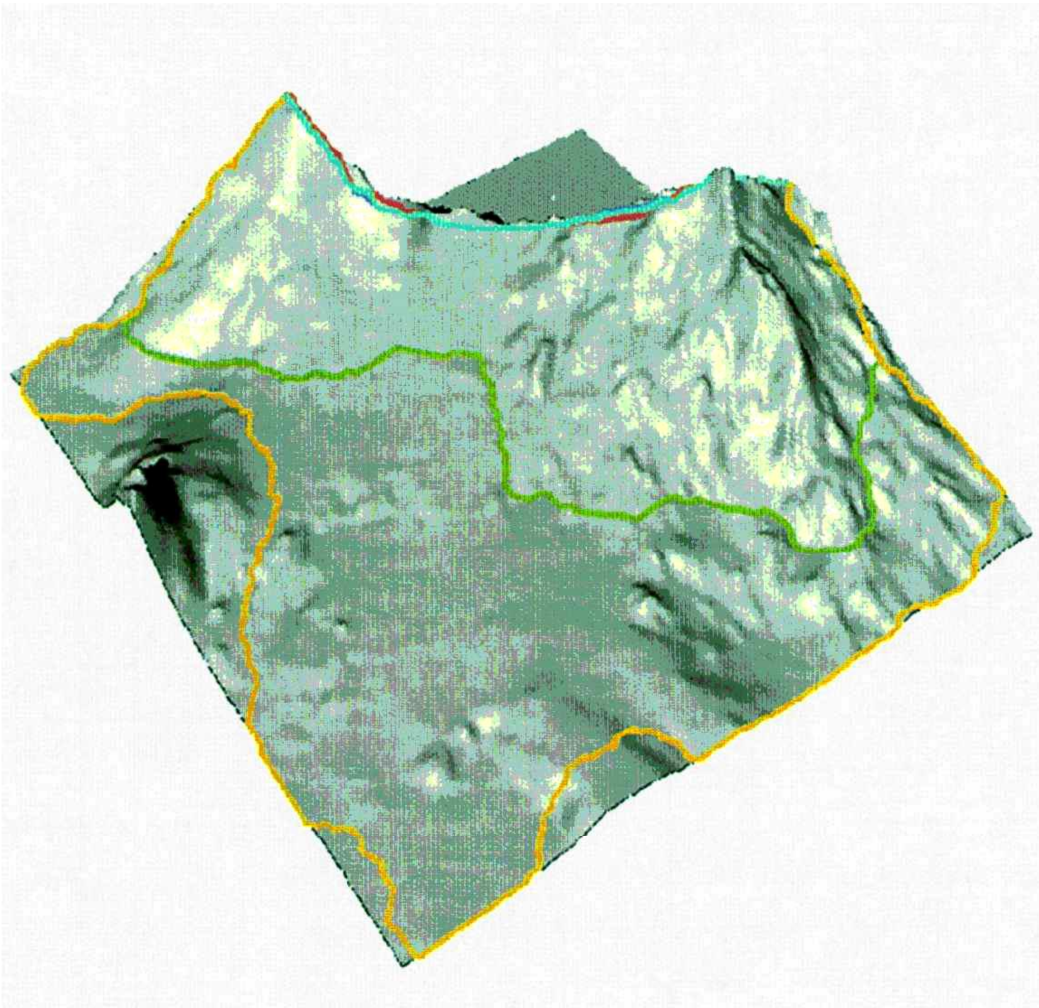


Figure 48: Example of least-cost-paths: Hiking path scenario, looking SE. The Euclidean path (cyan), the Scenic path (blue) and the Strategic path (red) follow the perimeter of the crater, while the Withdrawn path (green) makes a bypass winding around the feet of the hill and the Hidden path (yellow) perambulates the boundaries of the study area in an attempt to hide as much as possible.
After Lee and Stucky, 1998.

The work of Lu et al. (2008) resembles the previous analysis (least-cost-path computation for visibility information), proposing, though, a method that utilizes the 'reverse viewshed amalgamation' to obtain the optimal path exhibiting the minimal visibility dominance. In essence, reverse viewshed determines the visibility of a single given target/ viewed point from many observation points (Fisher, 1996a), while its amalgamation takes into consideration the adjacent points' visibility correlation in terms of overlapping, realizing a path-centred joint reverse viewshed, meaning that "the operation of amalgamation is equivalent to 'OR' operation in (Boolean) algebra" (Lu et al., 2008: 647). So, in contrast to the previous research and the research of Caldwell et al. (2003) who produced routes from friction surfaces harnessing *Descriptive Metrics* and *Tactical Decision Aids* (TDAs) derived from visibility-related analysis for determining the least/ most visible routes between a start and end-point, they (Lu et al., 2008) have portrayed the reverse viewshed of the optimal (least visible) path, plus attributing emphasis on edge effects, that is the visibility information alteration due to the DTM spatial extent limitation (Fig. 49).

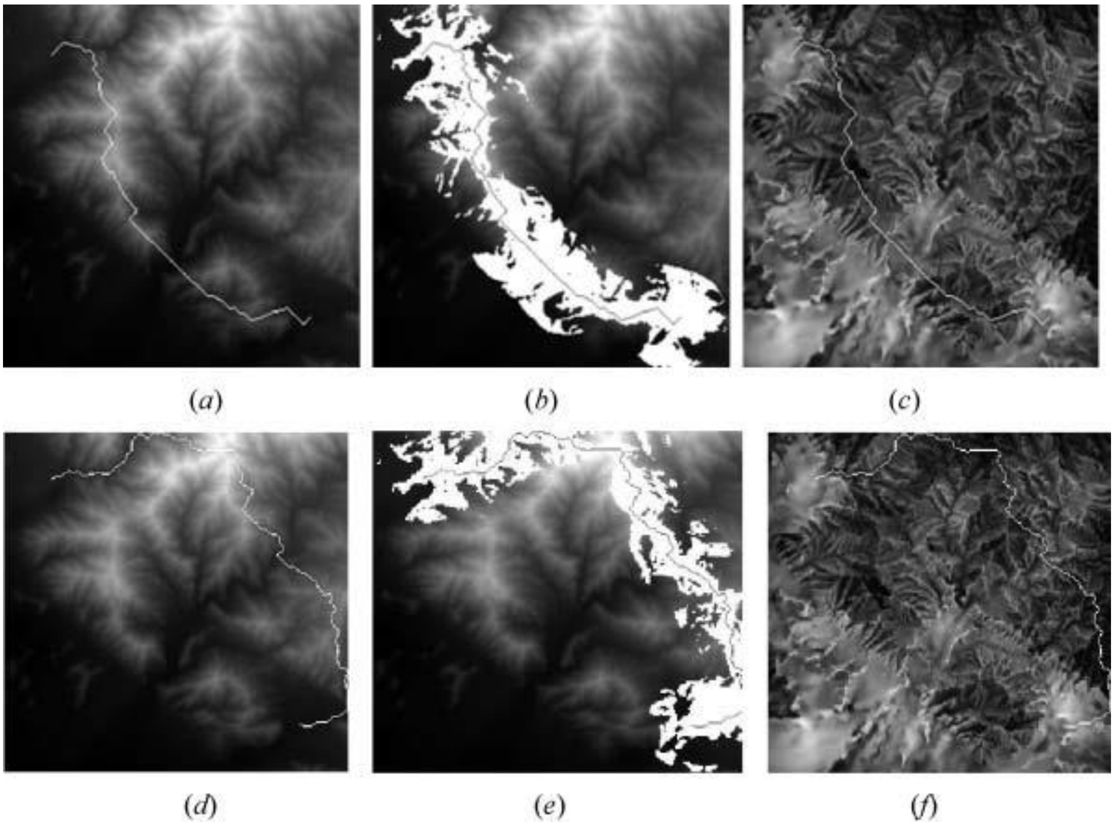


Figure 49: Least Visible Paths (LVP). LVP computed: i) without being under the influence of the 'edge effect' ((a)-(c)) and ii) under the influence of the 'edge effect' ((d)-(f)). Fig. (a) and (d) portray the LVP in a bright line; In Fig. (b) and (d) the LVP is presented as a dark line and its visibility dominance as a white area surrounding LVP; Fig. (c) and (f) depict the LVP as a bright line over the cumulative surface.
After Lu et al., 2008.

Even though the papers described in the above paragraph do not refer directly to (prominent) topographic features, they implicitly entail topography in the election of different sites (scenarios) and origin/ destination points. Another important element is the latent concept of continuity within a series of viewing or target points along a path or a route. Yet, a visibility information visualization method is not discussed, at least in a manner that an explorative procedure/ technique would reveal landscapes' visual configuration or properties. In the section below we suggest a methodology towards this direction which is subsequently carried out (experimentally) in the next chapter. Prior to these stages, though, it would be useful to clarify certain concepts pertinent to our scope in order to provide a framework of understanding with reference to visibility, and to summarize them along with some others already been determined.

5.3.4. Visibility Concepts and Indices

The most well-established concept in the realm of landscape visual exploration is that of ***cumulative viewsheds*** (Wheatley 1995): it results as the single output from the iterative map algebra overlaying function of union (Tomlin 1990) on viewsheds from various observation points. As such, they store the visual magnitude, i.e. the number of the observation points visible for every location of a landscape (for every rectangular cell, if a raster DTM is used). ***Total viewsheds*** computation is similar to cumulative viewshed computation, except that it applies not for a limited set of viewpoints, but for the DTM as a whole (Llobera, 2003). As an effect, it requires, in general, considerably increased computation load and time. Lee and Stucky (1998) have distinguished between ***general viewgrids*** storing the number of visible cell for each cell of the grid (view point) and ***dominance viewgrid*** recording the number of cells from which a cell (target) is visible; these two matrices do not coincide in practice "because the number of cells visible from a cell does not always equal the number of cells to which that cell is visible" (Lee and Stucky, 1998: 893-894). A special case for the dominance viewgrid is the matrix being created by the 'times seen' (Fisher et al. 1997) of a single target from many observation points, comprising ***reverse viewshed*** (Fisher, 1996a). Further more, there are the concepts of ***visibility dominance*** and of ***viewshed amalgamation*** along a viewpath, both been determined and categorized above (Lee, 1994; Lu et al., 2008). More recently, Danese et al. (2011: 75) have developed a new viewshed analysis, the ***identifying viewshed,*** "which shows which target is visible for each cell" and therefore comes to support and complement cumulative viewsheds who do not convey such information (Fig. 50). All those concepts can be seen as well as metrics, which along with others ***Descriptive Metrics*** and ***Tactical Decision Aids*** could be maintained and managed in a ***Complete Intervisibility Database (CID)*** recording multifarious viewshed information for every (sample) point in a DTM (Caldwell et al., 2003).

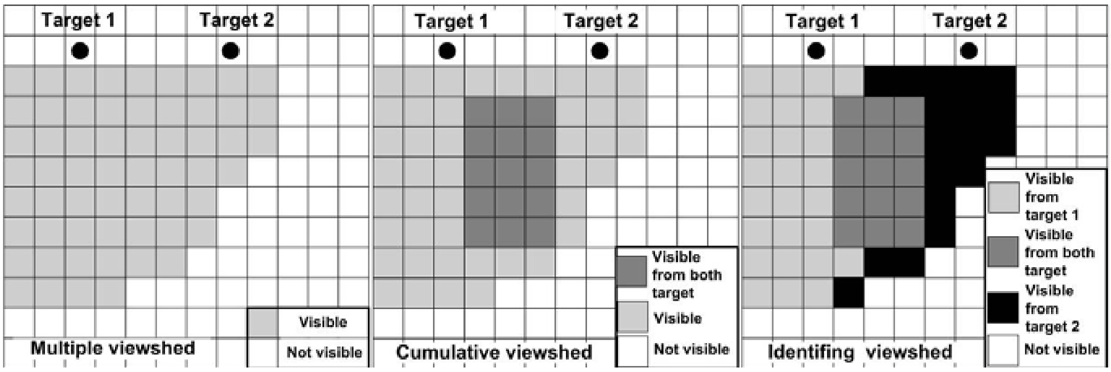


Figure 50: Principal (informational) differences among Multiple, Cumulative and Identifying viewshed for two hypothetical targets.
After Danese et al., 2011.

5.4. METHODOLOGICAL ASPECTS FOR THE VISUALIZATION OF DYNAMIC VIEWSHEDS FROM DIGITAL TERRAIN MODELS AND THEIR ANIMATION

The concepts and metrics described above provide a theoretical basis in order to understand what has been named by Llobera (2003) the 'visualscape' or by Llobera et al. (2004) the 'inherent visual structure of a landscape', while the means and techniques from the research papers analyzed above offer some methodological means and tools to achieve the aim of this thesis. As it has been partially mentioned, although these efforts:

- acknowledge the ubiquitous problem of computation complexity and time consumption, and tackle it by means of sampling observation-target points using random or regularly spaced samples, or (more often) topographically prominent features (e.g. Lee, 1994; O'Sullivan and Turner, 2001; Kim et al., 2004)
- extend the visibility information and visibility dominance to multiple observation/ target points (e.g. Rana, 2003; Kim et al., 2004)
- enable the potential of linear segments of observation like paths (e.g. Lee and Stucky, 1998; Caldwell et al., 2003; Lu et al., 2008)
- present a depiction of the overall (amalgamated) visual pattern along various routes (e.g. Lu et al., 2008),

they do not persist in the issue of how to visualize the evolution of the visual patterns (of visibility) for a non-stationary observer, which is the core matter of this thesis.

5.4.1. Requirements for the Dynamic Visualscape Visualization/ Exploration

Keeping in mind the above remarks, there is dire necessity for concepts and techniques to be adjusted so as to meet the needs of this thesis; in addition, it seems rather rational to enrich them with new ones. Given the fact that our aim is to provide spatial information (and knowledge) about viewshed along various paths/ routes in the form of dynamic visual 'magnitude' assessment while applying landscape/ data exploration, it emerges that it is vital that several major interrelated requirements be satisfied. Conceptually, there are two major aspects of those requirements: the one pertains to processing volumes of data and the respective computational load minimization; the other refers to the proper visualization of the changing 'phenomenon'. Yet, their simultaneous regard implicates interrelated requirements such as the selection of proper points of views and the creation of an optimized animation of the succession of viewsheds.

More specifically, one of the requirements is to determine the locomotion paths or routes within a landscape. Pfalz (1976) has suggested surface networks consisting of locations with topological significance such as peaks, pits and pass points, and points along ridge and valley lines for a consistent 'picture' of the landscape to be potentially rendered (Li, 1990; O'Sullivan and Turner, 2001). Since knowledge of the topology of the terrain, in general, can adequately assist in various applications (Morse, 1968) and since such networks, in particular, can serve as condensed/ compressed surface descriptors entailing an 'automatic abstraction process', they could "offer the potential of being a kind of 'road map' for the exploration of interesting regions of either a known, but very extensive, surface or an unsampled surface over a known domain" (Pfalz, 1976: 92-93). Our thesis demonstrates an attempt to explore the visibility structure of an extended landscape without any 'guide', other than significant topographic features. To illuminate this point, the rationale backing this undertaking is the following: in contrast with the utilization of multiple viewsheds (visualscapes) in the context of terrain analysis (i.e. landscape visual perception) on either cases of assigning values on each of the elected points (observers/ targets), or on cases of generating paths which tend to minimize some of the metrics of visibility, herein we address the issue of an active visualization of the space-time pattern fluctuation of what can be seen/ cannot be seen on a terrain (landscape). Particularly, our efforts converge at creating animations that provide this dynamic representation of these changing distributions in a (visual) way, without which it would not be possible to gain so much insight of these (changing distributions) with relation to their 'changing generating locations'. Locations along linear features, ridge lines, valley lines and pass lines[51] can serve at this exploration, corresponding to the locations of 'locomotive observers'.

Nonetheless, even though their placement is decided to occur on such predefined routes, this venture calls for location (i.e. viewpoints) selection in terms of proper spacing intervals, which is another crucial requirement. This density of viewpoints is of pivotal importance for it determines on the one hand the computation load and duration[52], while on the other it influences the

[51] Pass lines are conceived as linear features that pass through a saddle point perpendicularly to the pertinent ridgeline.

[52] The size (extent and resolution) of a DTM is considered as an 'independent variable' for the computation time, as it has been chosen on the grounds of a relatively high-resolution representation/ depiction of the landscape topography. It will be of concern only in relation to the spacing intervals of the viewpoints (see next Chapter).

geovisualization of the viewshed changes with observer's motion. This approach has been advocated by Nakos (1990: 35) – even though in a different context –, who asserts that "the specification of this minimal number of points"[53] prompts the adherence to the "required accuracy in the digital cartographic data base", while at the same time it does not induce the alteration of "the character of the cartographic phenomena", eventually leading to the proper compression of the pertinent data volume. Yet, as described in § 5.2.2., viewshed is not a local surface parameter and although it is derived from a point (in question), it heavily depends on the 'referent' landscape as a whole; as an effect, it cannot be predicted accurately enough by merely implicating local properties (e.g. elevation/ curvature), or even topographic feature types: even though viewsheds from adjacent viewpoints exhibit high positive spatial autocorrelation, there is no safety in claiming that a small displacement will induce only small modification in the respective visual patterns (Rana, 2003; Kim et al., 2004).

Consequently, the most generic problem of discretization emerges, but with reference to a derived product in which its effects are probably rendered even more drastic: if the difficulty of "recognizing intrinsically continuous features" due to discreteness (Peucker and Douglas, 1975: 386) is further expanded to the generated visualscapes, which are only partially dependent on the effect of this local discontinuity, let alone their interrelation with the rest of the landscape, then this difficulty rather mounts. To explain it, if the variation of a local attribute (e.g. elevation) at two neighboring locations ($elev_{i,j}$, $elev_{i+1,\,j}$, where i, j symbolize the rows and columns of the matrix) in a DTM is of a given deviation from real values because of the discreteness effect, then the respective viewshed (pattern) deviation would be probably of at least the same (or greater) magnitude. Yet, theoretically, if and only if the interval between spatially consecutive points of view (on a route) was infinitely small – within a DTM with an infinitely fine resolution –, then their respective visibility patterns would tend to demonstrate infinitely small variations. Thence, a venture towards simulating the 'phenomenon' as it really evolves in the natural landscape, that is the analogue world, would equal to detour the principles and limitations of the digital environments, which is by definition impossible. A more pragmatic perspective would dictate to focus on crucial considerations such as the computation load and the visualization suitability. The latter is to be attained in terms of a sequence with a high successive viewshed coherence entailing all the major distribution changes, but in rather smooth transitions, keeping in mind the distinctive character of the derivative viewshed information and its inherent fundamental changes as a process on the real world. Given the fact that computation loads and durations are to be as low as possible – a requirement that needs no further elaboration –, then the quintessence of our research expands on the visualization parameters.

5.4.2. The Dual Role of Dynamic Visualscapes in Visual Landscape Exploration

[53] (when digitizing cartographic data)

Under this premise, the real question and our contribution lies fundamentally on '*which are the optimal points of view along a linear feature?* or '*how close is close enough for a multiple, dynamic viewshed analysis to be implemented along routes on different linear fundamental topographic features to generate proper visualizations?* And that is precisely because geo-visualization (exploration) is to be facilitated by animation: since each frame of the sequence would elicit a viewshed from each viewpoint, or what Gibson would call "a pause in locomotion", then a consistent animation would convey and reflect all the crucial pattern changes in a smooth sequential transition, towards gaining insight of the 'process of what is visible and what is not visible as one moves'. Since animation is capable of providing information for what is between two frames (Peterson, 1995), it should be harnessed in a manner to approximate the evolution of the real process. Therefore, the solution to this matter is, on the one hand, the experimentation on various intervals on different topographic features and the subsequent analysis and evaluation of the results in terms of the visual (subjective) assessment of the visualization, while on the other the statistical analyses of qualitative and quantitative inputs and (numeric) results, and their subsequent explanation with reference to the phenomenon and processes at work. To elaborate, in the (geo)visualization corner of the cartographic cube (MacEachren, 1994a), visual exploration of animated representations – i.e. the visual spatio-temporal data exploration – precedes the application of statistical techniques (Blok, 2005a).

Rana (2003) has used the 'skip interval method' by which he has generalized elected topographic features 'by an equal and decreasing number' of the target point set and has compared the quality of the produced visibility patterns towards verifying the significance of the topographic features as targets, yet in a static mode. Within a different context, Ehlschlaeger et al. (1997) have promoted another, complementary role of animation at its exploratory dimension, which is to provide additional, added value information about the uncertainty of the data and the way that this uncertainty affects the application under study. In the case of this thesis, if we created several animated sequences consisting of series of viewsheds generated at different point intervals, then "the process of interpolation" that produces "a large number of statistically valid dependent realizations" (Ehlschlaeger et al., 1997: 391) could be replaced by the previous process, being, so, capable of electing from a sufficient number of alternative visualizations the one(s) minimizing the uncertainty. So, this unimpeded, 'quasi-natural' and time-effective manner to view a large influx of data (Dorling, 1992) could facilitate evaluation of the best visualization from the side of uncertainty reduction, without neglecting the concern of computational load mitigation. However, apart from the subjective[54] visual assessment of landscape exploration,

[54] Inter-subjectivity could be an approach for the assessment of the proper animation, but this kind of research is outside the scope and the limits of this Master's thesis.

and its potential for 'self-assessing uncertainties', statistical analysis could provide a more objective 'status of reference', or a means for 'calibration'. The calculation of indices or metrics arising from the processing of numeric results on data/ information extracted from the dynamic viewshed computation, could both promote the understanding of the flow of the process, and serve as benchmark for the consistency of the animation with reference to different intervals' and topographic features' election.

From the abovementioned, the animated visualization becomes both a medium to explore the inherent visual structure of the landscape – but, 'under the suffering' of discretization –, and a facilitator for the assessment of the 'quality' that stems from the placement of the intervening stages of locomotion observation, being a 'prosecutor' of discretization. Therefore, a succinct but accurate enough description of this venture could be summarized as "*which are the most suitable locations within each topographic feature so as to optimally approximate the process at work minimizing uncertainty and maximizing animation coherence, while in parallel mitigating the computation load/ duration and automating the procedure?* (Fig. 51). In other, even simpler words, we search for the minimum number of viewpoints that yield the best attainable geovisualization in an adequately automated procedure. The latter one, even though it is a matter not been regarded loud and clear until now, it is, in fact, a *conditio sine qua non* for this attempt, diffused for both the materialization of the application, in particular, and the corroboration of the present conception, in general. As it will be proven in the application of the next chapter, except for the stages that pertain to manual actions/ processes, such as the selection of routes[55], or the stages that require critical evaluation, such as the overall assessment of the animation properness, the establishment of a viable method or technique capable of integrating the abovementioned requirements hinges upon the automation of the whole workflow. This automation refers to the suitable and integral organization of data and derived information in file directories, and the utilization of suitable tools and code in order to generate and manipulate variable sets of points, their respective various types of viewsheds (similar to those at the figure of the previous section), and to extract useful numeric values. Consequently, this enterprise embraces the modeling of the workflow. As such, it refers to a lower level of connotation, i.e. an implementation level; so, it is described in the next chapter. While Figure 51 constitutes the conceptual scheme of the aspects involved in landscape visual exploration – functioning this dual role –, Figure 52 is the flowchart of the succession of actions, processes and decisions directing its materialization – under the perspective of its dual function. This materialization takes place as an *ad-hoc* experiment conducted in the next chapter. No matter

[55] Prominent topographic features can be derived automatically (e.g. see Wood, 1988), but in our thesis this was not the case. Besides, our aim was not to fully characterize/ describe the landscape, but rather to create route segments in linear topographic features to apprehend what viewshed change visualization can reveal, and which is an optimal way to be implemented.

how other questions such as 'in what ways are constant or variable intervals proper?' or 'would small systematic displacements on a series of elected points bring about significant changes in the dynamic visualscape?' are considered, yet deliberately are not answered in this thesis.

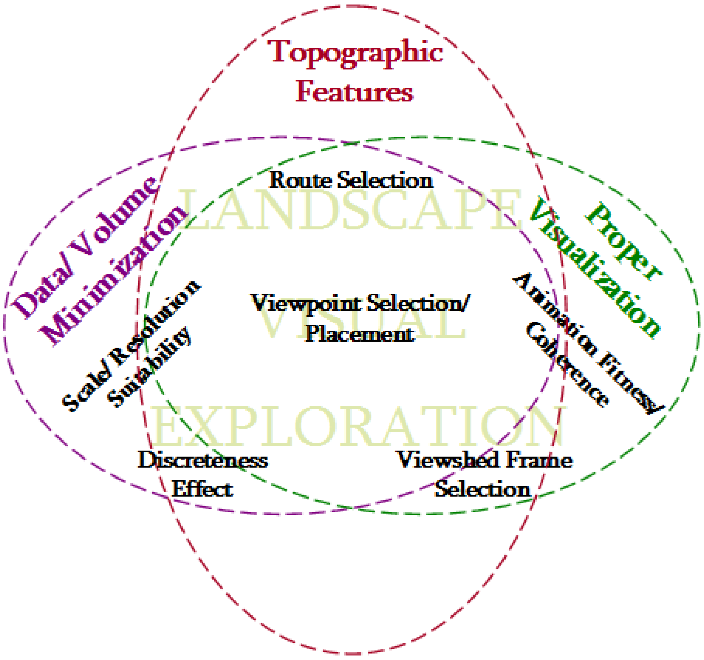


Figure 51: Interrelated aspects for landscape visual (visualscape) exploration: a conceptual scheme.

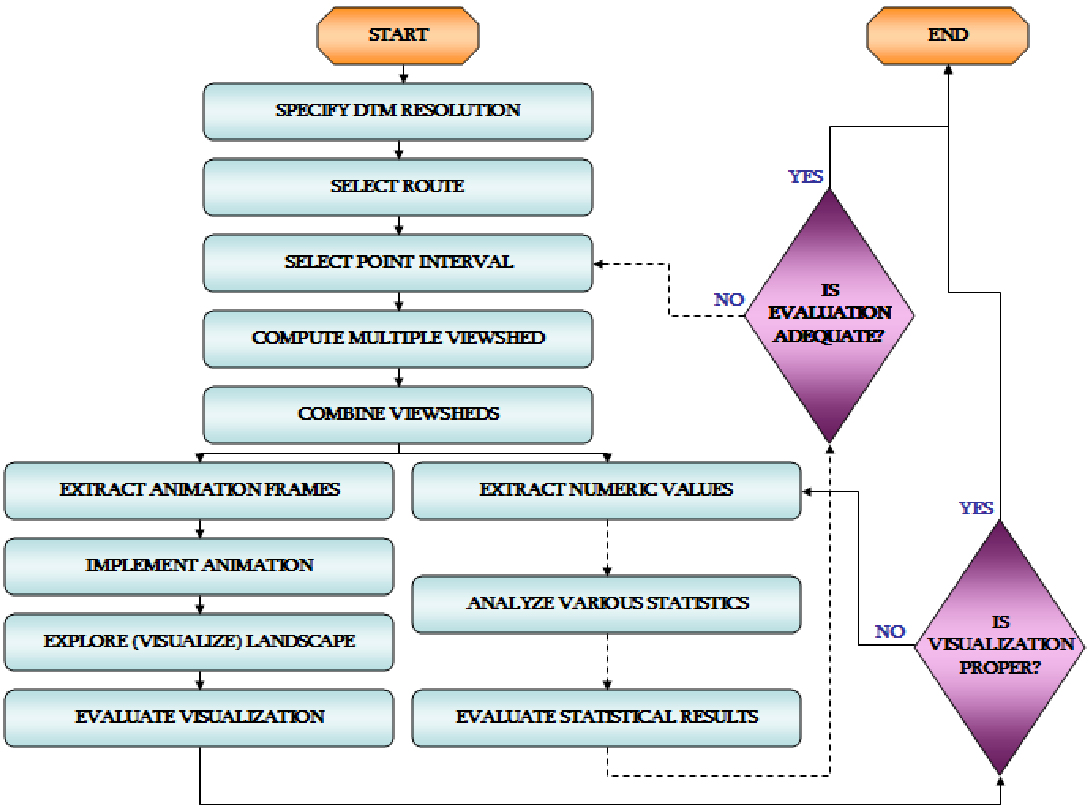


Figure 52: Flowchart for the dual role of viewpoint selection on topographic features. The results of visualization are utilized to i) (initially) analyze, explore and gain insight of the visual landscape and ii) (subsequently) assess the appropriateness of the viewpoint intervals selection.

6. ANIMATED VIEWSHED ANALYSES AND VISUALIZATION FOR SEVERAL LINEAR TOPOGRAPHIC FEATURES IN A MOUNTAINOUS AREA

"[[…] We never, even in experience, attribute to an object the notion of succession or effect (of an event – that is, the happening of something that did not exist before), and distinguish it from the subjective succession of apprehension, unless when a rule lies at the foundation, which compels us to observe this order of perception in preference to any other, and that, indeed, it is this necessity which first renders possible the representation of a succession in the object."]

Immanuel Kant

At this phase of this thesis, it is time that we carry into effect all the abovementioned theoretical background and methodological tools. More specifically, we take the plunge to implement a dynamic visualization of changing visible regions of a landscape by animating viewsheds from different observation points by taking into consideration all the aspects analyzed and described in the abovementioned chapters. Thus, each chapter equips us with a different perspective to materialize our venture integrating all of these perspectives into a more generic approach.

6.1. MATERIALS AND DATASET

6.1.1. Study Area Overview

Towards visually exploring a landscape by animating its viewsheds, a region including a variety of topographic features without at the same time demonstrating extravagant roughness is required. A landscape with those traits is found in Wyoming, USA, North America. So, the area of interest for this thesis is a 25-km^2 rectangular one[56], situated on the fringe of Bridger-Teton National Forest, at the Jackson Ranger District[57]. In essence, this area lies south of the Grand Teton National Park, with its centroid being approximately 95 km east of Idaho Falls, 25 km south of Teton Village and 15 km south-south-west of the town of Jackson (Wyoming). Located at the 'intersection' of Teton Range (a range expanding northwards) and Wyoming Range (a range expanding southwards), it is partially surrounded by Snake River – the river adjoins the study area mainly northerly and easterly (Map 1).

[56] Exact rectangle x,y coordinates – top left: 509570, 4803744, bottom right: 514574, 4798752.

[57] The area is not entirely within this National Forest: a little portion lies outside the forest.

Whereas the main portions of the ranges previously mentioned and the adjacent Wind River Range are rugged, the study area, although mountainous, exhibits a relatively even relief, sliding gently to the neighbouring (easterly) Jackson Hole, i.e. the valley/ alluvial plain generated by the Snake River. The moderate elevation range (447,37 m) between minimum/ maximum elevation values (1889,72 m/ 2337,09 m respectively), and the little standard deviation of 77,65 m for a mean of 2064,10 m, show this relative terrain smoothness. Concentrating on the landscape of concern, its main topographic feature is an oval-shaped mountainous landmass with a prominent ridge-line running NW-SE the landscape; this ridge is interrupted by a saddle (pass). Moreover, this elevated mass is well-defined by streams, creeks and valleys environing it. The southern part of the landscape is carved by a meandering stream exposing flat riparian regions, whereas the north-eastern border of the mass is bounded by a narrowly-notched valley created by a creek which flows north-eastwards, ending up to the Snake River. Another valley much wider than the previous is created at the east side of the mountain. Other notable features are some depressions (pits/ sinks); the more prominent one is situated at the centre (and a little northeast) of the study area, while the second one lies at the valley adjoining the south-east end of the mountain (Map 1). Last, the area includes a residential area (Red Top Meadows) and a network of roads and paths (some of them coincide with the creeks or the ridge line).

In a manner of speaking, the area of concern is selected upon the existence of several physiographic/ topographic features, thus comprehending distinguishable topographic features: ridges, valleys and passes. As for the delineation of its extent, the fundamental criteria have been: the volume of the data – i.e. the underlying terrain being represented by a DTM – and the requirements for proper viewsheds to be generated. The former has been dealt with as a compromise between planimetric resolution (accuracy), data volume, suggestions from the pertinent literature and our research aims, whereas the latter one by appropriately shaping the extent in a way that the topographic features be located at central sectors of the area and providing adequate space for the visible regions to occur, in order to mitigate the edge effect (see § 5.2.2.2., § 5.3.2. and Map 2). Moreover, this election has emerged due to ecological/ aesthetic and utilitarian reasons: As an effect, this 5 km * 5 km mountainous landscape at a forest region characterized by relatively mild relief variations and entailing only minimal anthropogenic infrastructures such as roads and paths appears most congruent with our scope of dynamic landscape visualization.

6.1.2. Data Acquisition and Pre-processing

The fundamental data, being virtually the only independent input for this case study application are the elevation data. To a certain extent, the availability of reliable, dense, and accurate elevation data has determined the election of the study area. To elucidate, as mentioned above, the NSF Open Topography portal

(Open Topography, 2013) provides web-based browsing access to datasets with such characteristics in several regions of the USA (with focus on environmentally/ ecologically sensitive areas such as National Parks or National Forests). Since data has been collected by LiDAR technology capturing a very dense point-cloud at up to 1 m planimetric resolution, we would be able to get a DTM at the finest possible resolution of 1 m. Nonetheless, it has emerged that for the requirements of the application, a 4-m DTM not only would suffice, but it would be also most appropriate. It should be also noticed that our DTM is a DEM, representing only the underlying topographic relief and not other features (e.g. vegetation).

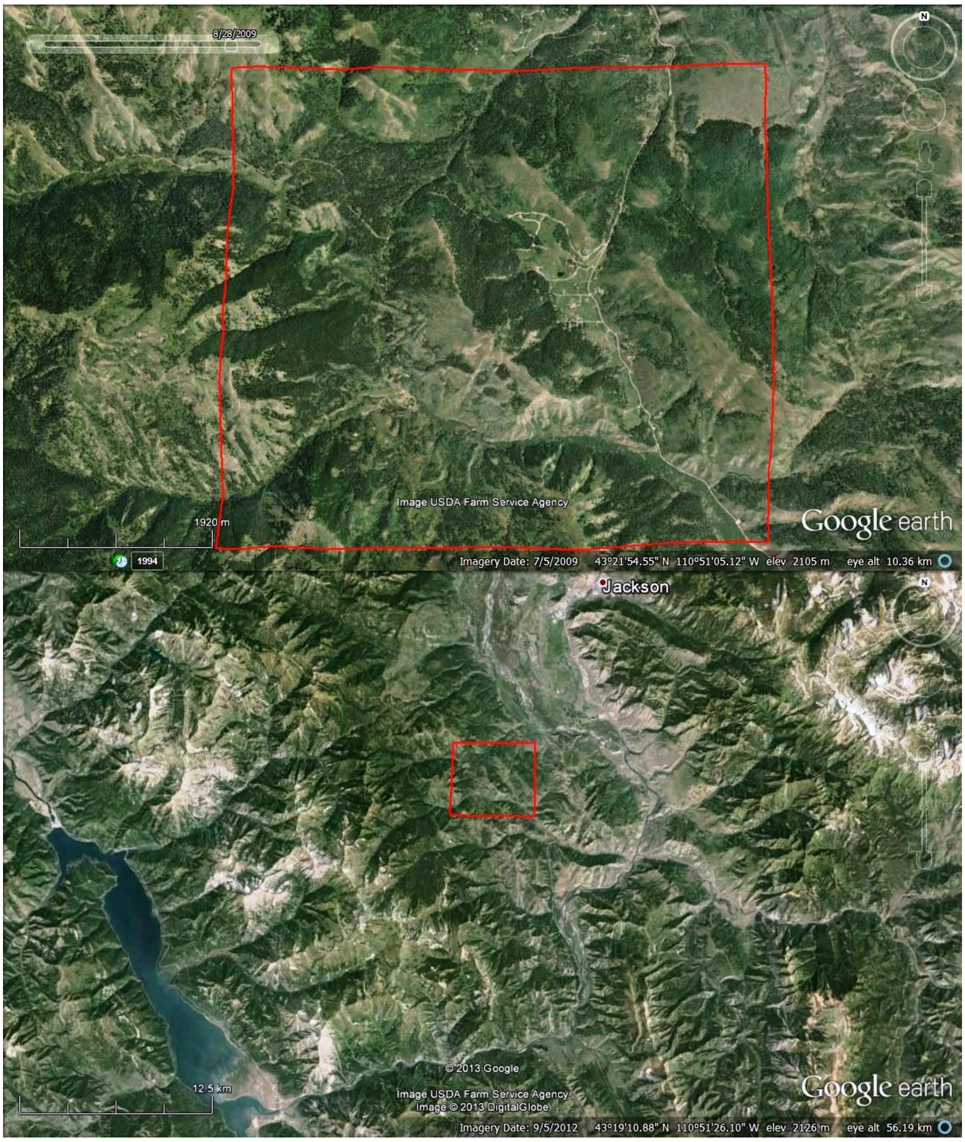
The reasons both originate from literature and relate to practical reasons. In § 5.2.1.2. and § 5.2.2.2. it has been shown that resolutions ranging from 1 to 10 m are the most proper for geomorphological applications; besides, the 4-m grid has been suggested for viewshed computation in particular. In addition, the gradual grid resolution refinement induces an abrupt (exponential) increase in DTM size and viewshed computation time[58] (Table 10). So the 4-m is deemed to be advantageous from this perspective as well. Besides, the vegetation cover is not considered here – although it can significantly modify the viewshed outputs – for it introduces an additional complication, not assisting this thesis' objectives. Yet, beyond these rather lucid suggestions, an implicit one emanates from the sampling theorem, as it will be described below. So, in practice, a 1-m gridded DTM has been extracted from the Open Topography portal; since the interpolation technique is not of concern because the elevation point sampling has been very dense and because the issue of interpolation lies outside the objective of this thesis, the DTM has been derived by implementing a simple IDW interpolation technique (see § 5.2.1.4.) in the environment of the portal. The generation of varying resolution DTMs was attained by implementing multiple re-sampling algorithms upon the highest resolution (1 m) DTM in the ArcGIS (*ArcMap*) (10.1.) environment. [59]

More specifically, at a stage before implementing the main workflow of the viewshed computation from appropriate locations-viewpoints, some pre-analytic actions are of importance. After inserting the DTM raster file in the GIS, the first action pertains to its geo-referencing. Since the study area befalls to the *12th NAD* (North American Datum) *Zone*, this is reflected in the respective option in ArcMap [Layers – Coordinate Systems]. Then, the volumes and number of cells are inspected for the DTMs of varying resolutions (see above), while the viewshed computation from one viewpoint reveals the time required for each generated DTM. Afterwards, for an augmented perception and apprehension of the

[58] The computation durations apply for an Intel Core i5-2410M CPU/ 2,30 GHz, and for the typical viewshed algorithm implemented in ArcMap 10.1.

[59] Algorithm implementation functions with the prompt of tools in ArcGIS. The *Resample* Tool (Data Management-Raster-Raster Processing-Resample): "alters the raster dataset by changing the cell size and resampling method".

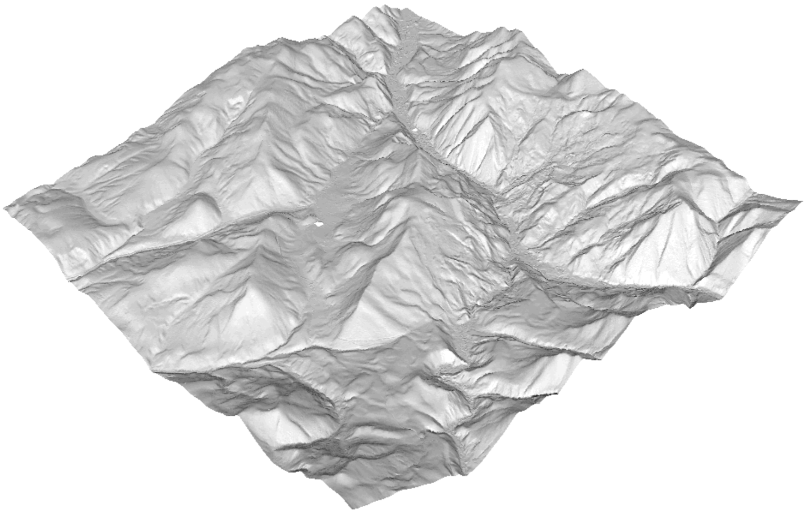
landscape's topography, a shaded relief (hillshade) is created (see § 4.4.3)[60]. The identification of the topographic features in particular, and the reconnaissance of the landscape/ terrain in general are further facilitated through some oblique views of the hillshade at the *ArcScene* module (Fig. 53).



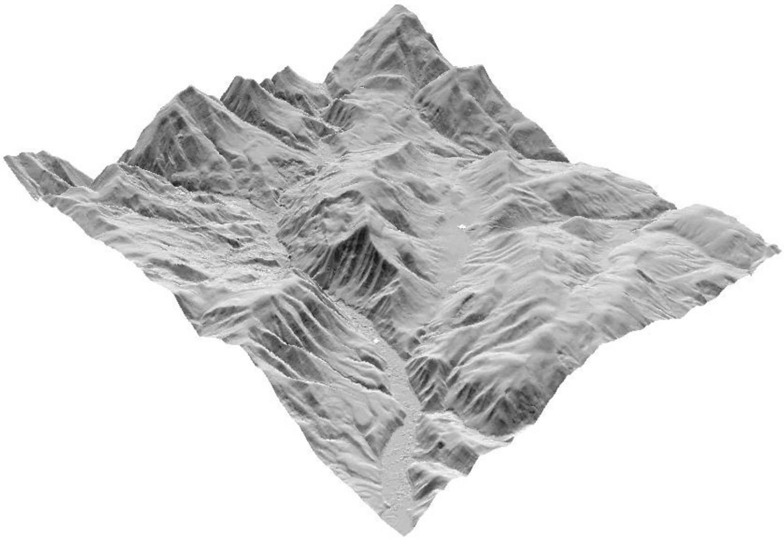
[60] In ArcGIS, this a standard function of the 3D Analyst Toolbox [3D Analyst – Raster Surface – Hillshade]; the parameters values of are set to the default ones (azimuth: 315°, altitude: 45°).

Map 1: Satellite images depicting/ locating the area of interest from finer (top image) to coarser (bottom image) geographic scales.
Source: GoogleEarth.

a



b



c

d

Figure 53: 3-d oblique visualizations of the landscape (hillshade) of concern from different perspectives: NE-SW (a), NW-SE (b), SE-NW (c), and SW-NE (d).

Table 10: DTM characteristics and viewshed computation time for one observation point across several resolutions for the study area.

DTM Resolution (m)	DTM # of cells	DTM Size (MB)	Viewshed Computation Time (sec)
1 m	24.964.982 – 5002*4099	95,23	27
2 m	6.242.496 – 2501*2496	23,81	7-8
4 m	1.561.248 – 1251*1248	5,96	2
10 m	249.500 – 500*499	0,95	< 1

6.2. METHOD – PROCEDURE

6.2.1. Principles and Limitations

Provided that the visualization that is to be implemented fundamentally involves the election of properly located/ spaced viewpoints, the rationale backing our options relies heavily on the sampling methods and intervals and (see § 5.2.1.4.). As it has been extensively demonstrated in Chapter 5, a terrain (landscape) can be described by capturing elevation or other terrain parameters measurements such as viewsheds from prominent topographic features (F-S method). Yet the generation of a fly-by calls for a linear pre-determined fly-path or route; (see § 4.4.). In this sense, linear topographic features can respond to this requirement for they are able to both hold accessional (aside from locational) land surface information and deploy change of this information in one dimension – via topographic cross-sections. On the other hand, the application of the sampling theorem in such topographic profiles on a DTM implicitly yields either the grid resolution for given average spacing between inflection points, or, inversely, the interval of inflection points for a given grid resolution. This means that for our 4-m elected DTM, the inflection point interval should be at least 8 m, and considering that the profiling can occur diagonally – the diagonal of the cell size is approximately 5,66 m –, the spacing should be over 11 m. So, in this case study we employ a 10-m base spacing interval between viewpoints for viewshed computation, i.e. the most narrow/ refined spacing to reveal viewshed variations, while two other integer multiples of 20 m and 40 m viewpoint intervals are utilized to make comparisons related to the visual exploration, always taking into consideration computational load issues.

However, because viewshed is a surface parameter that combines both local and non-local terrain characteristics, it is not so straightforward a procedure to determine a ‘visibility continuum’ from discrete viewpoints (see § 3.3., § 5.2.2., §

5.3.2. and § 5.4.). Nonetheless, the rule elicited from the sampling theorem can serve as a reference (a kind of benchmark) for 'distinguishing' the significant viewshed variations along profiles of linear topographic features. This difficulty emanating both from the nature of occurrence (inherent properties) and the digital derivation of viewsheds is further complicated by another difficulty, which, in our thesis, arises as a limitation. As previously mentioned, the geographical extent of the landscape of interest, and the spatial distribution/ patterns of the visible cells over it and further away pose such a limitation in the shape of the edge effect; since real-world visibility horizons extend tens of kilometres in cases of good atmospheric conditions and our area of interest is only 25 km^2, this means that the latter area (being the maximum available area – with a maximum of 3,54 km 1,5-d horizon – from the centre of the grid/ landscape, to its four corners) probably will not encapsulate all the visible regions emanating from viewpoints within our selected are – although this depends on the landscape type (see § 5.2.2.2.). Therefore, viewsheds can be possibly 'truncated', while the degree to which this truncation of their spatial pattern occurs within this region cannot be estimated or inferred; so, this edge or 'truncation effect' could play a significant role in modifying the viewshed visualization and the estimation of visible regions among different routes and different viewpoint intervals. More specific concerns emerge when it comes to the potentially differential effect of the geographic extent upon different viewshed routes, meaning that from some routes the viewsheds may remain (even practically) unaltered while for others, a growing geographic extent might bring about a dramatic alteration on their patterns.

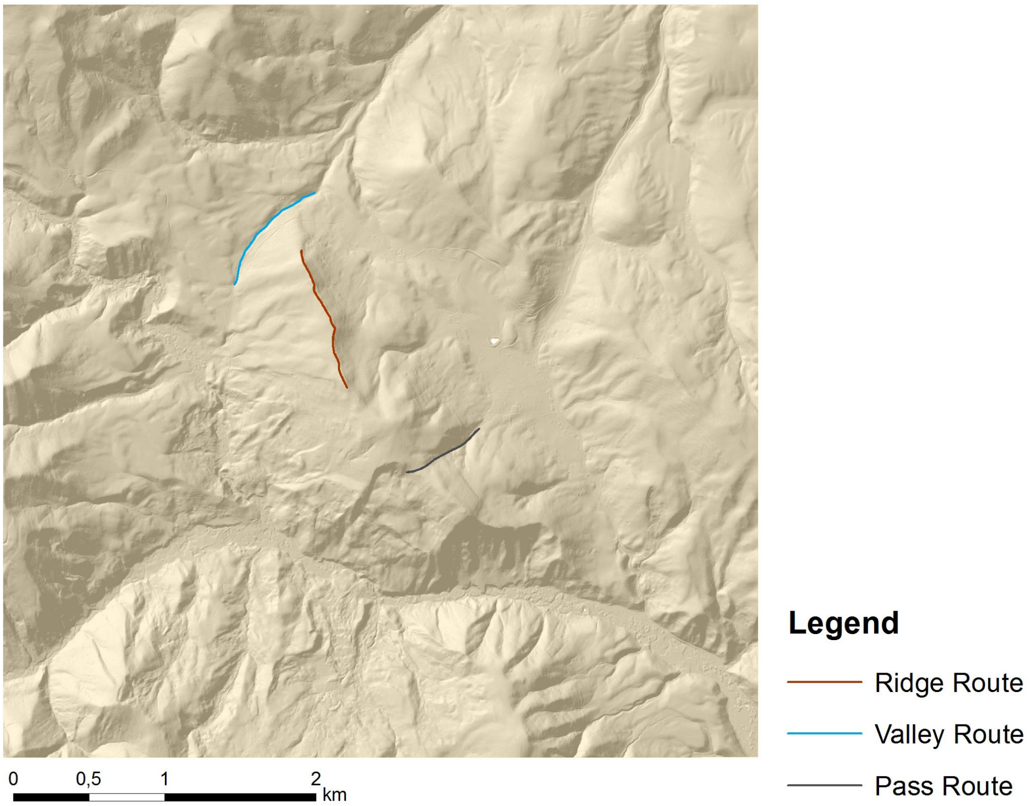
So, these considerations are inextricably linked to the realization of viewshed exploration and should be borne in mind when implementing the animation and when interpreting the visualization results. Towards mitigating the potential severity of the geographic extent limitation there is an attempt to locate viewing routes (*viewroutes*) away from the boundaries of our area of interest – i.e. near its central region. Moreover, we make the assumption that the occurrence of viewshed within the study area is representative for the different viewroutes (i.e. if the viewsheds where computed for expanded geographical areas, no significant differences would emerge at the comparison among these routes (e.g. the ratio of the numbers of visible cells among all viewroutes would remain relatively unchanged)). Other crucial issues pertaining to the cartographic (dynamic) visualizations' cognitive aspects are treated mostly in a practical manner; in essence, some of the core aspects like sequencing, segmenting (data filtering), smoothing and split attention management are embedded in the general design of the visualization: the election of proper viewroutes, their break down (segmentation) into separate viewshed animations with a duration of less than a minute, the enabling of morphing/ tweening techniques, the consideration of extrinsic distractions by insufficient cartographic design and the exigency for reproducing the animation over and over again (looping) meet such cognitive requirements.

In a sense, the most critical step towards the viewroute/ viewpoint designation is elicited by abiding by the rules originating from 1-d and 2-d sampling methods. Yet, these rules are far beyond being theoretically grounded for a robust deductive strategy to be established; thence, the empirical, inductive method is to be employed as well. However, this empirical, data-driven method entails the automation/ modelling of the procedure due to the large amounts of data being explored. The implementation tactics towards the modelling of viewshed computation from viewroutes are presented in the following.

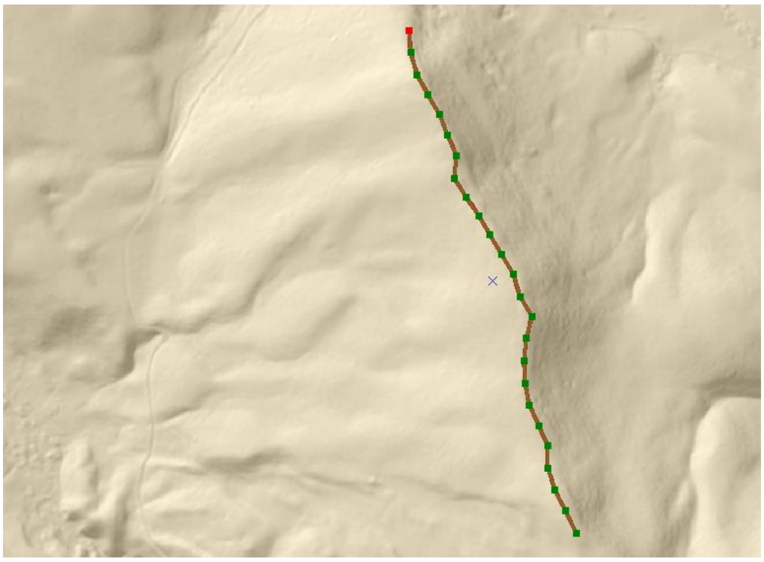
6.2.2. Semi-Automated Polyline Feature Digitization

After manually (visually) identifying the major linear topographic features of concern by harnessing the fine resolution hillshade raster surface[61], elected routes on them where digitized. For this digitization to be both accurate enough, and to be susceptible to its automation, the *streaming digitization mode* within the environment of the *Editor* Toolbar was implemented. This mode allows for the creation of linear geographic entities at predefined vertex intervals (streaming tolerance), as the subject of digitization drags the cursor over the desired direction. Thus, beginning with the spacing interval of 40 m (10 times the cell's size dimension, or about 7 times the size of its diagonal), intervening vertex intervals for 20 and 10 m have emerged utilizing *mid-points* (from the *Snapping* Toolbar – *Editor* generic Toolbar) of each successive digitization. Thus, for each of the three different topographic features, three linear segments were produced according to this varying streaming tolerance digitization (Fig. 54). Consequently, a polyline shapefile has been created maintaining all nine polyline features as distinct records. So, in this feature layer there is all the data needed (including the DTM previously been generated) to perform a viewshed analysis that utilizes several viewpoints, albeit in a latent form. The next step would only call for the extraction of the corresponding points; nonetheless, if this would be effectuated manually, it would be a rather tedious task, not adding utilitarian value to the procedure.

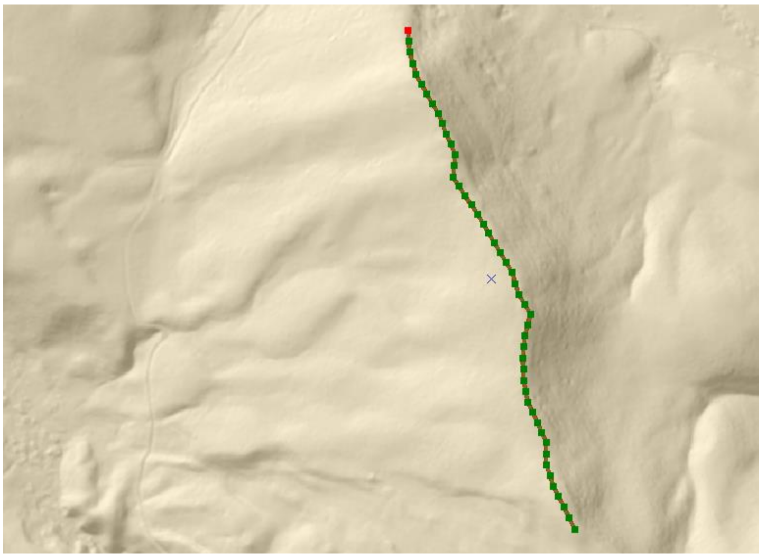
[61] The 2-m hillshade has been elected as the most suitable surface to render the landscape due to accuracy-volume considerations.



Map 2: Three routes (viewroutes) for visual exploration on different topographic features on a hillshaded relief of the study area.



a



b

c

Figure 54: Various intervals of digitization for the Ridge(line) Route: 40m (a), 20m (b), 10m (c).

6.2.3. Modelling the Workflow

No matter how instinctively fast can the manual 'run' of a standard Tool (function or operation) from the ArcGIS Toolbox be done after several repetitions, it cannot surpass the speed of an automated procedure when it is about tens or hundreds of iterations; even more important, though, is the convenience and the 'replicability'-repeatability/ extensibility that such an automation involves. As an effect, the beneficial potential for a *model* (or *models*) to be harnessed for the production of a multitude of outputs through a multiple run of a rather 'mundane' operation is very high. This potential is augmented even more in the case several sequences of operations are to be performed.

Thus, modelling can be a valuable solution; in ArcGIS, it is facilitated by Model Builder. As being stated in the ArcGIS Model Builder Help:

> *"ModelBuilder is an application you use to create, edit, and manage models. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. ModelBuilder can also be thought of as a visual programming language for building workflows."* (ESRI, 2010).

In fact, its importance to our scope is so great that without it the realization of our thesis would be either a very slow, manual procedure, or it would request an extensive and elaborate (low-level) programming code. Reaching the core of this case study, the exact actions/ decision been made and tools utilized within ModelBuilder are comprehensively described in the following.

6.2.3.1. Viewpoint Organization

As discussed above, the issue of converting the linear topographic features into separate point layers constitutes the first prerequisite. Since these linear segments have been digitized under different streaming tolerances, their vertices are the key towards this conversion (Data Management – Feature Vertices to Points[62]). Furthermore, the coordinates' assignment on each derived point has been emerging as equally essential to the needs of the thesis. So, their X,Y coordinates were retrieved by the relative function (Data Management – Add XY Coordinates), while the Z coordinates were elicited by the DTM (Spatial Analyst – Extract Values to Points[63]). However, for this workflow to yield the desired outputs, a means by which it runs for each record or row of the polyline shapefile is required. The use of the *Select* Tool (Analysis – Select[64]) and the insertion and utilization of the proper *Expression* (ModelBuilder Window: Make Variable > From Parameter > Expression) that harnesses the FID of the shapefile accomplish this task. In particular, by using the Expression: ''FID' = %n%', by adding to the suffixes of the outputs the same string (%n%), and by running the model for 9 *iterations*, nine different outputs – the name of which would differ only in number of the suffix (e.g. Point0, Point 1,…, Point8) – are produced. This could be enough for another case, but not for ours in which there is need to classify into both topographic feature and interval. For this reason, the model is broken down in three parts: the Expressions are ''FID' = '%n%', '%n%+3' and '%n%+6'' respectively, while the number of iteration is 3 (Fig. 55). In such a way, three triads of (observation) point layers have been produced (Poi_Z_Pass0/1/2, Poi_Z_Ridge0/1/2, Poi_Z_Valley0/1/2), the prefixes of which reflect the

[62] This tool "creates a feature class containing points generated from specified vertices or locations of the input features".

[63] This tool "extracts the cell values of a raster based on a set of point features and records the values in the attribute table of an output feature class".

[64] This tool "extracts features from an input feature class or input feature layer, typically using a select or Structured Query Language [SQL] expression and stores them in an output feature class".

topographic feature, whereas their suffixes the space interval (0=40m, 1=20m, 2-10m).

6.2.3.2. Multiple (Dynamic) Viewshed Computation

Having prepared the requisite inputs (i.e. the points of view in separate feature classes) for viewshed analysis, then the automation of the procedure according to our aims is potentially feasible. So, at first, we need to create the discrete visibility outputs (viewshed) corresponding to each of the viewpoints. The outputs are to comprise the frames for the subsequent animations. The workflow applies for each of the nine outputs of the previous model. It begins with the selection of the first record ("FID = 0") and afterwards the viewshed is computed for it (the other input is the available DTM). After all the necessary iterations (depending on the number of points on each feature class), all of the viewsheds-frames are computed by a process analogous to the abovementioned one (Expression: "FID' = %n%' and addition to the suffixes of the output of the same string (%n%)). In this way, it is ensured that the FID number of the point of view is the number of the suffix of the corresponding viewshed.

Apart from these computations, it has been deemed that the extraction of the numeric values of each viewshed output would be most purposive for further statistical analysis (which will be described in one of the following sections). Thereby, an operation that would convert the count[65] of visible and invisible cells on each viewshed and store them on suitable digital structures is employed (Conversion – Table to Table[66]). This operation is implemented and managed on ModelBuilder at a particular way: initially, a folder (or a geo-database) is defined, and then the name of the table with the extension '.dbf' is specified. So, a set of tables that correspond to each viewpoint and to each viewshed is generated. And because our interest lies primarily on the visible cells (since the sum of cells is always the same), the count of visible cells only are stored on these one row-tables, utilizing the expected Expression, that is 'VALUE=1'.

[65] In the next section the ArcGIS viewshed outputs are elucidated

[66] This tool "converts an input table to a dBASE or geodatabase table".

Figure 55: Workflow model of the conversion of the initial polyline feature class maintaining all the topographic feature routes into nine (9) separate point feature classes (shapefile layers) with XYZ coordinates.

6.2.3.3. Dynamic Intersected Viewshed Computation

If this analysis and exploration was not to be evaluated by some benchmarks outside the visualization of the visual landscape itself, these actions/ operations organized in a modelled work flow would be sufficient to create the pertinent animations. In this thesis, however, there is an attempt to utilize the capabilities of the workflow automation in order to provide a more rigorous research. These capabilities, though, provide only the technical (though critical) substrate to materialize some geoprocessing operations stemming from a theoretic perspective and conception. Herein, we introduce the *Dynamic Intersected Viewsheds*.

Nonetheless, before proceeding to the very essence of this modelling process, it is vital that we describe some of the 'vagaries' of viewsheds as data structures, and their response to analytical operations, when treated as inputs. In ArcGIS, the viewshed data structure is raster in principle, but it contains and manages the data as aggregate (agglomerations of) visible and not visible cells. So, a typical (binary) viewshed analysis from one viewpoint yields an output with two rows (records) registering these cell distributions; it also contains three columns (fields): the 'Rowid' – maintaining a separate id number for each record, the 'VALUE' – specifying whether the cells on this record are visible (value=1) or not visible (value=0), and the 'COUNT' – defining how many cells belong to each value (i.e. how many cells are visible/ not visible). In the case in which the viewshed from two or more viewpoints (simultaneously) is to be computed, then an output which maintains several records according to the number of these viewpoints emerges: for the generic case where *n* viewpoints are utilized, the number of records on the multiple viewshed's file is 2^n, since a (binary) viewshed output can receive two discrete values (0 or 1). In essence, multiple viewshed analysis, and more specifically the Observer Points Tool (3D Analyst – Observer Points[67]) implements viewshed analysis from different viewpoints, and it subsequently combines them in a new output in which the cells are classified in rows which correspond to non-overlapping aggregates of cells (or raster surfaces locations) that, in their totality fill the space (raster) and comprise the 2^n discrete cases that the cells of each row can represent with reference to the (number of) viewpoints been seen – ranging from *none* to *all* of the viewpoints (Spatial Analyst – Combine[68]). So, the spatial identification of cells according to their visibility from a number of viewpoints is based on defining suitable SQL Queries. The most prominent cases (and probably the most essential ones) are two: the cases (and the respective distributions and counts of cells) where a region is not visible from any of the viewpoints, and the regions that are visible from all of the viewpoints – (Cumulative) Intersected Viewsheds. Nonetheless, owing to the fact that from Combined Viewsheds (or *Observer Points* tool in ArcGIS) one can discern which raster surfaces locations can be viewed from each viewpoint, it could be considered a special type of Identifying Viewsheds (see Danese et al., 2011). In our application, though, this identification is unnecessary information, as it will be proven below, and thence, we cling to the notion of intersection.

After these necessary parenthetic remarks, it is now time we focused on our work. Provided that the visualization adheres to a set of spatially arranged points and, by extension, to viewsheds, their combination (and the identification of their spatial intersection) can acquire a dynamic character. While the operation of spatial combination/ intersection refers to the digital overlay of more than two (viewshed) layers emanating from more than two viewpoints, in our research which adopts an active perspective of locomotional perception, this combination could occur on sets of spatially successive view-points/ sheds. To elaborate – out of

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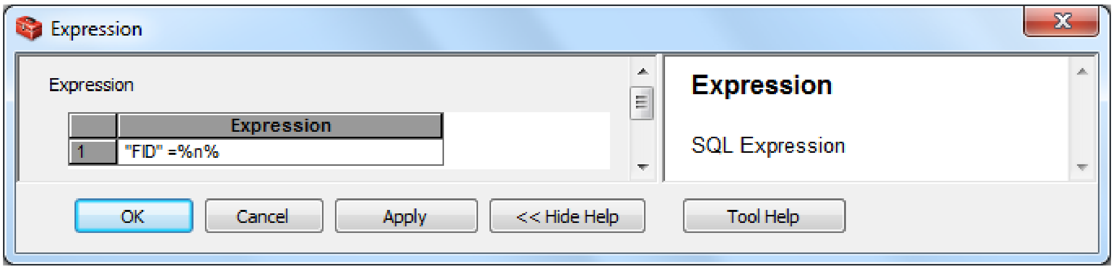
[67] This tool "identifies which observer points are visible from each raster surface location".

[68] This tool "combines multiple rasters so that a unique output value is assigned to each unique combination of input values".

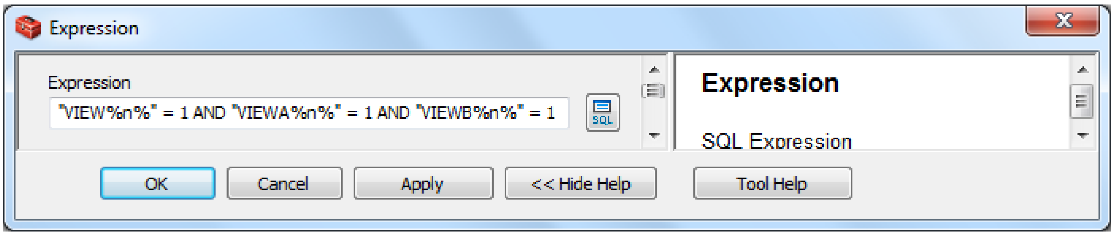
a set of properly spatially arranged viewpoints – if we initially regarded the common visible cells of three contiguous viewpoints and computed their viewsheds, afterwards the next three adjacent cells, and so on, until all the points were jointly utilized as 'spatial sequential triads', then a set of Intersected Viewsheds would occur. Conceptually, these viewsheds could aid to actively evaluate the consistency of the visibility change rate and the coherence of the animation, with reference to the topographic feature and to the viewpoint space interval – in terms of both spatial patterns and numeric values. In fact, the emerging spatial patterns could be compared on a visual exploration basis, whereas the figures associated with these patterns could be involved in a statistical analysis and evaluation. As Blok (2005a) suggests, visual exploration precedes the application of statistical techniques.

Given the potential significance of these Dynamic Intersected Viewsheds (DIVs) for this visibility exploration venture, their computation is indispensable. Moreover, the exploitation of a sequenced workflow of functions in the environment of a Model is a dire necessity for a visibility exploration both to worth implementing and to be convenient enough. Yet, the major matter here has been of technical origin, and more precisely: how could this combination apply iteratively for the suitable outputs from the previous tool implementation?, or, in practice, for a point feature class with *n* records, how could the Combine Tool run at the first iteration for viewshed_0, viewshed_1 and viewshed_0, at the second iteration for viewshed_1, viewshed2, viewshed3, and at the n-2 iteration for the viewshed_n-2, viewshed_n-1, viewshed_n? A 'fair enough' solution has been to select triads from the point layer and to impose different Expressions (on the Variables from Parameters). So, by using the Expressions ''FID' = '%n%', '%n%+1' and '%n%+2'', on each of the transient triad-points, having organized the respective directories and name files properly, and by running the Model n-2 times, the desired outputs can be yielded.

However, beyond the spatial information for animation and visualization, these outputs store the desired numeric information within one of each eight (2^3) rows. Thence, a means to extract this information in separate table is another required task. Once again, the Conversion tool of Table to Table facilitates this task, but with a limitation for this case. In contrast to the case of extracting the visible cells' count from one (at a time) viewpoint, where the solution has been simple and easy to implement, herein there are two issues perplexing the selection: the first pertains to the demand for simultaneous visibility values of '1', while the second relates to the fact that combined viewsheds arise from iterative sequences of geoprocessing tools. So, the matter cannot be solved by just selecting a single value or a specific rowid, for this single value simply does not exist, whereas the rowid for the requested record is not constant. Thereby, the first issue is tackled by selecting the requested record with a querying that involves the logical AND among the fields of the output, while the second, by adding the "%n%' suffix on each column (Fig. 56). Figure 57 presents the Model constructed in ModelBuilder Window, simulating the whole workflow without any manual intervention.



a



b

Figure 56: The simplest case of successive selection based on the FID (a), and the more elaborate sequential selection, based on the simultaneous satisfaction of visibility value to be '1' (b).

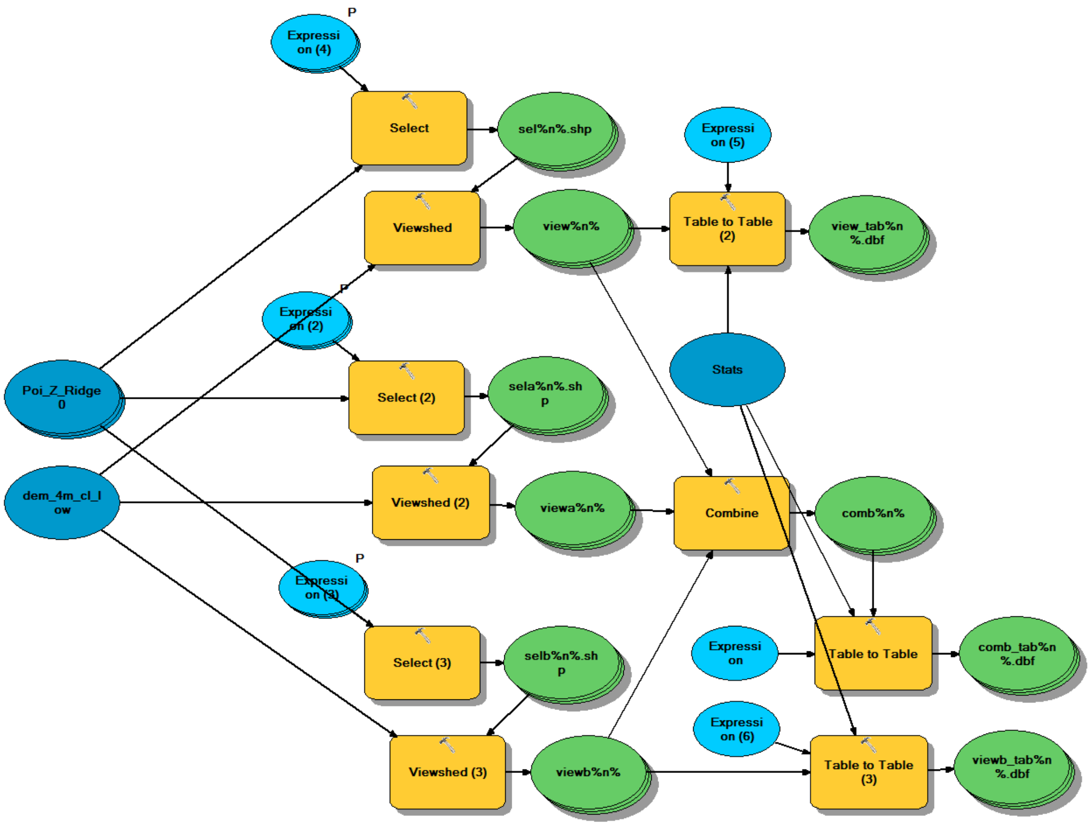
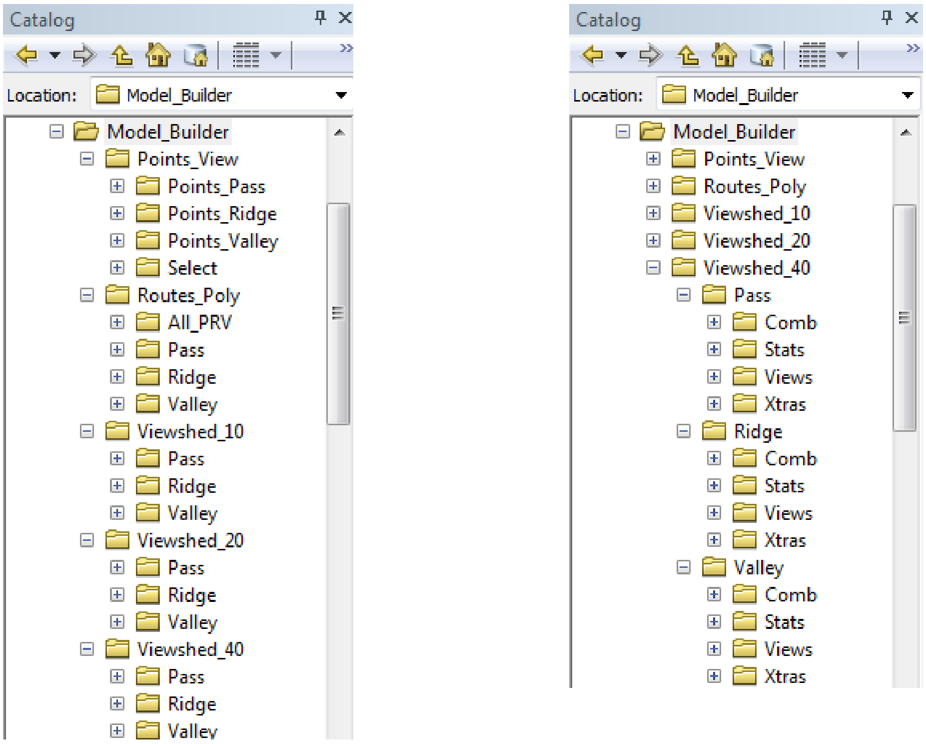


Figure 57: Model utilized to automate the workflow of the generation of i) multiple viewsheds and their numeric elements and ii) combined viewsheds and their numeric elements.

6.2.3.4. Overall Remarks

As it can be apparent, the previous Model entails the computation of the visibility regions for the same viewpoint two, or even three times. Therefore, the computation load is multiplied for the left side of the model, while the redundancy of spatial outputs is large. Although we admit this to be a deficit of our model, it can be easily understood that the benefits from the automation of a process easily overwhelms the demand for the minimization of computation load and the superfluity of information. Both in theory and in practice, it is by far much preferable to model and simulate a workflow at the expense of some additional time (that is some seconds on each run), than to try to address this time loss by manual means. In any case, since the number of viewpoints is the independent and determinant factor for the computation complexity, the temporal comparisons are to be made according to the digitization interval, until a more efficient better model can exclude this added computation burden.

Irrespectively of the previous discussion, it should be stressed out that the overall functionality and efficacy of the model relies heavily on the integral organization of the directories, and the conducive labelling of folders and outputs (Fig. 58). Even though, some of the steps required for the achievement of the aims of the thesis, could not be parts of this model, and, thus, be automated (i.e. they cannot be modelled). These steps pertain to the final formatting and layout of each frame (requisite for the animation) and the aggregation of the numeric values extracted above for further statistical analyses. These stages are described below.



a b

Figure 58: General directories' organization (a) and viewshed-related outputs directories organization for 40m viewpoint interval (b) for ModelBuilder simulation.

6.2.4. Extraction and Organization of Statistics

Although the elicitation and processing of the required static aspects of visible regions for each viewpoint (i.e. viewshed frames) are stages preceding in the flowchart of Figure 52, owing to the fact that the visualization/ exploration implicates several actions other than those been carried out in GIS, it is preferable to begin with the numeric extraction and its pre-processing. So, from the run of the first Model, the FID and XYZ coordinates are extracted into several dBASE file (.dbf), being managed as Excel files (.xls). Thereof, nine such files are created. From the second Model run, for each of the nine cases, lots of one-row tables are produced, bearing information about: i) the count of visible cells for each viewpoint and ii) the count of overlapping (intersected) visible cells for every three spatially consecutive viewpoints. Having organized the directories as mentioned above, these tables are to be merged into one table – for each case – maintaining the numeric information into rows of tables that follow the order (FID) of the rows of the abovementioned Excel file. So, in a rather swift (yet manual) procedure the separate tables are merged within ArcGIS (Data Management – Merge[69]). As a result, nine Excel files are created, storing all the fundamental information (see Supplementary Material II: these files are integrated) which is to be harnessed in the statistical analysis and evaluation conducted in the § 6.3.2. and § 6.3.4.

6.2.5. Visualization Concerns: Frame Pre-Processing and Animation Creation

Since ModelBuilder cannot interfere in issues related to the symbology and layout designing of each frame, these steps are also manually dealt with. Moreover, for an animation to be implemented in a proper way, and, thus, procure a reliable and effective visualization, it is vital that no other parts-components of the image/ map than those that actually do change, be modified even slightly. This means that at least the scale of representation has to be the same and the layout/ structure has to be identical for each frame; in addition, the latter should be as simple and inornate as possible. The cartographic elements of this 'moving' or 'animated map' are by and large determined by the perceptual and cognitive capabilities specification of the visualization (see § 4.3.).

6.2.5.1. Static Map Display/ Frame Preparation

But, what would the layout design of each display for a visualization destined to explore the visual landscape include – aside from the visible/ not visible regions? Since each viewshed is connected with its 'generating' viewpoint, each static snapshot would involve both of them. The topographic relief of the landscape itself should be also incorporated in this static map, for it is a factor (along with

[69] This tool "combines multiple input datasets of the same data type into a single, new output dataset. This tool can combine point, line, or polygon feature classes or tables".

the viewpoint location) that determines the viewshed. Yet, it should be included in a 'discreet' (without overwhelming the theme of the map that is the visibility structure) but recognisable way: So, it is decided both the viewpoints and viewsheds to be overlaid against the background of the relief which is rendered as a hill-shaded surface. Moreover, because the viewshed output fully covers the DTM by which it is computed, a percentage of transparency should be applied on the former – as the customary practice dictates –, while the viewpoints should be on top of this layer superimposition, being totally opaque. As discussed in the 4th Chapter, this kind of visualization is founded on abstraction and, thence, it should stay minimal in terms of (cartographic) design and synthesis. The only additional component/ element that can be included is a means to visualize elevation information and its changes, as the location of the observer changes. This information could be depicted by a ***topographic profile graph*** showing at each snapshot the location of the observer on it (i.e. on the profile). The construction of the previous is described further below. Yet, in order to realize the effectiveness and utility of the visualization, it is to be implemented in *two modes*: one without including the elevation profile and one including it.

Another crucial parameter for the cartographic design refers to the colours utilized to depict the spatial distributions of visible and not visible cell surfaces. Thus, after trial and error, we ended up assigning: a hue of green, and specifically the 'Leaf Green' (RGB: 56, 168, 0), and a hue of Beige, the 'Sahara Sand' (RGB: 255, 235, 190) to the not visible ones[70]. As literature suggests, the latter can be used to portray soils and generally land backgrounds, while the former is assigned to forest lands (Peterson, 2009). In addition, green is generally used to connote a feeling of goodness or likability, or environmental correctness (Peterson, 2009). So, greenish hues are cool and vivid, in comparison with the relatively dull land/ soil-like hues, thus, being able to link the human cognition to something that is 'relaxing for the eye', or 'worth observing', while these dull hues attributed to land background appear much less important than the green ones, potentially imbuing the respective patterns (i.e. the beige cells) with the connotative meaning of something that does not deviate from standard, does not extrude, and, to a certain extent to something that is 'covered' or 'unseen'. With regard to the points of observation, it is advisable to symbolize them with a small sized (6 pt) red ('Mars Red' – RGB: 255, 0, 0) circle [71] so as to be easily discernible, i.e. to contrast against a background with the abovementioned hue, without consuming 'vital space' from the visibility distribution portrayal (Fig. 59). As for the Profile positioning scheme, the cross-section should be depicted by a black, dashed line, whereas the moving viewpoint(s) on it should be indicated by a similar (to the previous) red circle; Profile's location should be to the right of the main display, given that we are

[70] These colors refer to the default color palette of Symbol Selector in the Layer Properties' Symbology in ArcMap, ArcGIS.

[71] In the case where the topographic profile is also included in the visualization, a 14 pt circle is employed.

accustomed to read from left to right. After accomplishing the cartographic synthesis according to all these specifications, every single static map display should be exported as an image file (.png or .jpg/ 96 dpi resolution/ 24-bit True Color).

6.2.5.2. Topographic Profile and Viewpoint Positioning Construction

The prerequisite information for the creation of topographic profiles with moving viewpoints attached on them is stored on the dBASE file maintaining the FID and XYZ coordinates (for each viewpoint of each route). The Matlab 7.7.0 programming software can be a very convenient means to manipulate and portray the pertinent figures. The procedure begins with loading the respective file after converting it in a Text Document File (.txt)[72]. To that end, the identification of each of the columns that contain the X, Y, Z information should be considered and be defined separately.

Afterwards, the structuring of a simple function that calculates the Euclidean distance ('dist_2_p') between pairs of consecutive viewpoints is realized. So, by creating one loop referring to the function of distance, the shape of the topographic profile is yielded, while with another loop, the specific location of each viewpoint on the profile is rendered separately and distinctively (Table 11). As a consequence, several profile figures are plotted, the number of which equals with the different viewpoints on each viewroute. The position of each viewpoint is distinctively depicted (red circle) against the profile curve, as presented in Figure 60. So, by automatically producing a series of profiles while exhibiting the different location of viewpoints and by subsequently involving them in an animation sequence, a viewpoint position change can be achieved along a topographic cross-section. This dynamic transition of the observation point with elevation, along with the dynamic portrayal of viewshed changes can enable a dynamic visual interrelation of elevation with viewshed along different viewroutes.

Table 11: The code required to portray each of the profile frames entailing different viewpoint positions in Matlab.

```
clear all
clc
close all
format long g

file=load('Poi_Z_Pass1_New.txt');
x=file(:,1);
y=file(:,2);
z=file(:,3);
n=length(x);
```

[72] Also, the commas (',') should be replaced by dots ('.') in this .txt file.

```
position=zeros(n,2);
position(:,2)=z;
for i=2:n
    d=dist_2_p(x(i-1),y(i-1),x(i),y(i));
   position(i,1)=position(i-1,1)+d;
end

for i=1:n
fig=figure
axes('Parent',fig);
box('on');
hold('all');
plot(position(:,1),position(:,2),'LineWidth',2,'LineStyle','--','Color',[0 0 0]);
hold on
plot(position(i,1),position(i,2),'Marker','o','LineWidth',6,'LineStyle','none','Color',[1 0 0]);
grid on
saveas(fig,num2str(i),'png')
end

                                                  …And

function d=dist_2_p(x1,y1,x2,y2)
d=sqrt(((x2-x1)^2)+((y2-y1)^2));
end
```

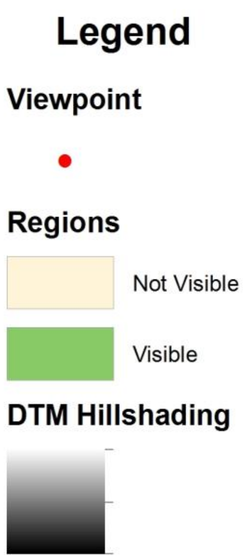
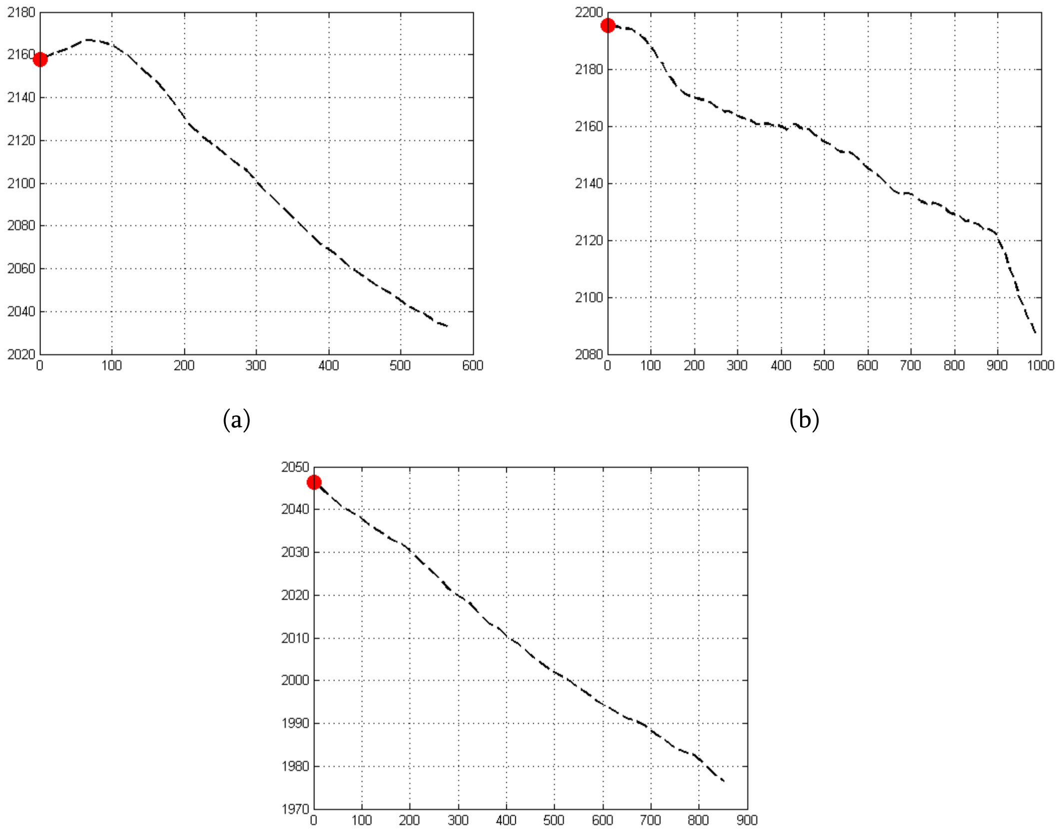


Figure 59: Legend for the interpretation of the visualizations: Hillshading comprises the background on which the visible/ not visible regions are superimposed, while the (moving) viewpoint is on the top of the visual hierarchy.
Note: this legend is not included in the visualizations because it would add nothing of value other than augmenting the extraneous cognitive load – distracting the attention.



(a) (b)

(c)

Figure 60: Illustration of one of the topographic cross-section frames prominently depicting the position of the viewpoint on each viewroute: pass route (a); ridge route (b); valley route (c). The horizontal axis represents length (m), whereas the vertical one represents elevation (m).

6.2.5.3. Animation Implementation: Considerations for a Sound GeoVisualization

Thus, having decided on the elements and parameters that will designate the snapshots of each pause in locomotion observation (static display), the generation of the animated sequence ensues. In this attempt, it should be taken into consideration that this sequence refers to both *changes* in ***position*** – that is the locomotion of observers in the area of concern (main map/ display) and in the profile graph (inset graph) – and to *changes* in ***spatial patterns***. Thus, from a standpoint, it is a special type of fly-by, while from another it is an areal animation. In fact, it is both of them: it is an abstracted, two dimensional fly-over in which the changing locations of the locomotive observer are depicted by moving points, whereas the views/ vistas are radial (panoramic), being represented by changing spatial patterns. Being apparent that animating the latter ones (patterns) is much more complicated, it is this animation type that prevails, entailing the creation of proper frames between consecutive spatial distributions; from all the available techniques for animation (see Peterson, 1995; Gomes et al., 1995), the most suitable for this case is the ***morphing*** technique.

The software facilitating this technique is GIMP 2.8. The animation creation process begins with the import of the frames-images (File > Open as Layers). Subsequently, these frames are manipulated in the *Layers – Brushes* Window: initially, the images-frames have to be prepared to constitute compatible layers for a video-type generation (the 'Add Alpha Channel' has to be checked on each of them); afterwards, between each consecutive layer pair, several in-between frames are created. So, in the *Morph* dialog box (Video > Morph), certain specifications are required to be set, with the number of steps (*'morph-tweens'*) being the most crucial one. Ultimately, by executing a successive *tweening* process, and by exporting it in a proper moving image sequence (.gif), the nine different visualizations can be effectuated; the parameters here are also crucial (Fig. 61).

In fact, the election of values set on these specifications/ parameters relies on a hypothesis which proceeds as follows: Since we are to visually explore a landscape from 3 different viewpoint intervals (for the three viewroutes) at this 'abstracted fly-by', then for each of the three triads[73] of animations to be comparable, it seems rational to last for the same *duration*. Also, they should be equally smooth (at least at a 'surface' level). So, they should exhibit the same *rate of change* (see Chapter 4, dynamic variables). The overall *magnitude* of each of the triads is the same – since the starting and the ending route viewpoints are the same; but, the existing intervals are different. Since the *inherent propensity* of the evolution (see Chapter 4, rate of change) of viewsheds with viewpoints changing locations cannot be approached or rendered in realistic terms (infinitely small viewpoints distances required), then we cling to the continuously diminishing space intervals to adjust to this propensity. Ergo, this means that for the same rate of change/ smoothness to be attained, then the duration of the scene-sequence (delay between frames) and the steps between the varying 'time' intervals[74] at which data (i.e. viewsheds frames) are available should be both regulated properly. Constructing such equivalent animations with a typically[75] same rate of change, and taking as granted the axiom that the reduction (minimization) of the space intervals entails the tendency towards the approximation of the inherent nature of this evolving pattern, it can be deduced that:

- Starting from animations that refer to the sparsest viewpoints, if no significant differentiations in the spatial pattern sequence occur in comparison to animations that correspond to denser intervals, then it is safe to keep the animation generated by a lesser interval; contrariwise, significant alterations in the animations call for the election of the densest viewshed frames, since any

[73] The first triad refers to the Pass-line Viewsheds, the second to the Ridge-line Viewsheds and the third to the Valley-line Viewsheds.

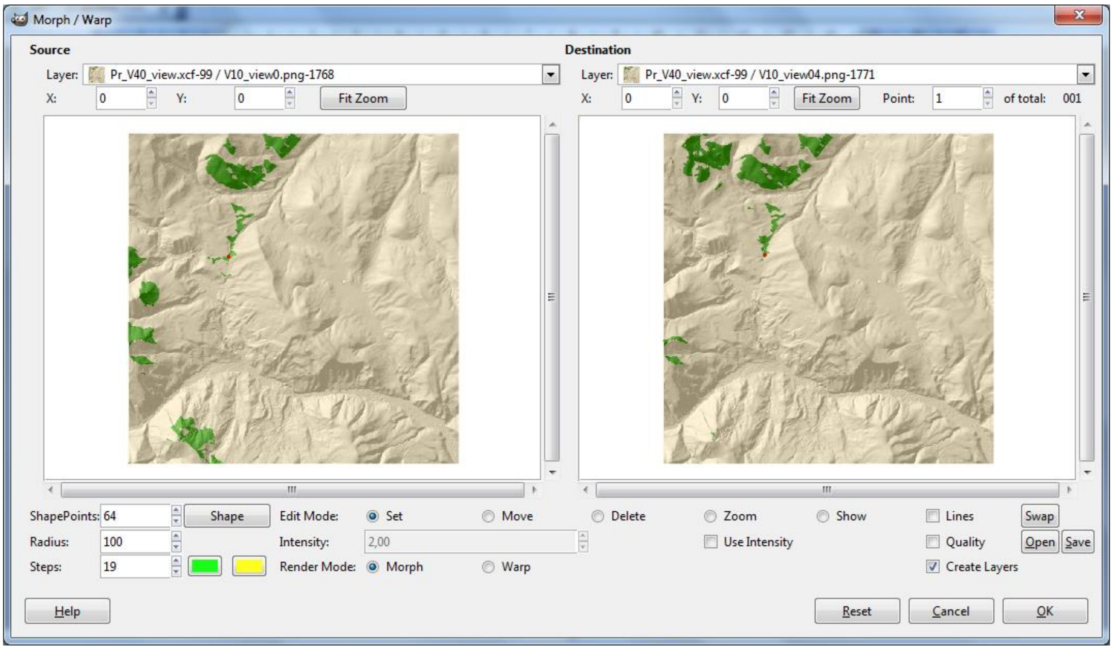
[74] In a fly-by animation, time can refer to the change of location of viewpoint.

[75] Since the overall magnitude of change and the duration of each animated sequence is the same, then the overall rate of change is the same for every triad. However, the intervening frames that have been yielded by direct computation – and not from tweening/ morphing – differ among those sequences. As an effect, the same rate of change refers to more or less realistically approximated dynamic viewsheds – i.e. viewsheds computed from more or less densely located viewpoints.

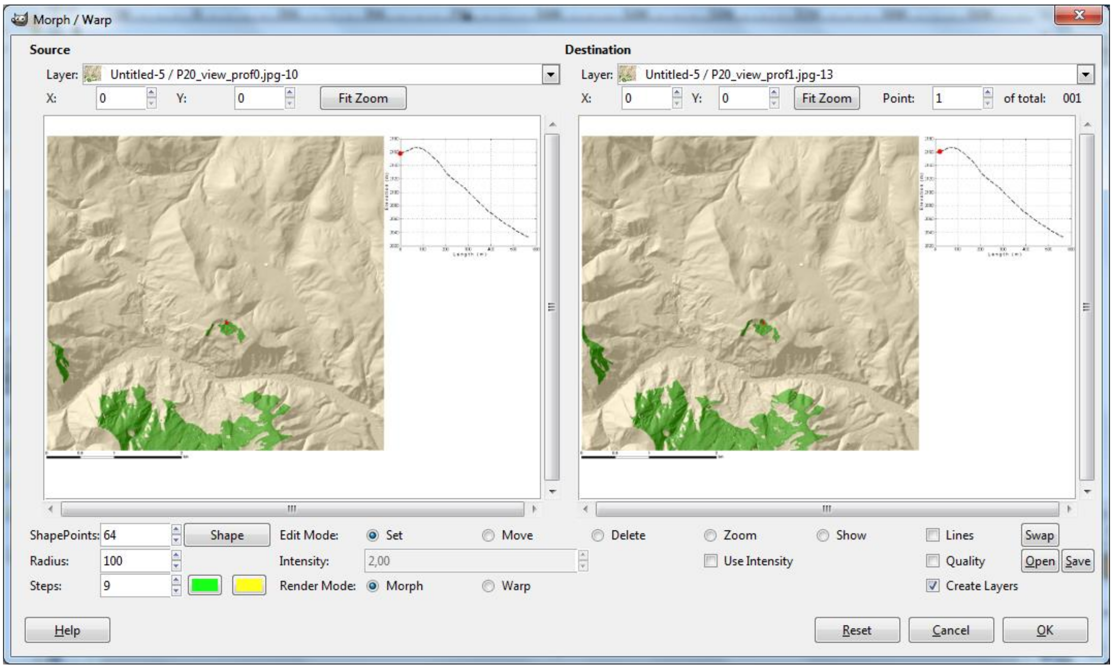
deviation from the innate evolving nature of the process cannot ensure the fidelity and coherence of the animation, and, therefore of landscape exploration.

- There can be discerning differences in animations among the different topographic features on which the viewroutes abut for each visual exploration; as an effect, for instance, while the exploration for the route on the Valley could equally approximate the evolution under any interval, the exploration for a route on a Pass(line) could not retain its coherence from animations emanating from 20 or 40m viewpoint intervals.

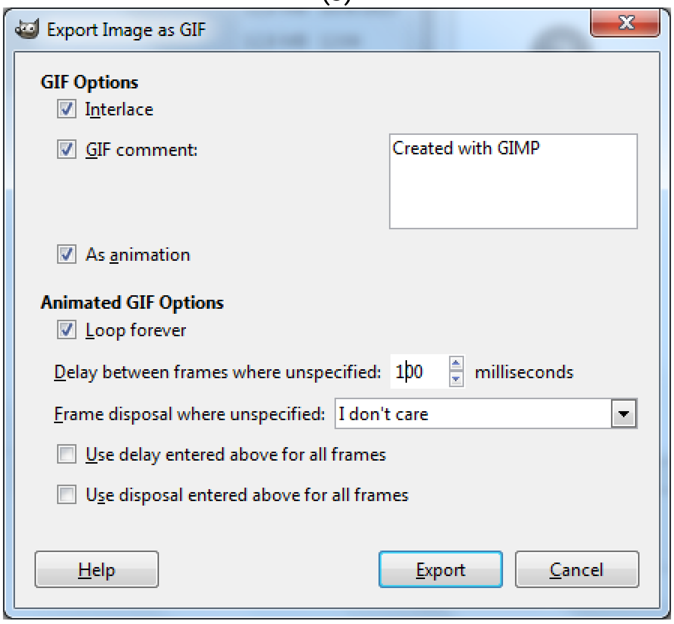
For these reasons, the parameterization of the animation values is not primarily concerned with absolute figures, but chiefly with the respective ratios among animations of different intervals. So, for the same intervals of different viewroutes the elected numbers were, apparently, the same. More specifically, the values selected for the various intervals are summarized on Table 12. In any case, though, the overall duration should be kept low (less than one minute); this is due to two reasons: i) mitigation of the cognitive load (i.e. increase of the cartographic visualization effectiveness) and ii) adhesion to the principle of temporal abstraction (i.e. the animation is not to visualize the process in real time). This dual purpose is partially achieved by filtering the data/ information included (election of the routes on which dynamic viewshed are to be visualized) and by further segmenting the animation sequence into three parts according to the linear topographic feature that each route is located.



(a)



(b)



(c)

Figure 61: Crucial parameters' specifications in the Morph/ Warp Window (a, b) and in the Export Image Window (c).

Table 12: Animation sequence parameters – steps and time delay – according to viewpoint interval. The aim is to produce animations of the same durations in order to evaluate and compare their behavior depending solely on the intervals.

Viewpoint Interval	# of Viewpoint Transitions - Pass/ Ridge/ Valley	Steps	Time Delay (msec)
40 m	14/ 24/ 21	19	100
20 m	28/ 48/ 42	9	100
10 m	56/ 96/ 84	4	100

6.3. RESULTS: EVALUATION AND DISCUSSION

Bearing in mind the aforementioned rationale, the animated sequences have been approached as three triads of viewroutes. Table 13 presents the elements for the computation of all the prerequisite frames within the GIS Model, whereas Table 14 summarizes the animation parameters and outputs in terms of frames and duration in this three-triad perspective. The results derived from the GIS modelling include: i) the principal (computed) spatial data – corresponding to the real viewshed images/ frames based on which the 'in between' frames are produced so that visual exploration can take place, and ii) the numeric data (visibility cell count) based on which a statistical analysis can occur. Additionally, the geographical/ graphical results are processed in two modes: i) the first entails a comparison of equivalent animations/ statistical indexes for each triad of viewroutes – by testing the optimal viewpoint interval route, and ii) the second one scrutinizes the subsequent contribution of the elevation in landscape visibility exploration. In other words, the second processing mode (ii) can take place only having yielded a visualization that is proper enough (i), following a procedure described in the Figure's 52 flowchart.

Table 13: Different viewroutes, varying intervals and the respective computational loads (time) for the Model utilized to automate the workflow.

Topographic Feature		Viewpoint Interval (m)	# of Viewpoints	# of Runs	Time (sec)
Type	*Length*				
Pass	569 m	40	15	13	115
		20	29	27	262
		10	57	55	519
Ridge	989 m	40	25	23	237
		20	49	47	393
		10	95	93	988
Valley	851 m	40	22	20	177
		20	43	41	397
		10	85	83	842

Table 14: Frame numbers and duration for the morphing/ tweening phase and the overall animation sequence.

View-Route	Viewpoint Interval (m)	# of Viewpoints/ Viewpoint Transitions	# of 'In Between' Frames	Morph Time per Transition (sec)	Total # of Frames	Animation Time (sec)
Pass	40	15/ 14	19	≈68	19*14 +15 = 281	≈29
	20	29/ 28	9	≈33/	9*28 + 29 =	≈29

				277*	281	
	10	57/ 56	4	≈16	4*28 + 29 = 281	≈29
Ridge	40	25/ 24	19	≈68	19*24 +25 = 481	≈49
	20	49/ 48	9	≈33	9*48 + 49 = 481	≈49
	10	97/ 96	4	≈16/ 122*	4*96 + 97 = 481	≈49
Valley	40	22/ 21	19	≈68	19*21 +22 = 421	≈43
	20	43/ 42	9	≈33/ 271*	9*42 + 43 = 421	≈43
	10	85/ 84	4	≈16	4*84 + 85 = 421	≈43

* This duration of morphing applies to those animations the frames of which include the topographic profile and a scale bar.

6.3.1. Visualizing Landscape Visual Changes with Animation

Consequently, the visual exploration of viewshed changes has been approached in these two modes. In the CDs included (see Supplementary Material I), there are nine (three triads of) animated sequences visualizing the viewshed changes (dynamic visualscapes). By comparing these equivalent animations – as triads of the same viewroute – several results occur; furthermore, the animation itself is evaluated so as to elect which best fits for a visualization entailing a moving viewpoint topographic profiling. Therefore, three other separate animated visualizations emerge (CDs).

Starting from the nine visualizations without topographic profiles, the results for the three cases-viewroutes are the following; it should be noted, though, that the results presented apply to all three viewpoint intervals for each case-viewroute:

- **Pass Route**: The locomotion of the viewpoint exposes a considerably distinguishable behavior for the dynamic visualscape of this viewroute, the direction of which is SSW – NNE. What is distinctive about this visualization relates to an extremely abrupt change, breaking the otherwise sufficiently cohesive viewshed propagation. This ‘rupture’ emerges at the segment of the viewroute at which the locomotive observer is transcending over the pass point (or area). Prior to this stage, the observer is able to ‘look’ only at the SW part of the landscape: the constantly increasing visual spatial patterns spreading from south and SW parts of the landscape towards the location of the viewpoint are suddenly ‘leaping’ to another, more gently varying pattern. Indeed, the visualscape – after the first viewing intervals corresponding to a few dissected patterns – remains generally stable, consisting from a non-fragmented distribution; it chiefly entails and retains a fan-shaped pattern being diffused from the moving viewpoint, and few ‘patches’ located at some adjacent or more isolated peaks and their slopes opposite to the viewpoint locations.

- **Ridge Route**: In contrast to the more even and ‘predictable’ evolution of the dynamic viewshed of the pass viewroute, ridge route viewsheds display a much more rough and ‘erratic’ performance. As the observer moves from SSE to NNW, the visible cells cover a large proportion of the landscape at first; these cells, east of the ridge are initially declining and then are gradually being augmented, whereas at the WSW portion of the landscape they are quickly being withdrawn to a significant extent. After a while, landscape’s western part is reclaiming part of its viewshed, and visible cells remain almost still in general. Moving further NNW, after a ‘moment’ of diminution of the NW viewsheds, the visible regions west of the ridge remain relatively unaltered, while at the same time the eastern part is changing constantly. At the last third of the animation, the viewshed east of the ridge is retaining a stable pattern, changing only in the vicinity of the viewpoint, while the western domain is constantly varying. Last, the viewshed is modified in a very gentle way mainly east of the ridge-line.
- **Valley Route**: The basic traits of the visible patterns for this viewroute refer to their small covering area and their ‘patchiness’. Compared to the animation of the other viewroutes, these dynamic viewsheds are more fragmented than these of the pass viewroute, but not as irregular and expanded as those of the ridge route. The valley route approximates a circular sector directed from SW to NE. The dynamic behaviour of its viewsheds being displayed at the beginning of the animation resembles the pass’s initial transitional steps: the visible regions existing diametrically opposite to the direction of the observer locomotion (WSW in the study area) are ‘vanishing’ after a few moments; only a few patches re-occur later on and for a little while at this part of the landscape. At the southern, SE and eastern region of the landscape no cells are visible along this valley route. The viewsheds are mainly spatially clustered around few dissected ‘growing-shrinking’ patches at the northern part and generally lie within a small field of the observer’s view: in fact, the vistas are by and large evolving as linear occurrences within the valley itself, and are emerging and re-emerging on adjacent or more distant opposite slopes – or upon the ridge-line of the elected ridge-route.

By meticulously and repeatedly watching the animations of the three viewroutes, it may be remarked that:

- In general, the tactics of implementing the three viewroutes as triadic sequences and regarding them also as triads provide a common overall pattern trend irrespectively of the viewpoint spacing interval. Thus, these generic patterns being delineated above can provide an overall inter-viewroute comparison (i.e. among different types of routes).

- Nonetheless, in particular, both an intra- and inter-viewroute (i.e. within the differently spaced and among topographically different routes) comparison can yield some first useful remarks about the role that different viewpoint interval could serve, and how could these intervals be modified depending on the topographic feature of the viewroute. As a matter of fact:
    - By inspecting the triad of different viewpoint intervals in ridge viewroute, it emerges that when the visualization is materialized with the densest available viewpoint interval, significant pattern variations are revealed: in fact, in several cases many visible regions that dwindle and then re-appear cannot be portrayed in a less dense viewpoint interval, owing to a more 'flattened' dynamic visualscape occurring from less 'representative' viewpoint changes;
    - The pass viewroute is not that dependent on a dense viewpoint interval to visualize all the prominent and less prominent visibility pattern variations, even with the sparsest viewpoint spacing; exception to the selection of this spacing interval might constitute the abrupt change coming about at a specific location (as raised before) disrupting the cohesion of viewsheds;
    - The approximation of what happens in the dynamic visualscape from the valley viewroute does not seem to require as densely located viewpoints as possible.

So, in the case of the ridge viewroutes, one could induce that for a faithful approximation of the landscape's dynamic visual properties the densest possible viewpoint vistas are highly recommended; nevertheless, the problem of the mounting intrinsic load referring to the increased complexity of the visible cells animated sprawling is to be considered as well. In contrast, for the other two visualizations, the 10-m interval appears an extravagance: especially for the pass viewroute, the respective viewsheds of which are generally spatially correlated, the 20-m interval seems more than adequate. Although the valley route exposes a patchier dynamic visualscape, due to the few aggregation nuclei and their coherent growing-shrinking evolving visibility distribution a 20-m viewpoint spacing is deemed satisfying.

This cartographic exploration of the viewshed animation across different topographic features and intervals promote an essential visual assessment for the appropriateness of the visualization. In addition, the statistical analysis conducted below aims at further corroborating the selection of the most proper interval for each viewroute – in order to subsequently explore the visualscape evolution in association with viewpoint elevation changes (with the most congruent viewpoint 'step').

6.3.2. Statistical Analysis and Evaluation of Dynamic Viewsheds (*DVI* and *DCVI*)

The statistical analysis being implemented with *SPSS* [76] entails an important preparative stage for organizing the pertinent data. In addition, there is need to calculate some indices that will be proven highly useful in determining the coherence of the animation. So, beginning with the initial organization of data exported by the Model (see Fig. 57) and stored within an Excel file, the basic elements concerning the statistical analysis are present, arranged by topographic feature and interval, namely: i) the number of visible cells for every (x,y,z) viewpoint and ii) the combined (intersected) viewsheds, for every three consecutive viewpoints. While the elevation (z) variation is probed in the following sections, the analysis and evaluation of this section examines the effect of the topographic feature and space interval in the visibility of a landscape and in the 'quality' (coherence) of the visualization.

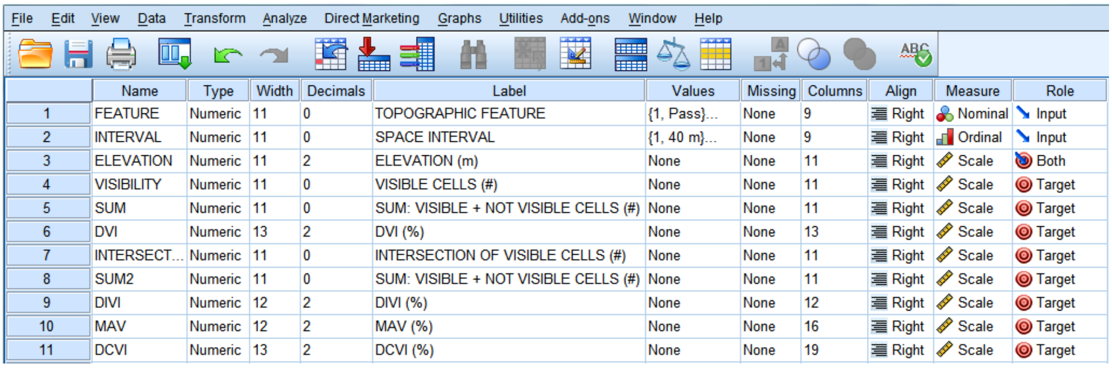
In order to investigate the first (i), a very simple index is used which demonstrates the ratio of visible cells to the total number of cells, that is the *Dynamic Visibility* [77]*Index (DVI)*; this index is an expansion of the general viewgrids (see § 5.3.4) towards presenting viewsheds along paths and expressing them as percentages so that the comparisons among and within the three topographic features or viewroutes can emerge directly. On the other hand, the second (ii) is approached through an index that is developed in two steps: in the first step the number of the intersection of visible cells for every three consecutive viewpoints in every viewroute is harnessed, and the ratio of this combined/ intersected visibility to the total number of cells is expressed as a percentage and in a dynamic context *(DIVI – Dynamic Intersected Visibility Index)*; subsequently, by calculating the average of the visibility index for every three consecutive viewpoints – 3 point *Moving Average Visibility Index (MAVI)* –, an index that integrates these two figures results from the ratio of the first to the second one (DIVI / MAVI): in practice, this index – *Dynamic Coherence Visibility Index (DCVI)* – approximates the degree to which the visible cells alter for every three consecutive viewpoints (or animation frames). (In Supplementary Material II all of the numerical data and derived indices are displayed in a table, whereas the organization of the pertinent statistical data in SPSS is presented in Figure 62).

It should be noticed, though, that the 3 point moving average does not hold an explicit spatial reference or connotation; yet, it assigns for every (except for the first and the last) viewpoint the visibility index among its previous and following viewpoint along the viewroute in a flattened manner with which the intersection of viewsheds for the same three viewpoints is to be compared with. Owing to the fact that the DIVI by default cannot surpass the minimum of the DVI for the three consecutive viewpoints, DCVI exhibits a normalized quantification of the visualization/ animation coherence: as the index is approaching 100%, the variation of the viewsheds tends to be minimized, and the approximation of the animation is deemed to be consistent and coherent. Therefore, a considerable

[76] *IBM SPSS Statistics 20*

[77] 'Visibility' can be replaced by 'Viewshed' or 'Visualscape'.

fluctuation of this index under the effect of different viewpoint space intervals should mean that the change of the density of viewpoints induces a significant alteration to the cohesion of the viewshed visualization. So, it is crucial to investigate the existence and the degree of such an influence. Nevertheless, the topographic feature itself could entail different requirements in viewpoint density selection, since the evolution of the viewshed visualization process along different viewroutes may be inherently different.



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	FEATURE	Numeric	11	0	TOPOGRAPHIC FEATURE	{1, Pass}...	None	9	Right	Nominal	Input
2	INTERVAL	Numeric	11	0	SPACE INTERVAL	{1, 40 m}...	None	9	Right	Ordinal	Input
3	ELEVATION	Numeric	11	2	ELEVATION (m)	None	None	11	Right	Scale	Both
4	VISIBILITY	Numeric	11	0	VISIBLE CELLS (#)	None	None	11	Right	Scale	Target
5	SUM	Numeric	11	0	SUM: VISIBLE + NOT VISIBLE CELLS (#)	None	None	11	Right	Scale	Target
6	DVI	Numeric	13	2	DVI (%)	None	None	13	Right	Scale	Target
7	INTERSECT...	Numeric	11	0	INTERSECTION OF VISIBLE CELLS (#)	None	None	11	Right	Scale	Target
8	SUM2	Numeric	11	0	SUM: VISIBLE + NOT VISIBLE CELLS (#)	None	None	11	Right	Scale	Target
9	DIVI	Numeric	12	2	DIVI (%)	None	None	12	Right	Scale	Target
10	MAV	Numeric	12	2	MAV (%)	None	None	16	Right	Scale	Target
11	DCVI	Numeric	13	2	DCVI (%)	None	None	19	Right	Scale	Target

Figure 62: The SPSS variable view environment corresponding to the manipulated statistical data (input data and indices).

At first, the analysis is facilitated with *descriptive statistics* (Table 15). With reference to the DVI (i), it is apparent that its arithmetic mean is much greater for ridge viewroutes – approximately five times greater than the DVI of pass routes and 14 than the DVI of valley routes. On the other hand, the DVI means within the same route remain practically unaltered with interval changes. These results show that viewsheds are persistently different in quantitative terms regardless of the viewpoint density on a view route. In a sense, the aggregate visibility is 'affected' by the topographic feature on which the viewpoints are placed, but not by their spacing. This could apply in particular to our case, provided that we have assumed that elevation is a major determinant of viewshed (according to our initial hypothesis): because the linear topographic features by default do not exhibit elevation 'breaks', relatively moderate spacing fluctuations would not induce variation in visibility. As an effect, the DVI range and standard deviation (stdev) in ridge and valley routes remain constant or tend to dwindle. Contrariwise, the pass route exhibits a rising trend for these descriptives, a fact that is attributed to the particularity of this linear feature. Actually, its innate morphological character does not hold the 'topographic purity' of the other two – the elevation of this feature mounts until the pass point and subsequently it declines (see Fig. 60a); consequently, it is possible (and also observable in the pass route case) that the densification of viewpoints will include locations that are higher in the route, and, according to our hypothesis, with augmented visibility. However, apart from the introduction of 'global' elevation maxima (through densification), local maxima can raise the DVI as well, something that is discernible in the ridge viewroute. Such an eventuality, though, cannot apply to the valley route, given that the elevation maximum is not increased (not even locally) as the space interval is lowered (densified) (see also Fig. 60).

The coherence of the viewshed visualization is statistically examined with the DCVI (ii). As it can be clearly observed, a decrease in space interval imposes a rise in the coherence – the DCVI mean. Nonetheless, its growth is not 'homogeneous' across intervals and viewroutes. For the pass and valley viewroutes, the transition from 40 m towards 20 m involves much more percentage units of DCVI mean increase than the transition from 20 m towards 10 m, while for the ridge viewroute the increase is roughly the same between the two transitions. This is in part expected, i) since we have posited that variation below 10 m would be insignificant, and thus this interval acts as a kind of a limit, and ii) simply because the absolute drop in the viewpoints' distance for the first transition is 20 m, whereas for the second transition is only 10m; additionally, the pass route's DCVI stdev remains relatively high, even for the 20-m interval, when the ridge's DCVI stdev is much lower, even for the 40-m interval. But, the seeming contradiction of how this calculation can be consistent with the visual exploration evaluation of the most suitable interval for each viewroute (pass: 20 m, ridge: 10 m, valley: 20 m) is explained as follows: In spite of the adequate coherence of the viewsheds (frames) for the ridge route even from the 40-m spacing, the increased DVI involves a considerably larger amount of real changes. Even though the DVI coefficient of variation (CV) is much lower for the ridge route, the sheer figures (and the spatial patterns) of visible cells are that larger (and that more irregularly distributed) that the ridge dynamic viewshed visualization requires the densest available interval.

In essence, for the resulting animated map to be mentally perceivable and cognitively manageable, the spatial pattern variations (appearance-disappearance, growth-shrinkage etc.) should be held to the minimum possible. Thence, in all, a compromise is to be made among the sequences of usable viewshed images-frames, so that the respective elected interval: i) approximates the inherent nature of the evolving process of visibility, ii) effectively reduces the innate cognitive load and iii) achieves data volumes and computation requirements mitigation for each route. In this sense, the topographic feature can play a significant role in the viewpoint interval specification. So, for the pass route, the unambiguous case of the discontinuity described in § 6.3.1. affects the DCVI mean and DVI stdev in a 'dramatic' manner: as a consequence, a 10-m denser network greatly aids the visualization by adding one critical viewshed frame. In valley route, the increased DVI CV does not appear to be reduced, no matter how the interval becomes denser. On the other hand, owing to the very limited visibility values (DVI mean ≈ 1,8%), a densification of the viewpoint spacing by 10 m is considered satisfying. Therefore, the 20-m viewpoint spacing is suggested for both pass and valley linear topographic features, whereas the ridge viewroute calls for a 10-m spacing interval due to the large amount of occurring changes.

In general, though, the DCVI provides an indicant of the discontinuity of the dynamically computed viewsheds. So, when the DCVI (minimum) reaches very low values (e.g. 0,02 for the 40-m pass route), it can be inferred, without watching the animation, that there is a 'rupture' in the succession of visibility, and that the computation of an additional intermediate viewshed frame is an exigency[78]. In other cases where DCVI is not very low (> 50%), the DVI CV should be as well (jointly) taken into consideration. Furthermore, it should be borne in mind that the statistical analysis of figures and indices can and should act only supplementarily to the visual apprehension and assessment of the visualization (i.e. visualization cannot be substituted by statistical calculations).

Setting aside descriptive statistics, the observation sample is treated now with a different – bivariate analysis – perspective. For such an analysis, the first exigent step is to execute a normality test – that is to check whether the sample adjusts to a normal distribution. However, the sample needs further classification in sub-samples; given that the exploration is carried out with relation to the three topographic linear features and their three sets of vertex-viewpoint spacing intervals, one should examine the normality of all the sub-samples. As it emerges from normality tests (*Kolmogorov-Smirnov* and *Shapiro-Wilk*) for the majority of the sub-groups and variables (Table 16) and from the visual inspection of their *histograms* and *P-P Plots*, their respective distributions deviate significantly from the normal ones. Yet, while normality is one of the most crucial "assumptions of parametric data", the independence of data comprises another important assumption (Field, 2009). When implementing analyses on varying spacing intervals, there is, in fact, a repetition of observations. For instance, the 20-m viewpoint interval valley viewroute comprehends all of the observations present on the 40-m valley viewroute; in the same manner, the 10-m one contains the totality of the observations present in the 20-m one. Thus, the 40 m viewroutes are subsets of the 20-m ones, while both 40-m and 20-m viewpoints are subsets of the 10-m viewpoints and as a consequence, when the analysis entails the spacing interval, not only the normality, but also the independence assumption is violated.

Moreover, the fact that the related (non-independent) observations are members of samples of different size (i.e. sets and subsets) signifies that they cannot be subjected to a non-parametric *ANOVA* (analysis of variance) test either for independent samples (*Kruskal-Wallis* test) or for related samples (*Friedman* test). For this reason, the most convenient way (considering the goal of this thesis) to approximate the variance of the DVI and DCVI is through the portrayal of the *means Plot* of an ANOVA. The shift from larger- to lesser-interval series of viewpoints has been shown to affect the DVI occasionally and only marginally – something that coincides with our intuitive appreciation. But the DCVI is significantly influenced by the space interval order shifting: as interval decreases, the DCVI mounts. Figure 63 illustrates this tendency quite articulately.

[78] Such frames should be created as outputs derived from an explicit GIS (viewshed) analytical computation function and not from a tweening/ morphing process within an image manipulation/ analysis software.

Table 15: Descriptive statistics for elevation, DVI, DIVI and DCVI across different topographic features and space intervals.

TOPO. FEATURE	SPACE INTERVAL		N	Range	Minimum	Maximum	Mean	Std. Deviation	Coef. of Variation (CV)
Pass	40 m	ELEVATION (m)	15	133,45	2032,80	2166,25	2103,8143	48,35676	2,298528
		DVI (%)	15	5,17	3,79	8,96	5,8020	1,62031	27,92675
		DIVI (%)	13	6,05	,002	6,05	3,9227	1,58667	40,44842
		DCVI (%)	13	90,74	,02	90,77	72,3836	26,87345	37,12643
	20 m	ELEVATION (m)	29	134,05	2032,80	2166,85	2104,0435	47,00565	2,234063
		DVI (%)	29	6,48	3,79	10,27	5,8235	1,68852	28,99493
		DIVI (%)	27	5,37	1,77	7,15	4,7882	1,33797	27,94307
		DCVI (%)	27	75,74	19,81	95,55	85,2280	18,02176	21,14535
	10 m	ELEVATION (m)	57	134,29	2032,80	2167,08	2104,2631	46,20678	2,195865
		DVI (%)	57	9,01	3,76	12,77	5,8408	1,80456	30,89577
		DIVI (%)	55	4,15	3,54	7,69	5,2880	1,28355	24,27288
		DCVI (%)	55	53,11	44,41	97,51	92,2661	9,77772	10,5973
Ridge	40 m	ELEVATION (m)	25	108,84	2086,52	2195,35	2150,5492	27,55424	1,281265
		DVI (%)	25	19,75	16,50	36,26	24,8028	5,23847	21,12048
		DIVI (%)	23	16,20	12,52	28,72	18,9994	3,96183	20,8524
		DCVI (%)	23	38,86	51,44	90,29	77,1429	11,02264	14,2886
	20 m	ELEVATION (m)	49	108,84	2086,52	2195,35	2150,8718	26,23846	1,219899
		DVI (%)	49	19,75	16,50	36,26	24,9395	5,15305	20,6622
		DIVI (%)	47	17,81	13,68	31,49	20,9690	4,34747	20,73284
		DCVI (%)	47	37,39	56,66	94,05	84,2039	8,49383	10,08722
	10 m	ELEVATION (m)	97	108,84	2086,52	2195,35	2151,0511	25,49836	1,185391
		DVI (%)	97	20,21	16,41	36,62	25,0432	4,95629	19,79096
		DIVI (%)	95	19,54	14,03	33,57	22,6623	4,47067	19,72734
		DCVI (%)	95	32,29	64,34	96,63	90,5685	5,63817	6,22531
Valley	40 m	ELEVATION (m)	22	69,80	1976,51	2046,32	2010,2541	21,83887	1,086374
		DVI (%)	22	3,19	,71	3,90	1,8326	,93876	51,22558
		DIVI (%)	20	1,81	,58	2,39	1,2054	,58472	48,50838
		DCVI (%)	20	31,41	50,84	82,24	67,0944	9,61807	14,33513
	20 m	ELEVATION (m)	43	69,80	1976,51	2046,32	2010,2325	21,15079	1,052156
		DVI (%)	43	3,19	,71	3,90	1,8291	,89490	48,9257
		DIVI (%)	41	2,14	,63	2,76	1,4314	,66959	46,77868
		DCVI (%)	41	34,14	55,02	89,16	79,4067	8,80742	11,09153
	10 m	ELEVATION (m)	85	69,80	1976,51	2046,32	2010,2324	20,81315	1,03536
		DVI (%)	85	3,19	,71	3,90	1,8208	,86776	47,65817
		DIVI (%)	83	2,21	,67	2,88	1,5836	,73316	46,29704
		DCVI (%)	83	24,59	69,93	94,52	87,6510	6,29841	7,185782

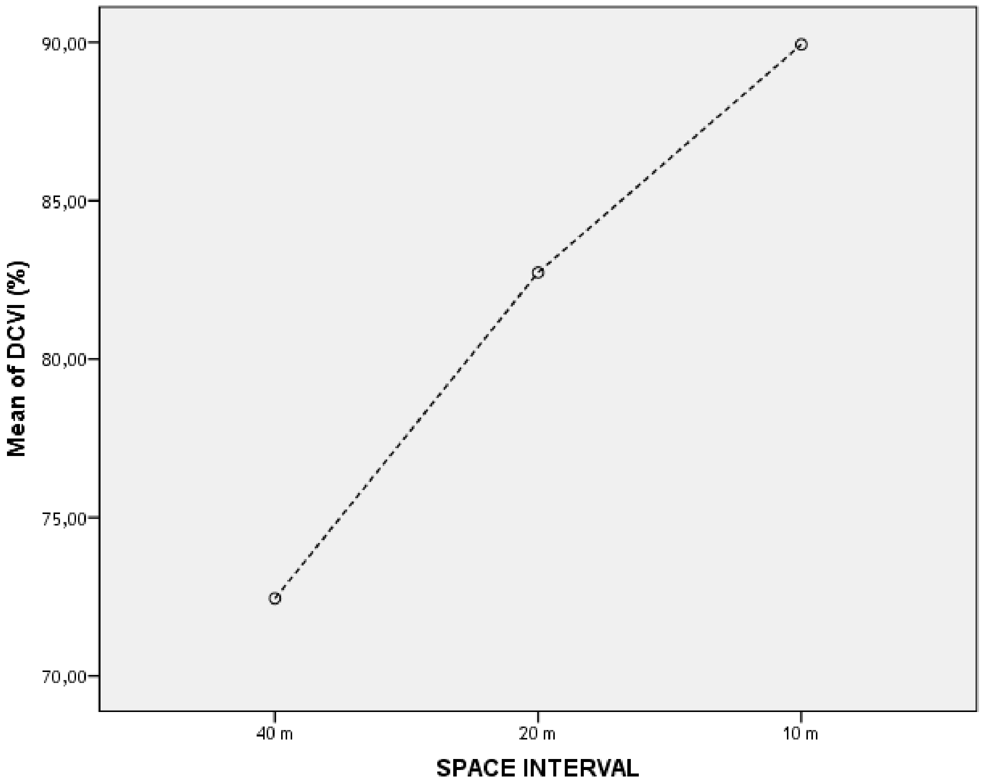
Table 16: Tests of Normality.

TOPOGRAPHIC FEATURE	SPACE INTERVAL		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
			Statistic	df	Sig.	Statistic	df	Sig.
Pass	40 m	ELEVATION (m)	,128	13	,200*	,928	13	,320
		DVI (%)	,191	13	,200*	,900	13	,134
		DIVI (%)	,170	13	,200*	,919	13	,245
		DCVI (%)	,366	13	,000	,654	13	,000
	20 m	ELEVATION (m)	,119	27	,200*	,916	27	,032
		DVI (%)	,162	27	,068	,907	27	,019
		DIVI (%)	,097	27	,200*	,978	27	,825
		DCVI (%)	,359	27	,000	,519	27	,000
	10 m	ELEVATION (m)	,114	55	,072	,911	55	,001
		DVI (%)	,156	55	,002	,880	55	,000
		DIVI (%)	,128	55	,025	,922	55	,002
		DCVI (%)	,361	55	,000	,469	55	,000
Ridge	40 m	ELEVATION (m)	,100	23	,200*	,986	23	,979
		DVI (%)	,100	23	,200*	,962	23	,495
		DIVI (%)	,105	23	,200*	,961	23	,475
		DCVI (%)	,262	23	,000	,802	23	,000
	20 m	ELEVATION (m)	,087	47	,200*	,980	47	,601
		DVI (%)	,060	47	,200*	,972	47	,312
		DIVI (%)	,120	47	,086	,950	47	,045
		DCVI (%)	,188	47	,000	,782	47	,000
	10 m	ELEVATION (m)	,092	95	,045	,977	95	,098
		DVI (%)	,056	95	,200*	,975	95	,063
		DIVI (%)	,071	95	,200*	,960	95	,005
		DCVI (%)	,211	95	,000	,688	95	,000
Valley	40 m	ELEVATION (m)	,096	20	,200*	,947	20	,321
		DVI (%)	,227	20	,008	,900	20	,041
		DIVI (%)	,237	20	,004	,855	20	,007
		DCVI (%)	,151	20	,200*	,942	20	,264
	20 m	ELEVATION (m)	,087	41	,200*	,944	41	,045
		DVI (%)	,195	41	,000	,901	41	,002
		DIVI (%)	,250	41	,000	,868	41	,000
		DCVI (%)	,197	41	,000	,873	41	,000
	10 m	ELEVATION (m)	,085	83	,200*	,944	83	,001
		DVI (%)	,190	83	,000	,902	83	,000
		DIVI (%)	,210	83	,000	,870	83	,000
		DCVI (%)	,217	83	,000	,815	83	,000

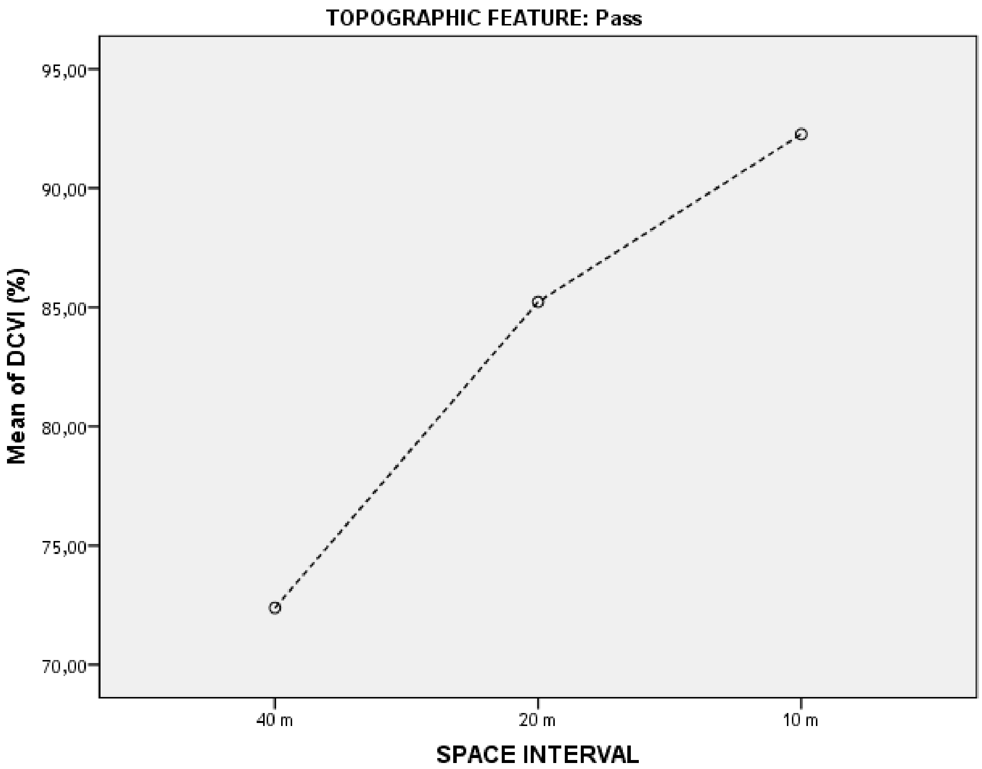
*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

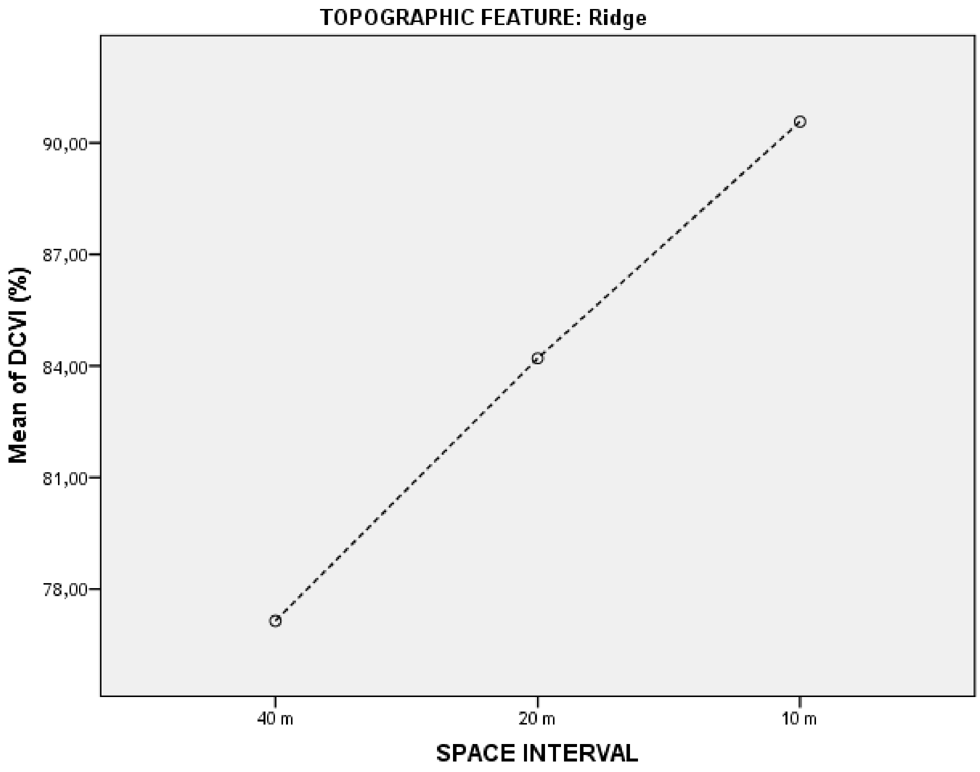
More precisely, though, while the diagrammatic depiction for the overall (i.e. irrespective of the topographic feature) DCVI arithmetic means present the generic trend of all the topographic features or viewroutes to attain improved DCVIs, this improvement is lessened when transiting from 20-m towards 10-m intervals, compared with the transition from 40-m to 20-m ones. Delving even deeper, by comparing these plots per topographic feature, more enriched information is revealed: whereas for the valley viewroute an 'asymptotic tendency' (with reference to (a 100%) DCVI) is beginning to emerge – a tendency even more conspicuous for the pass feature –, the ridge feature plot exhibits an equivalent DCVI amount of change (variance) from 40 m to 20 m and from 20 m to 10 m – even if the absolute distance decrease between consecutive viewpoints is greater when transiting from 40 m to 20 m (i.e. 20 m) than when transiting from 20 m to 10 m (i.e. 10 m). In other words, while the valley and (especially) the pass routes appear to have reached a 'critical point' – the 20-m interval –, over which the densification of the viewpoint spatial arrangement (i.e. the 10-m interval) will probably add only a little more coherence in the animation, the ridge viewroute is demonstrated to remain unaffected, and thus further densification is accompanied by a fair amount of coherence enhancement. This finding corroborates in a more direct, visual/ graphical manner what has been shown in the aforementioned, namely that the ridge viewroute requires the finest possible spacing interval (10 m), whereas pass and valley viewroutes can cope adequately with an intermediate interval (20 m).



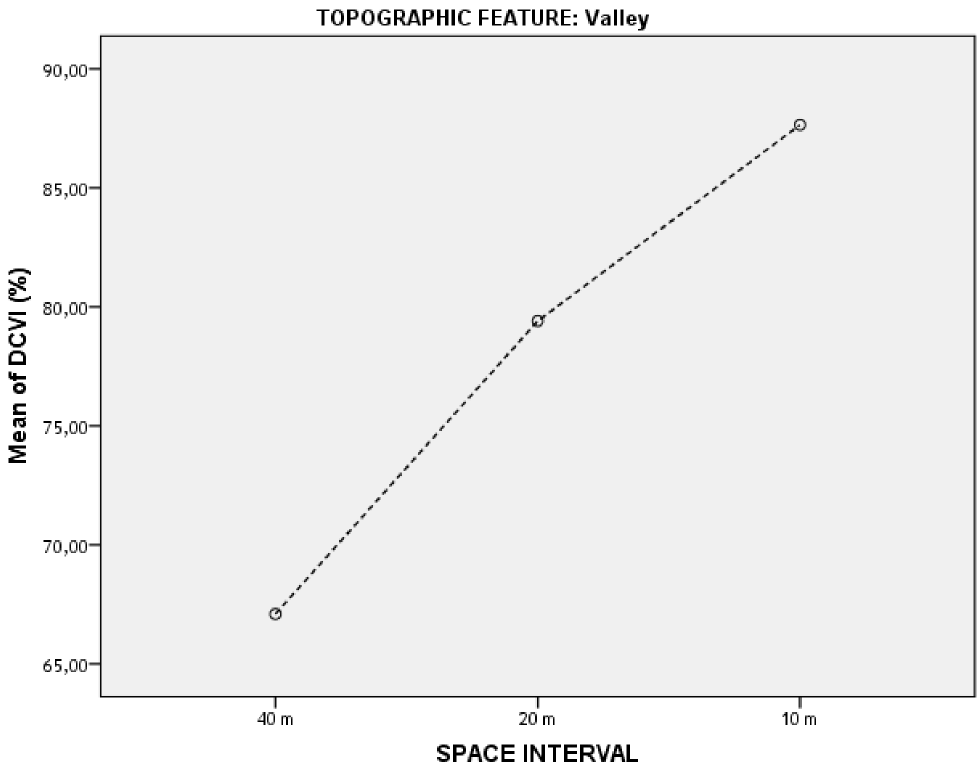
(a)


TOPOGRAPHIC FEATURE: Pass
95,00
90,00
85,00
80,00
75,00
70,00
Mean of DCVI (%)
40 m
20 m
10 m
SPACE INTERVAL

(b-i)


TOPOGRAPHIC FEATURE: Ridge
90,00
87,00
84,00
81,00
78,00
Mean of DCVI (%)
40 m
20 m
10 m
SPACE INTERVAL

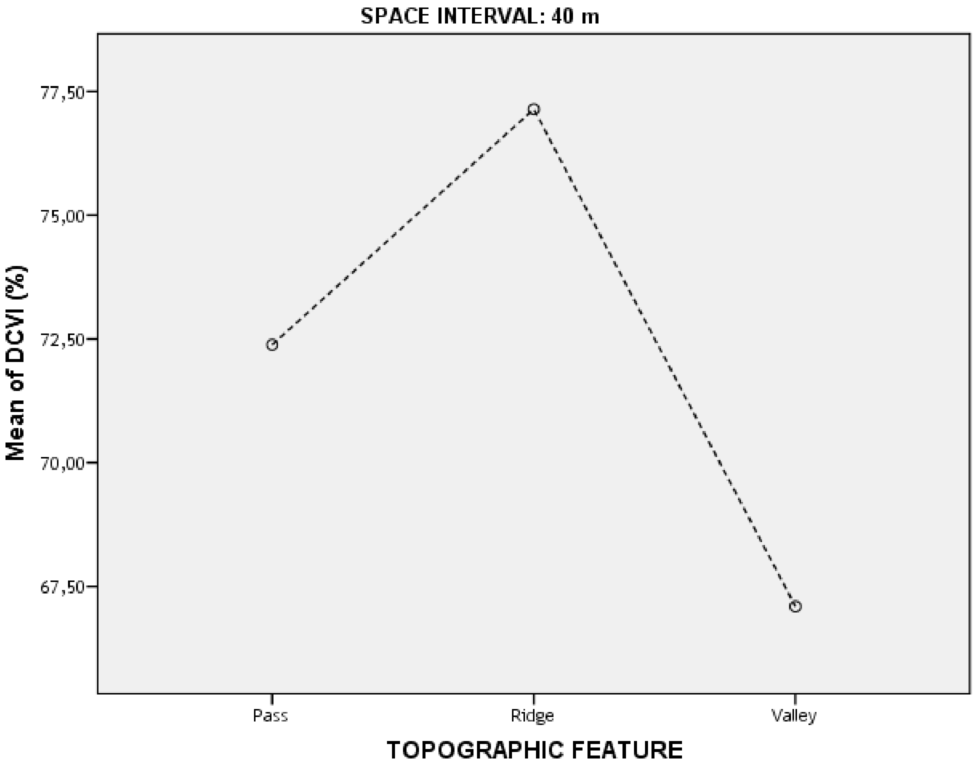
(b-ii)



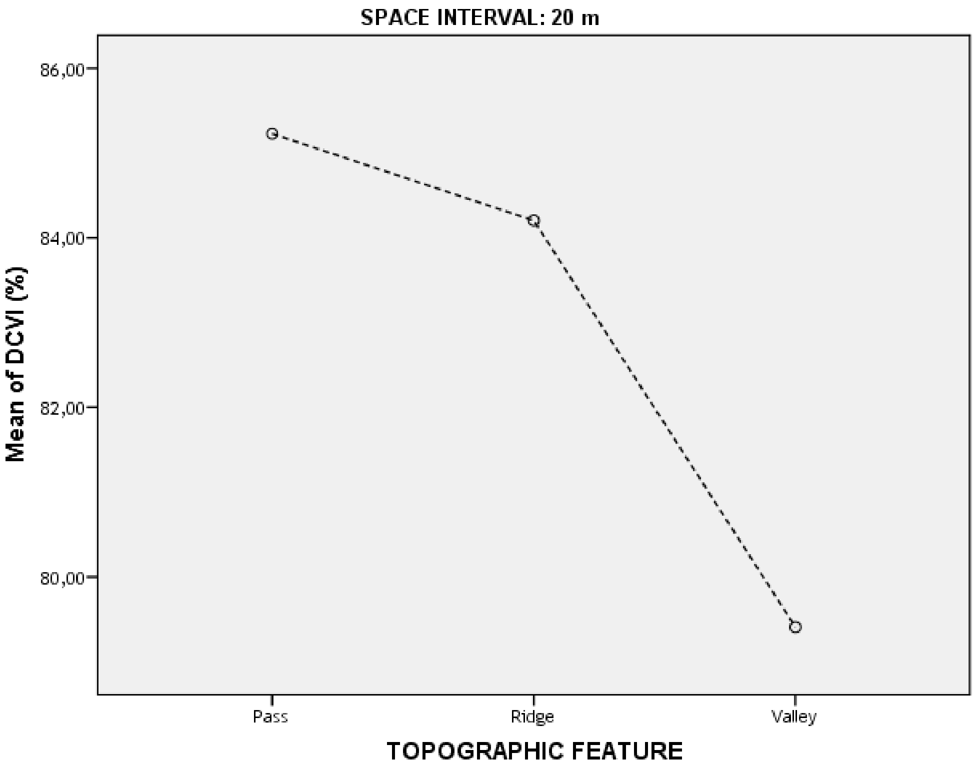
(b-iii)

Figure 63: ANOVA *means Plots* linking the DCVI with space interval: aggregate (irrespective of topographic feature) DCVI means (a); pass feature DCVI means (b-i); ridge feature DCVI means (b-ii); valley feature means (b-iii).

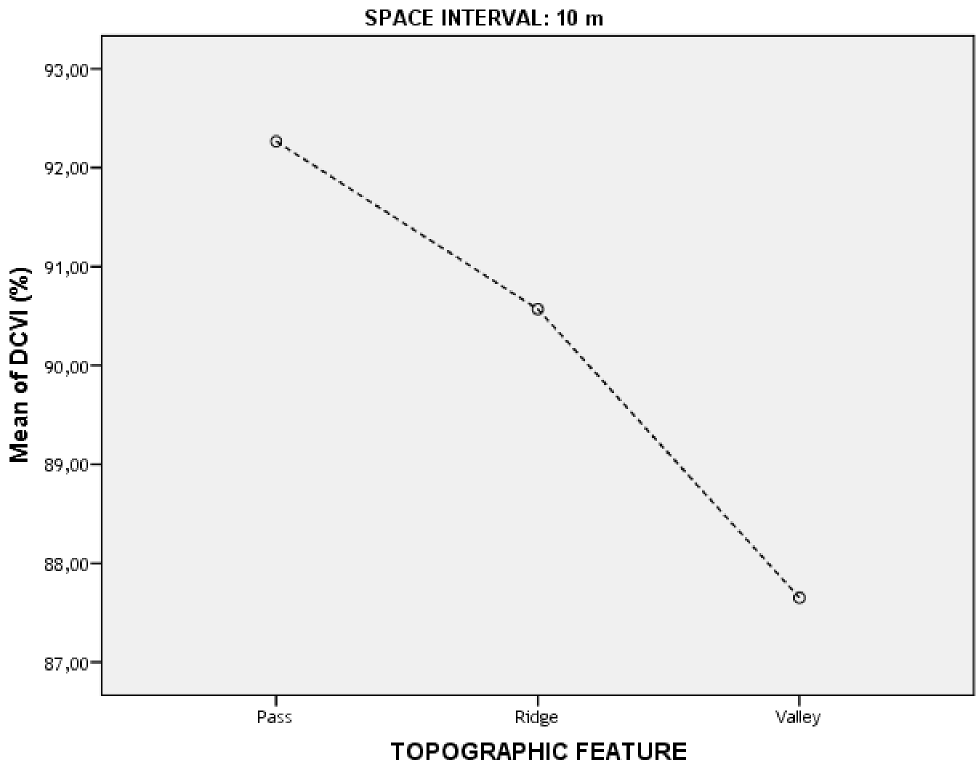
In a similar vein, if the ANOVA is carried out per space interval, then the DCVI means can de graphically compared among the three different topographic features. In Figure 64 such a comparison can take place since one can apprehend in a very explicit manner the effect of space interval across different topographic features. More specifically, while the DCVI arithmetic means of pass and ridge are higher at every interval than those of valley, pass viewroute grants an exceptional case (compared to the ridge one): by a 20-m densification of the initial 40-m viewpoint interval, its coherence has been significantly enhanced, to an extent that it has surpassed the DCVI mean of the 20-m viewpoint interval ridge viewroute – even though at the 40-m interval the ridge DCVI mean has been higher than the respective pass DCVI mean. This outcome has been partially expected due to: i) the generally coherent propagation of the viewsheds in the 40-m pass viewroute animated map/ geo-visualization and ii) the presence of an anomaly disrupting this continuity in visualscape evolution. Even so, by employing Figure 64 (chiefly Fig. 64a and Fig. 64b) it is lucidly portrayed that a little densification (20-m) offers a much greater coherence enhancement in comparison with the ridge viewroute animation coherence; or, in a different sense, that the intrinsic spatio-temporal visibility structure for the pass viewroute relies heavily on the viewpoint spacing – and that there is indeed a critical threshold for viewpoint spacing.


SPACE INTERVAL: 40 m
77,50
75,00
72,50
70,00
67,50
Mean of DCVI (%)
Pass
Ridge
Valley
TOPOGRAPHIC FEATURE

(a)


SPACE INTERVAL: 20 m
86,00
84,00
82,00
80,00
Mean of DCVI (%)
Pass
Ridge
Valley
TOPOGRAPHIC FEATURE

(b)



(c)

Figure 64: ANOVA *means Plots* linking the DCVI with the different topographic feature: 40-m space interval DCVI means (a); 20-m space interval DCVI means (b); 10-m space interval DCVI means (c).

6.3.3. Dynamic Visualscape + Elevation Profiling Visualization Discussion

According to the rationale of the two previous sections, three visualizations out of the initial nine have been opted as the most proper ones for the scope of the research: the 20-m pass, the 10-m ridge and the 20-m valley ones (see Supplementary Material I). Thereby, the integration of topographic profiling with moving viewpoints is implemented only on these three particular cases/ animated maps. Since the dynamic visualscapes are properly approximated at these intervals, we assume that only those should be considered; this decision depends heavily on the fact that the preparation of the cartographic frames – which now include the changing viewpoint position along the terrain cross-section and a scale bar – and, chiefly, the procedure of linking these frames in an animation (.gif) excessively extends the processing duration (see Table 14).

So, as these three visualizations are watched several times and by directing the attention on the viewpoint elevation changes as well, it emerges:

- **Pass Route**: This viewroute involves one conspicuous peculiarity with regard to its cross-section: there is a convex segment along the route (at the beginning) at which not only the respective angles considerably vary, but also the slopes values do swing from positive (+) to negative (-). More precisely, at the first steps of the animation, as the locomotive viewpoint proceeds, it moves upwards, and then, quickly, it turns downwards; after this initial change of direction, it continues to move from greater elevations to lower ones. But at this critical segment where the angle of locomotion is changing in terms of both value and sign, the animation is also accompanied by a major shift in the respective viewsheds. The upwards movement on a frontal impeded profile allows potential visibility to other areas other than the one that is in front of the observer. When the observer reaches the pass point (where slope and curvature are locally zero), both sides along the direction of locomotion can be visible. On the other hand, when this 'obstacle' has been overcome, the rear 'horizon' is blocked, whereas the visibility is permitted at the direction of the movement. So, the viewshed patterns emerging NE of the viewpoint begin to expand towards the latter, until they are becoming merged with it. Only a subtle concave-convex succession occurring until halfway the route delays this connection. In fact, the generally moderate elevation (and slope) variation gently modifies viewshed patterns for the most of the duration of the rest of the animation (after the change of slope sign). But the role of the elevation is controlled and 'restrained' within the bounds of the topographic feature's influence: may the visibility appear to dwindle with elevation decrease, but a little before the end of the route, even if the viewpoint keeps on moving downwards, visibility rises again. This is due to the fact that viewpoint eventually 'finds an opening' from the previous route segment which is generally secluded/ bounded at both sides perpendicular to the direction of the observer movement. As a result, the fan shaped viewshed starts becoming more flattened and widened at the end (as the observer 'exits' the confined pass route).

- **Ridge Route:** The topographic profile of the ridge line exhibits a jagged form, and, although the generic trend of locomotion takes place apparently from higher elevations to lower ones, at some points this trend is locally inversed since there are some cusps or stairs. From a cross-section perspective, this route could be partitioned into some topographically homogeneous segments, occurring along the route, namely: a) the 0-180-m relatively steep concave-profile, b) the 180-340-m gentle straight-profile, c) the 340-750-m 'terraced', d) the 750-900-m mild straight-profile and e) the 910-990-m steep straight-profile. It is worth noticing that we have presumed that the elevation and its variations significantly impinge on viewsheds; so, in order not to be biased at any fashion, we initially fix our attention to the main geo-visualization display, and subsequently we locate the positions or segments (on the topographic profile) for which extreme fluctuations take effect. Such a visualscape exploration tactic – heavily depended on many times of watching the animation – induce us to spot four 'discrete' cases in which the viewshed patterns are fundamentally altered: i) the most abrupt changes emerge at the route segment between 380 and 430 m, while ii) a sequence of very swift visible regions' supersessions (at relatively adjacent locations) are clearly discernible at about 550 m; iii) the 680-750-m section presents a major 'amount' of viewshed fluctuation and iv) a less significant series of variations take place along the penultimate (d) part of the route (800-900 m). By carefully inspecting the profile for these cases (segments/ points), it can be inferred that the presence of successive local minima/ local maxima bring about significant visualscape sudden shifts. In other words, the alternation between convex/ concave curve segments and the changing values and signs of slopes greatly affect the viewshed evolution (see above/ Pass Route) both quantitatively – number of visible cells – and geographically – spatial distributions. This is in particular true, as far as almost the totality of the 'violent' changes take place within the c route segment. But segment d also contains two inconspicuous yet sharp cusps, and the 'jerky/ jumpy' viewshed shifts do coincide with these slope transitions. On the other hand, segments a, b and e are characterized by a hypsometrically strictly decreasing sequence. An equally important remark is that from all these three segments, the most coherent one – in terms of visibility evolution – is the e; nonetheless, this segment entails the highest elevation change (i.e. slope) values. No matter how this effect/ result could be partially attributed to the specific natural meaning of this route segment (observation is at the phase of 'exiting' from the ridge line), it could prompt us induce that the elevation shifts (even great ones) do not impose erratic viewshed twists. Such an extrapolation does not contravene the premise/ observation according to which visibility co-varies with elevation: in essence, the 'breaks' in visibility values (DVI) and distributions coincide with the local elevation increase (i.e. cusps), within an overall trend that both elevation and visibility values decline (see also Supplementary Material I).

- **Valley Route:** The profile graph for this route differs from the other two in this: it does not present prominent irregularities, and when some micro-bulges protrude in this gentle curve slope (≈ 9% mean slope), they comprise neither absolute, nor local maxima elevation points. Such a typical – almost featureless – route segment comes about between 400 and 600 m. Along this segment, visualscape variations are very low, and mostly between 400-500 m where visible cells exist mainly within the valley's surroundings. On the other hand, the most conspicuous viewshed spatial transitions take effect at 170-230 m, 300-400 m and 600-700 m: but it is at these specific points/ segments that the subtle slope modifications emerge. And, in spite of the slight visible area variations in absolute figures, their relative transitions are indeed very intense, due to the overall very low DVI values. So, whenever a significant spatial (and numerical) alteration occurs, it is linked to a slope modification. In addition, another peculiarity that characterizes this viewroute is that whereas elevations constantly decline along the valley route, viewsheds do not; instead, they tend to increase at the aforementioned segments. Therefore, it could be reckoned that even if no higher grounds are present (as in pass's and ridge's cusps), visibility is augmented only 'for slope's change shake'.

Summing up, after scrupulously observing the animation looping of these three visualizations, some remarks emerge regarding both their comparison in terms of the elevation effect, and the exploration procedure itself:

- Elevation and elevation difference (of the moving viewpoint) exerts a major influence on the evolving complex viewshed patterns. However, it appears that the topographic feature's particularities play a decisive role as well; it could be assumed that these particularities shape the range within elevation variation can act. To elucidate, on the one hand, it generally appears that as elevation decreases, visibility also declines within each viewroute; on the other hand, the consequences of elevation variation on dynamic visualscapes are differentiated across different topographic routes. So, for instance, the effect of elevation is not the same for the ridge and the valley route; moreover, while only a small change of slope is enough to cause a large percentage viewshed transition in valley route, for significant viewshed pattern alterations to come about in the ridge route, changes in the sign of slope (i.e. convex/ concave segments – local/ absolute elevation maxima) are required to be present.
- Regarding the procedure/ tactics for exploring viewshed data while assessing the role of topography, it seems that the presence of the profile potentially distracts attention. However, the split attention mitigation, along with the proper harnessing of the invaluable benefits stemming from the profile's presence can be attained if one initially directs its attention only on the main display; after several loops and when the generic trend and specific irregularities have been surfaced, the actions of tracing the locations upon the cross-section ensue. At this first reading, the 'seeing that' (visible regions) is being attached to a 'reasoning why' (topography), but, afterwards, a more cognitive/ knowledge-based approach takes place by which the initial data-based approach is reversed; so, now the focus is on the profile and at these segments/ points that both observation and some of our initial hypotheses dictate us to concentrate on (which in our case coincide to a certain extent). After several times of watching this movie, we can assess whether our initial hypothesis is corroborated pertaining to the effect of the linear topographic feature and elevation on viewsheds; afterwards, we may once again fixate our gaze to the main display, recapitulate the break-points locations on the cross-section, re-explain and re-assess the influence of topography, and so on. In such a manner, this cyclical process – that includes two discrete stages – provides us information and insight, by dynamically imbuing with meaning the evolving spatial data (see MacEachren, 1995; Blok, 2005a; 2005b).

6.3.4. Statistical Analysis and Evaluation of Dynamic Viewsheds in Association with Elevation

Elevation is a factor that significantly modifies viewsheds; yet, as it emerges both by the descriptives and (as it is explicitly visualized) by the three final animated maps, the elevation differences among topographic features are not so high. For instance, the maximum elevation of valley viewpoints is only 40 m lesser than the minimum elevation of ridge viewpoints, but their discrepancies in the DVI is roughly 23 percentage units (!); similarly, the mean elevation of pass viewroute (≈2100 m) is hardly 50 m lesser than the mean elevation of the ridge viewroute (≈2150 m), a difference that cannot by itself explain/ justify such enormous disparities in viewsheds (almost 20 percentage units). It emerges, thus, that elevation difference (‘δz’) (as an independent variable) both *within the same* and *among different types* of topographic feature(s) does affect viewsheds, but in radically different manners (quantitatively and spatially). Besides, what figures and statistics can explicitly tell about the areas of changing visible regions, they cannot tell about the patterns, agglomerations and their spatial ‘stories’.

In an attempt to find any relationship – causative or not – between the visibility (DVI) and the terrain morphology (topographic feature or elevation) we should employ bivariate analyses as well. At this point, it is essential that we consider another important assumption (along with normality and independence): the measurement scale of the data. In addition, granted that visibility cannot be a determinant of the terrain morphology, intuitively, we are compelled to reckon that DVI is the dependent variable.

Therefore, in order to specify the influence of the different topographic feature (nominal scale data) on DVI (interval scale data), the Kruskal-Wallis test can be employed. Yet, this test should be conducted per spacing interval: since the data is dependent (structured in sets and subsets), comparisons can occur only within the same interval. Even so, the DVI mean ranks among the three topographic features (for each interval) significantly differ: Valley viewroutes display the lowest mean ranks and ridge routes the highest mean ranks, whereas pass routes receive intermediate values (irrespective of spacing interval) (Table 17). This is consistent with the results from the descriptives: DVI arithmetic means are ascending from valley viewpoints towards ridge viewpoints. Yet, what bears great importance is the zero value (0,000) of the asymptotic significance value, and the zero value of the *Monte Carlo* estimate of significance (< 0,05) (Table 18). On these grounds we can safely conclude that the (geomorphologically different) type of the topographic feature (independent variable) – or the configuration of viewpoints along these different routes – genuinely and significantly affects the DVI (viewsheds) (dependent variable). Nonetheless, this test (being a one-way ANOVA) signifies that a difference exists, but does not inform us exactly where this difference lies (Field, 2009).

Seeking for a quantitative interrelation between elevation (ratio scale data) and visibility (ratio scale data), it appears proper to harness “Spearman’s correlation coefficient: a standardized measure of the strength of relationship between two variables that does not rely on the assumptions of a parametric test” (Field, 2009: 788). The Spearman’s correlation coefficient suggests association, not causation.

However, once again, since visibility cannot be the independent variable and by sub-categorizing (grouping) per space interval, the correlation between elevation and DVI is demonstrated either without distinguishing between topographic feature types (Table 19) or by enabling this distinction (among different topographic features (Table 20). When attempting to link elevation with DVI in an aggregate manner, the correlation coefficient is very strong positive at the 0.01 level, irrespective of the space interval. When the same relationship is investigated with regard to the differing topographic feature, the correlation turns out to be (very) strong positive for pass and valley viewroutes and moderate positive for the ridge viewroute at the 0.01 level. (Only for the 40-m ridge the correlation is significant at the 0.05 level). The values of the first 'version' (Table 19) are larger than the largest values (pass feature) of the second 'version' (Table 20): considering the 10-m space interval, as being the most representative sub-sample, the pertinent values are 0,893 and 0,881 respectively (very high). This is not surprising since the sample in the first version integrates inherently (geomorphologically) different (and thus not dependent/ related data) samples on a more aggregate manner and, therefore, can encompass more diverse cases, ending up in more consistent associations between elevation and DVI. On the other hand, when comparing the correlation coefficients among topographic features with DVI, it appears that their values for the pass (0,881) and the valley route (0,785) are very high and adequately considerably high respectively, while for the ridge this value (0,416) is moderate.

As a consequence, the dynamic visualscapes owe their changing visible cell numbers not simply to the elevation, but to the *elevation differences* between successive locations of the moving viewpoint – the (elevation) values of which are quantized according to the DTM resolution and the spacing interval viewpoint arrangement. Nonetheless, this dynamic interrelation is not developing in a uniform manner. More precisely, the elevation differences *are not 'equivalent'* in *'determining' DVI regardless of their spatial occurrences*; contrariwise, their leverage depends on the (linear) topographic feature where they take place. In effect, the pass viewroute's correlation coefficient strongly indicates that as one is moving from lower altitudes to greater ones, the visibility is increased, and something analogous applies for valley route, even though in a somewhat weaker/ lesser extent; for the ridge viewroute, though, which displays the lowest correlation value, this association is not so straightforward. Such a finding has been already visually elicited from the visualizations including the moving viewpoint profile: regarding ridge viewroutes, not (only) the changes in elevation (slopes), but *changes in slopes* (curvatures) may impinge on the viewsheds in a more decisive manner.

In any case, however, one should keep in mind that when dealing with numerical (i.e. non-spatial) statistics, the pertinent analysis and interpretation should and could not appertain to terms like expansion or shrinkage which bear spatial reference. If one jointly takes into consideration the previous analysis of §

6.3.2. regarding DCVI – DCVI entails the spatial dimension in a latent manner – along with the DVI analysis of the § 6.3.2. and of the present section, he/ she may only partially overcome the intrinsic barriers of the understanding and interpretation of the *spatial* dynamics. For instance, relatively with the 20-m interval pass viewroute, by the combined harnessing of the aforementioned statistical analysis of DVI and DCVI one can only acquire the knowledge: i) that its DVI and DCVI variations are deeply rooted on its 'being a pass-route and not another topographic feature', while its DCVI variations are further dependent on the fact that is consists of 20-m spaced viewpoints; ii) that the visible covering percentage of the total area fluctuates around the arithmetic mean of its DVI (≈ 5,8 %), being strongly and positively correlated to viewpoint elevation variations: as the moving viewpoint hypsometrically either ascends or descends, the DVI percentage responds in a highly straightforward manner, by either mounting or diminishing respectively; and iii) that the manner in which these fluctuations occur is adequately coherent (DCVI mean ≈ 85,2 %) (except for a viewpoint-viewshed transition that exhibits a 'break').

So, these figures and the respective associations, correlations, determinants, explanations, even though they prompt us understand and statistically test and ground the importance of some factors which do impinge on viewsheds and on the consistency of their dynamic transition, they tells us almost nothing about their (viewsheds') spatial configuration or about the fashion in which they are spatially and temporally propagating. No matter how many and how dense viewpoints we set along a viewroute, the spatial 'story' of the viewsheds could not be reconstituted or approximated on the basis of these quantitative, numeric data, even if the corresponding visibility spatial pattern of a given viewpoint was granted. Solely the geo-visualization can address the dynamic spatial transition of the visibility patterns and enable/ render the existing connection with the topography in an explicit/ graphical way – not being intermediated by figures and arithmetic indices. Yet, the insight provided by visual exploration – albeit instantaneous, even apperceptive – is not rooted on a robust and empirically/ experimentally firmly grounded theoretic framework with a generalized (universal) validity, and, therefore, its explanatory potency is limited (especially in the case that one wills to extrapolate the explanation procedure to different landscapes).

Table 17: The mean DVI Ranks – Kruskal-Wallis test – among topographic features per space interval.

SPACE INTERVAL		TOPOGRAPHIC FEATURE	N	Mean Rank
40 m	DVI (%)	Pass	15	29,93
		Ridge	25	50,00
		Valley	22	11,55
		Total	62	

20 m	DVI (%)	Pass	29	57,93
		Ridge	49	97,00
		Valley	43	22,05
		Total	121	
10 m	DVI (%)	Pass	57	113,93
		Ridge	97	191,00
		Valley	85	43,05
		Total	239	

Table 18: Test Statistics[a,b] for the validity of the influence of the topographic feature upon the DVI.

SPACE INTERVAL				DVI (%)
40 m	Chi-Square			53,312
	df			2
	Asymp. Sig.			,000
	Monte Carlo Sig.	Sig.		,000[c]
		99% Confidence Interval	Lower Bound	,000
			Upper Bound	,000
20 m	Chi-Square			104,884
	df			2
	Asymp. Sig.			,000
	Monte Carlo Sig.	Sig.		,000[c]
		99% Confidence Interval	Lower Bound	,000
			Upper Bound	,000
10 m	Chi-Square			208,039
	df			2
	Asymp. Sig.			,000
	Monte Carlo Sig.	Sig.		,000[c]
		99% Confidence Interval	Lower Bound	,000
			Upper Bound	,000

a. Kruskal Wallis Test

b. Grouping Variable: TOPOGRAPHIC FEATURE

c. Based on 10000 sampled tables with starting seed 2000000.

Table 19: Correlation between elevation and DVI per space interval.

SPACE INTERVAL				DVI (%)
40 m	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,896**
			Sig. (2-tailed)	,000
			N	62
20 m	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,894**
			Sig. (2-tailed)	,000
			N	121

			Correlation Coefficient	,893**
10 m	Spearman's rho	ELEVATION (m)	Sig. (2-tailed)	,000
			N	239

**. Correlation is significant at the 0.01 level (2-tailed).

Table 20: Correlation between elevation and DVI distinguishing among topographic features per space interval.

SPACE INTERVAL	TOPOGRAPHIC FEATURE				DVI (%)
40 m	Pass	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,857**
				Sig. (2-tailed)	,000
				N	15
	Ridge	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,471*
				Sig. (2-tailed)	,018
				N	25
	Valley	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,809**
				Sig. (2-tailed)	,000
				N	22
20 m	Pass	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,881**
				Sig. (2-tailed)	,000
				N	29
	Ridge	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,435**
				Sig. (2-tailed)	,002
				N	49
	Valley	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,792**
				Sig. (2-tailed)	,000
				N	43
10 m	Pass	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,880**
				Sig. (2-tailed)	,000
				N	57
	Ridge	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,416**
				Sig. (2-tailed)	,000
				N	97
	Valley	Spearman's rho	ELEVATION (m)	Correlation Coefficient	,785**
				Sig. (2-tailed)	,000
				N	85

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

7. CONCLUSION

[“Cartography needs to make a major push to expand its theoretical base because it is clear now that no matter how powerful, the computer may not be able to empirically or heuristically solve certain classes of numerical problems.”]

Harold Moellering

[“The long-lasting fertility of the good theory cannot be accounted for by simply alleging the endless creativity of the human mind in the face of anomaly. The model guides, and it guides in a way that a summary of the original ‘data’ could never do, no matter how ‘creatively’ made, unless there was a resonance between model and object.”]

Ernan McMullin

In the previous it has been demonstrated how the venture of visualizing viewshed changes via cartographic exploration and animated maps is effectuated – from its initial apprehension (both intuitively and empirically) until its final implementation and evaluation. Even though some significant findings and other crucial elements have already been noted and commented, in this chapter we summarize all the conclusions drawn from the totality of this thesis. These conclusions are organized in the shape of i) a ***synopsis*** which provides an overview of the overall contribution of this master’s thesis with regard to the goal and objectives, while the most specific inferential information arises as ii) ***explicit answers and declarations*** to the research questions and hypotheses of the Introduction; iii) last, ***further research*** is suggested by promoting ***follow-up*** inquiry.

7.1. SYNOPSIS

The generic framework whereby this thesis is conceived relates to ‘rendering tangible’ the visual landscape for locomotive observers along different tracks (routes). Towards this end, the map (vertical projection) is to serve as an optimal medium – owing to its being an abstraction. To further elaborate, the cartographic visualization (geo-visualization) paradigm is employed: as a consequence, the *2-d fly-over animated map metaphor* has been utilized to facilitate and approximate the portrayal of the changing visual landscape; for our goal and objectives, this communicative means of depiction is shifted towards more explorative tasks of examining the *dynamic visualscapes* in association with the underlying geomorphology (i.e. topographic feature and elevation) of a study area.

In the introduction we have assumed that in order to investigate (some of) the visual properties and spatial configurations of a terrain or a landscape, a continuous dynamic depiction of what is visible from a variety of observation points could comprise an intuitive and viable solution. Moreover, such an investigation should be facilitated by a digital/ computer assisted modeling and visualization method and procedure.

The concept of visibility and its digital counterparts – isovists, viewsheds, visualscapes – can immediately serve the second requirement, that is digital visualization of the landscape visibility, although in a static manner; in addition, all of these (data) representational structures are compatible with the vertical projection in which maps tend to be portrayed. Viewsheds and visibility analysis abut in certain algorithms that produce maps of visible and not visible regions. Both the election of the visibility algorithm and the pertinent DTM (grid) affect the viewshed output. So, the (theoretical) conceptualizations of how visibility occurs in digital environments gains extraordinaire importance; this means that faulty algorithmic assumptions and inaccurate digital representations (e.g. DTM error) play a far more essential role than non-adequately accurate elevation measurements in the field. In this context, the issue of varying degrees of uncertainty emerges, and the 'fuzziness' of the viewshed derivation appears to be inherent to its algorithmic computation, as it is afflicted by the omnipresent discretization effect/ problem – i.e. the transition from analog to digital world. As a result, the debate between Boolean *vs.* Fuzzy viewsheds poses a great consideration for the study of visibility in either static or dynamic terms. Our decision to utilize binary (Boolean) viewsheds stems from the practical reason to work with the simplest (typical) version of viewsheds in this tentative attempt.

Therefore, as (binary) viewsheds are digital products derived from GIS's analytical functions and can provide an inimitable but also abstracted representation of the visual landscape, they are considered proper enough to even approximate the changes of the visual landscape in cases of a moving observer (viewpoint). At this point, the crucial aspect of viewsheds' proper representation in the GIS context emerges. By adopting a representational model that incorporates both the object- and the field-perspectives (OF), the issue is partly remediated – even if there are many more to be contemplated and implemented for a dynamic OF model to be established. In a more practical manner, our tactic of circumventing the problem of developing a rigorous representational scheme (OF) is based on the fundamental premise that: by linking each viewpoint with its visible regions in separate frames and then by dynamically merging these frames we can reconstitute the propagating spatial pattern of what is visible from adjacent-successive viewpoints along a pre-defined route; but, such an animated sequence is rated as an *abstracted 2-d exocentric fly-over*.

Moving from conceptualization to implementation, and aside from addressing such representational issues, the distinctiveness/ uniqueness of viewsheds in geomorphological and geomorphometrical terms calls for their scholarly inspection and special treatment. Since they rely on both local-specific characteristics of the viewpoints and the topographic surface of the (non-neighbouring) totality of the study area, the separate visible regions are partially dependent on each viewpoint location from which they stem; not quite surprisingly, these individual visible regions are not directly correlated one with each other. Therefore, in a sense, the spatial correlation between two separate viewsheds is intervened by the two viewpoints from which these visible regions emanate; and so, the 'action-at-distance forces' present in such a regional (or at least non-local) parameter are reduced to an extent to the local-specific interactions between nearby (view)points. Yet, this interaction gains 'a more regional character', by tracing geomorphologically/ topographically intrinsic sequences (series) of points; such sequences exist in linear topographic features which entail properties that tend to unify a succession of spatially adjoining viewpoints, and, to some extent, the succession of their respective viewsheds. In such a manner, the attainment of viewshed continuity and consistency is significantly attributed to the local interactions of viewpoints located on 'topographically privileged' linear features (ridge-lines, course-lines, pass-lines).

Our venture to further experiment on the *description of a mountainous visual landscape* does pivot on these generic principles, but also requires digital elevation data to simulate the process. So, in a digital-terrain-modeling-oriented approach, aspects of scale and sampling appear extremely important for both the static and the dynamic rendering and visualization of the viewsheds; the spatial resolution and geographical extent of the DTM (i) and the locations of the observation points, as well as their intervening distances (ii) comprise two outstanding issues. In practice, the optimal (if there are such) measures are sought for both scale (resolution and extent) and viewpoint spacing intervals; but the latter appears to constitute a vital parameter for dynamic visualizations with reference to the selected (proper) scale. So, after several experimentations with varying DTM resolutions and by delving into the literature regarding the land-surface parameters in general and viewsheds in particular, we end up electing a single resolution (4 meters) – for practical reasons. In addition, the geographic extent of the study area (a square 25 km^2 moderately rugged mountainous landscape) puts inevitable inherent limitations (see § 6.2.1. and § 5.2.2.2.). By keeping the scale constant, we have been able to explore the evolving patterns of visibility data under different spacing intervals by creating certain pre-defined animations. In essence, it is the discretization problem that further feeds a healthy skepticism; in other words, our venture has been directed to heuristically inspect 'how close' should the viewpoints be placed with relation to the DTM grid's resolution and subsequently compute their respective viewsheds in order to satisfy a multitude of requirements. The compromise of: data volume and computational load/ time mitigation, adequate approximation of the innate spatial variation of the evolving visualscapes, and the cognitive perceptibility of dynamically visualizing viewshed changes have been explicitly considered in this thesis for generating feasible, reliable and effective animated geovisualizations.

Implicit to the mitigation of computation time is the issue of automating the procedure of calculating the viewsheds and other useful products. So, the extensive utilization of the ModelBuilder in ArcGIS – through which the initial digitization of certain predefined viewroutes under different space intervals ends up in outputs necessary for the frames of the animation and other numerical data – is of great importance for the feasibility of the visualizations and their statistical evaluation. Even though the modeling of the procedure may has not been optimized in this thesis, the resulting redundant data/ information is counterbalanced by the capacity of automation to expel the need of manual intervention in tasks that are mundane and time-consuming. So, the computation of some extra outputs is deemed acceptable compared to the time that manual manipulation would require and it is saved due to procedure automation. The duration of the model runs ranges from 2 up to 16 minutes, with these durations being approximately proportional to the numbers of viewpoints. Yet, even if the viewshed calculation durations are mitigated and, even if the manual data manipulation burden is substantially lowered because this is an unattended procedure, the time requirements for a complete visualization is very high if one includes the time needed to prepare the frames and to implement the subsequent animation. Thence, the (ordinal) level reduction for the viewpoint space interval (e.g. from 10 meters to 20 meters – from a more to a less dense interval) is proved to be extremely beneficial in saving time and manipulation burden for the frame preparation; as for the animation sequence, the durations are virtually the same for each viewroute across different viewpoint intervals, but the user mediation is much more frequent for 10-m viewpoint interval animations compared to 20-m and even more to 40-m ones. So, it emerges that the complete visualization durations and manipulative tasks are fairly mitigated due to the automation effects offered by modeling (GIS ModelBuilder), and greatly reduced when a less dense viewpoint array is harnessed; as a consequence, both modeling is crucial (it would be most convenient if the whole procedure could be automated), and the harnessing of the possibly less dense array of viewpoints.

Nevertheless, it cannot be told that – irrespectively of volume and manipulation requirements – the dynamic visualscapes approximate more faithfully (in realistic terms) the evolution of terrain visibility changes simply because the densest possible sequence of viewpoints (and their intertwined viewsheds) are readily available, facile and convenient to manipulate. The discussion about uncertainty in viewsheds further connotes that with reference to the dynamic visualscape visualization there can be no single optimal animation of the real-evolving spatial pattern – since there is no such thing – but only more or less faithful approximations of it. However, this conclusion is not to be interpreted in the sense that dynamic viewshed visualization is a sheer *ad hoc* venture (i.e. each case should be regarded individually); nonetheless, viewshed visualization should heavily depend on the distinguishable topographic/ landscape character.

Thus, the exploration of this kind of spatial data in a pre-destined animated sequence provides significant insight about the dynamic evolution of the visibility itself with a moving point of view, whereas it can adumbrate the uncertainty among varying intervals and along different viewroutes. Yet, a careful observation of the different visualization loopings reveals their cognitive requirements, and so their suitability in terms of their differential capability for apprehension. Since the viewroutes are far from being selected by random but their very 'substance' is rather 'carved by nature', the exploration of spatial data is not carried out blindly; contrariwise, it involves an implicit hypothesis that different topographic features entail different visibility patterns – i.e. both uneven number of visible cells and spatial configurations – which behave differently with locomotion or time – i.e. viewpoint changes (attributed to motion and/ or time) – while there is an indirect and inexplicit spatial correlation between viewsheds emanating from successive viewpoints on prominent linear topographic features. To a certain extent, that is why the generated geovisualizations have been preferred to deviate from interactivity: the distinctiveness of each topographic feature pertaining to visibility urge us as 'map-makers' to create pre-ordered animated sequences – with in-between frames (micro-steps) being considered indispensable for meaningful visualizations. Besides, our tactic of keeping a uniform 10-frame-per-second (fps) frequency and maintaining a constant rate of change for all animations guarantees that the animations are equivalent, or at least comparable.

As a consequence, it is the Apprehension Principle that appears to primarily steer the animated rendering of such visualizations. Even though spatio-temporal data exploration appertains to the private realm of geovisualization, the communication between the map-maker and the map-users – the latter ones can be either exclusively the same person or a group of domain experts – is still essential. Therefore, as this thesis predominantly explores the effect of topography on visualscapes, there has been a dire necessity to elect some tracks (viewroutes) along which the dynamic viewsheds are to be visualized and be compared – but in a means that the extraneous cognitive load is mitigated and by maintaining the intrinsic cognitive load as low as possible. Whereas the latter is addressed by employing generalized, abstracted 'aspects' of relevant spatio-temporal data (refraining from visual realism), the former is achieved by adhering to fundamental principles in (animated) cartographic design and by maintaining only the most cohesive and easy to apprehend animated sequences: this 'weeding out' occurs by posing some initial theoretical/ intuitive hypotheses and then by empirically experimenting with equivalent sequences. Since animated maps are temporal abstractions as well as semantic and geometrical ones, the utilization of the most proper viewsheds and viewpoints befalls into the former kind of abstraction (serving in both extraneous and intrinsic load diminution). In a sense, the viewroutes have acted as sampling frames of the overall landscape of the area of concern. Inside these frames, from a finite number of viewpoints[79] capable of being placed along these routes, the most suitable intervals are to be selected; and

[79] The infinite number of viewpoints of the real, analog world is reduced to a finite number of them, due to discreteness effect (DTM cells).

based on the occurring viewpoints the fundamental association between topographic feature, elevation and visibility is to be unraveled. In contrast to what common sense would dictate, neither terrain visibility visualization necessarily optimally approximates the real (field) process as the resolution is perpetually refined and the viewpoint interval is minimized, nor the more refined resolutions and the more adjacent viewpoints are solely liable to augment the effectiveness of the geovisualizations. Even more paradoxically (?), it is not visual realism but its opposite pole, abstraction, which lends both perceptual and meaning-derivation potency to these geovisualizations.

Besides, the implementation of dynamic viewshed (data) exploration by means of breaking up an (otherwise) aggregate animation in three different parts according to the type of route, entails four assets: i) better understanding of topographically different paths through separate animations of limited duration (less than a minute), ii) examination of the different requirements for each viewroute with relation to viewpoint space interval, iii) the potential need for a variable viewpoint interval – at least in cases where a route entails several types of viewroutes – as a consequence of (ii), and vi) explanatory specifications of the elevation (difference) contribution to the dynamic visualscapes at different topographic features-routes. In relation to the latter advantage, it should be highlighted that the final animated maps enable the graphical dynamic correspondence between elevation fluctuations and viewshed pattern transitions in an unambiguous and perceivable manner, eventually adding vital information and deep, active insight. More precisely, the presence of the moving viewpoint along a topographic cross-section actively links together user's attention on viewpoint's elevation differences and viewshed changes, and so the user engagement mounts enhancing the germane cognitive load. Furthermore, this afore-mentioned segmentation itself is also augmenting the germane load: the comparison of the viewshed-elevation covariance behavior among different parts of animation (i.e. viewroutes) entails user involvement.

Summing up, spatio-temporal data filtering and active linkage between the moving point elevation profiling and the main map in the dynamic visualization prompts users to interplay with them instead of merely and passively watching them as integral sequences. May these visualizations not be typically interactive, yet, if they are treated as series of associated sequences – owing to their being segmented and entailing active linkage between elevation and visibility – they could be rated as guided, low-level interactive engagement visualizations. In any case, though, high levels of interactivity and user control would be prohibitive for the goal of this thesis, since attention would be split and mental activity would be consumed by the more complicated interface existing in geo-visualizations enriched with such levels. In a more practical manner, increased interactivity and exigent interface controls would: i) nullify the potential of enabling gradual transitions (spatio-temporal data smoothing) and ii) deter complexity mitigation and generalization of the evolving spatial patterns. As a consequence, the overall (most prominent) viewshed trend visualization in relation to elevation in different viewroutes would be far from being facilitated.

7.2. RESPONSE TO THE RESEARCH QUESTIONS (R.Q.) / HYPOTHESES (H.)

As this concluding synopsis sheds new light in the domain of visual landscape exploration via animated viewshed visualizations, this thesis' goal and objectives have been addressed. However, towards dealing with the subtleties of these problems, we are to respond to the research questions and hypotheses posed in the Introduction.

7.2.1. R.Q.1 / H.1

It has been previously promoted that a landscape's surface (terrain) can be completely 'reconstructed' or fully described by its slope angles; yet, slope is a local-specific land surface parameter. On the other hand, viewshed is a non-local parameter, and thence attributing to each cell its visual magnitude (total viewsheds) is extremely computationally intensive, especially for extensive, fine-resolution DTMs; even more difficult is to render not only how many, but also which cells are observable (identifying viewsheds). Besides, the second type raises issues of dynamically depicting the visible target-cells for each observer-cell. Research in DTM visibility has employed certain functions to trace out paths that satisfy certain requirements, whereas, inversely, sampling in 2-d space and DTMs implicates some tactics for optimal/ compressed point selection. In fact, there are certain DTM cells that are prominent and particularly liable to convey augmented information about visibility. These cells coincide with peaks, pits and passes. As this thesis is to fulfill an explorative venture, we have adopted an approach that merges the advantages of prominent topographic features, and the consistency of a linear sequence. More precisely, given that not only the description, but also the visualization of this non-local surface parameter is to be considered, except for the extensive data volume computation and manipulation, the more intriguing question would be in what way the succession of viewshed should take place (e.g. blindly?). It appears that a visualization of viewshed changes along a route that has no predetermination with reference to its visual properties or configuration (e.g. minimal visual exposure) but is rather dependent on an inherent structure of the topography can respond to this question: Guided by the linear topographic features, the exploration can come about taking advantage of a both 'bottom-up and theory-laden' approach. So, the elevation continuum derived from the input data itself due to the topographic consistency of such surface lines is roughly extrapolated to the manner that the emerging results are to propagate – although we are aware that the latter continuum is sometimes prone to fall apart. So, if one has to 'reconstitute' the visual structure of a DTM in a representative but also cognitive/ intuitive manner, then the linear topographic feature perspective arises as a viable and enhanced alternative for approximating both visual land surface description and geovisualization.

7.2.2. R.Q.2 / H.2

The overwhelming majority of computer-users are well-acquainted with conventional fly-overs. However, according to our assertion, the geovisualization of visualscapes (viewroutes) equals to an abstracted fly-over, since for every viewpoint along a track a viewshed is available. In practice, by visualizing the viewpoint and its respective viewshed in an animated sequence, we can reconstitute a 2-d generalized flow of panoramic vistas (without regard to the field/ cone of view) of a landscape for 'every possible' position along the route. Even though such a sequence is used as a medium to explore viewshed evolution from a moving point of observation, it can serve as a communicative means for simulating the succession of vistas along a flight-path. Since there have been proposed several cues for reducing the negative effects of egocentric, oblique-perspective, immersive, informational congestive, disorientating, visually augmented 3-d fly-bys, the real question is to what extent all these traits of these typical 3-d fly-overs are particularly purposeful for a meaningful visualization. No matter how such a visual realism including dynamism can induce an exciting and rich-in-information experience, it emerges that more generalized visualizations can provide more lucid understanding for the spatial evolving behavior of a phenomenon or process. In cases where either the visual occlusion is high, the visualization 'substrate' (background) is bewildering, or the information load is immense, and the purpose of geo-visualization is specific (e.g. 'locomotive vistas processes'), such pre-defined animated sequences could even substitute the more sophisticated 3-d fly-bys if additional cartographic information is properly added (i.e. generalized spatial/ thematic information about e.g. roads, land parcels, land use, etc.).

7.2.3. R.Q.3,4,5,7 / H.3

In this research we have dealt with the probe of the viewshed evolution with a moving viewpoint on special, pre-defined routes. But visibility occurrence differs in analog and digital worlds due to the generic effects of discretization, the assumptions made pertaining to the computer analytic (algorithmic) procedure, and the static and dynamic representation of terrain/ viewshed properties – that is scale and sampling viewpoint interval. Moreover, the computation of visible regions irrespective of the field of view (use of a 360-degree field of view) implies that the animated sequence is not to simulate what would be seen from a human observer moving at realistic conditions (i.e. vehicular, cycling, hiking/ walking locomotion). As a consequence, there are no actual benchmarks (e.g. speed of movement), but only data-driven (different visibility pattern transitions along different viewroutes) and cognitive-driven (visualization comprehension) ones. So, the faithful simulation of the process *per se* cannot be established, simply because there is no such (self-existent) spatio-temporal process. Nonetheless, several auxiliary sources ‘rationalize’ this research: bibliographical and empirical evidence of a DTM cell range for geomorphometric parameters representation and depiction, the sampling theorem with reference to terrain profile (1,5-d) sampling intervals (inflection (view)points), and the Apprehension Principle for a pragmatic approximation of the visual landscape evolving process. Besides, the Congruence Principle can only delineate the parameters for sampling viewsheds: according to this principle alone, one could claim with certainty that two successive viewshed-frames could not be located at the diametrical ends of a 1-km route, albeit not being able to suggest which is a fair enough interval. However, by extrapolating the sampling theorem in dynamic viewshed visualization, and by setting as a lower threshold the viewpoint interval of 10 m for a 4-m resolution DTM and by selecting some multiple intervals (20m, 40m), we have created a spectrum for empirically testing the viewshed evolution by means of visual exploration.

The simultaneous manipulation/ regulation of these inflection viewpoints across different viewroutes comprise the basic independent inputs/ variables for the parameterization of our experimentation (for a constant DTM scale). We could infer that the selection of a coarser resolution (e.g. 8-m cell) may not have deteriorated our geo-visualization, although we are certain that for a very large cell size the exploration would be meaningless. Nevertheless, if we imagined the prospect of a user attempting to investigate the visualscape variation for an area equal to the Wyoming state, a much larger cell for an extended route would not be expected to cause any inconsistency; contrariwise, cartographic (visualization) generalization itself would call for a significant resolution coarsening. In our case, though, it has been proven that the cognitive limits of animated maps (Apprehension Principle) with relation to the differential inherent spatial variation of the different viewroutes seem to steer the election of the viewpoint interval (for a constant 4-m DTM resolution).

So, whereas DTM resolution can fluctuate within a certain range, it does not follow: ‘the finer the better’; moreover, the viewshed computational assumptions and algorithms, and the geographical extent that is studied should be taken into consideration. As for the sampling (viewpoint) interval, it appears to emerge in association with (as a function of) resolution, but with regard to the route segment (linear topographic feature) along which the visual exploration is conducted. And even if the paradox of increasing the scale (i.e. enabling a denser viewpoint spatial array) entails the emergence of more details and irregularities, this does not apply homogeneously for all routes. Furthermore, the succession of more or less detailed viewshed-frames has different implications on the apprehension of the animation depending on the viewroute. The inauguration of the Dynamic Coherence Visibility Index (DCVI) offers a good indication of the continuity of the animated visualization, yet it does not explicitly verge on the pertinent spatial pattern evolution. While an enhancement of the DCVI as the viewpoint interval drops demonstrates cohesion augmentation, it is not necessary for all viewroutes to be driven to utilize the densest available viewpoints (in this thesis: valley and pass routes); in contrast, for some others (ridge route), the 10-m interval (densest viewpoint configuration) best satisfies both the corresponding congruence with the significant pattern variations and their communicative potential – in the shape of animated sequences.

So, as a general conclusion, it comes about that neither the finest possible resolution is desirable, nor the densest viewpoint spatial array is optimal for the approximation and apprehension of the locomotive observation visualscape transition (the visualization could be swamped with extreme, unwanted details (patches), and the cognitive capability would be impaired). Implicit to the latter conclusion is that if we where to explore a landscape by sampling its totality of linear features and by dynamically computing viewshed upon a continuous viewroute – transiting amongst ridges, pass-lines and valleys –, then a constant viewpoint interval would not be congruent. So, a variable step (interval) would be needed. If we extent this rationale, and because nature 'hates sharp boundaries', even in otherwise integral route segments (i.e. a valley) the animation frames could require a variable step for viewshed computation. In addition, the very nature of viewsheds themselves – i.e. regional land surface parameters – and their dynamic approximation imply that the parameterization of local attributes alone – i.e. the viewpoint interval – could not perfectly match all the prominent changes in viewsheds. That is why the topographic feature has been included in the analysis/ exploration: to offer a more regionalized perspective. Even so, one cannot claim that either the totality of the landscape to which visibility refers can be absolutely condensed and attributed to a prominent linear feature, or that the discrete location for every viewpoint can be rated to occur on a single, spatially well-defined topographic feature (e.g. the pass point (area) comes under both the ridge and the pass-line topographic features). As a consequence, a latent fuzziness permeates both the static viewshed analysis and the dynamic viewshed visualization. Nonetheless, the inclusion of viewsheds' fuzzy character would further intricate such a tentative explorative approach.

7.2.4. R.Q.6 / H.4

Commencing by the platitude that one has to climb up at higher grounds to be able to see the most of a landscape, elevation seems to be rated as a salient determinant for visibility. As it is empirically corroborated, elevation fluctuations (i.e. difference) are accompanied by visibility variations; and as one explores the advancement of the moving point along a viewroute (topographic feature), it clearly arises that elevation shapes the behaviour of viewsheds. However, it does not ensue from the former that viewsheds 'are yielded' only under the effect of elevation – irrespectively of the specific landscape/ landform character. In other words, other factors contributing to viewshed evolution are to be examined. The empirical comparison among different routes – linear topographic features – illuminates this premise: viewshed patterns significantly deviate from route to route, although the viewpoint altitude exerts influence over visualscape's evolution. This could mean that the additional surrounding terrain information implicitly carried within linear topographic features complements visualscape dynamic behaviour explanation to a very high degree; as the topographic feature entails encrypted terrain information, it can be considered as another dominant factor (aside from elevation itself) that adumbrates visibility. Therefore, the influential action of elevation cannot but be inquired within the overarching context of the topographic feature. Even within such an explorative context, one should consider not only the elevation of the topographic cross-section of each route-topographic feature, but its first and second derivatives. More precisely, it has been shown that the profile (i.e. 1,5-d) *slope* and *curvature* variations significantly explain the prominent viewshed transitions – even more definitely than elevation. Yet, while for pass and ridge viewroutes the changes in slope direction/ signs and the transition from convex to concave sub-segments coincide with such major visibility pattern shifts (often both in spatial and quantitative terms), for the valley viewroute even moderate changes in slope induce visibility patterns to significantly alter. To sum up, it could be inferred that the topographic feature-viewroute does not directly regulate the partial viewshed transition within a route, but it delineates the overall trend, while the variations of the terrain profile (elevation, slope and curvature) do affect this 'internal' visualscape shift.

For all these associations to arise, an utilitarian visualization synthesis should be employed. To this end, the insertion of the moving point topographic profile substantially facilitates the enabling of a link between the moving viewpoint's elevation (z) and its dynamic viewshed (DVI) for the changing x,y viewpoint location; even though it is time-consuming to include this profile in the animation and it takes several repetitions for a comprehensive understanding to take place, the time dedicated to this explorative task is vital, while the interpretive process of visual exploration cannot be substituted by another one. The particular potency of the dynamic viewpoint elevation profiling lies on the readily-perceivable graphical depiction of the 1,5-d morphological status – elevation, slope, curvature – of the route segment and the explicit dynamic presentation of the viewpoint's elevation difference with relation to the distance between two observation locations ($\frac{dz}{ds}$); thence, the viewpoint's changing locations are *a priori* given and known in a predetermined cross-section (the graphical existence of) which significantly facilitates learning of the 1,5-d topographical regime and the quicker and more convenient linkage of the latter both to the '2,5-d' (vertically projected) route positioning and to the changing viewsheds on the main map ($\frac{dDVI}{dz}$). Eventually, by watching multiple times the animations loops – and by simultaneously consulting the respective numerical values and statistic calculations/ correlations – a thorough and profound insight is gained which would be missed if the profile was not incorporated in the visualization.

Aside from all these conclusions that arise as responses to questions and hypotheses of this research, a more generic conclusion emerges with relation to the strategy that we have elected and shaped for the geovisualization of this particular aspect of the terrain/ landscape. The process of testing a variety of viewpoint spacing intervals (steps) with the aim to maintaining only the optimal animated sequences can be rated as an explorative strategy mitigating uncertainty and enhancing effectiveness – in other words bridging the gap between Congruence and Apprehension Principles. In this perspective, as we have been creatively constructing the animated visualscape maps, the persistent exploration of denser/ sparser inflection viewpoints has led to more communicable outputs, proper for the exploration of the 'inherent' visual structure of the landscape. As a consequence, after having explored the medium of approaching the evolving process – i.e. abstracted 2-d fly-over – the main exploration of the process itself takes place. But such a succession entails an association between exploration and communication: a schema (i.e. abstracted 2-d fly) is selected/ promoted to facilitate viewshed sequences, the visual exploration is creatively establishing more effective dynamic visualizations, and the latter ones are ultimately harnessed to add understanding to the dynamic propagation of viewshed with topography (Fig. 65).

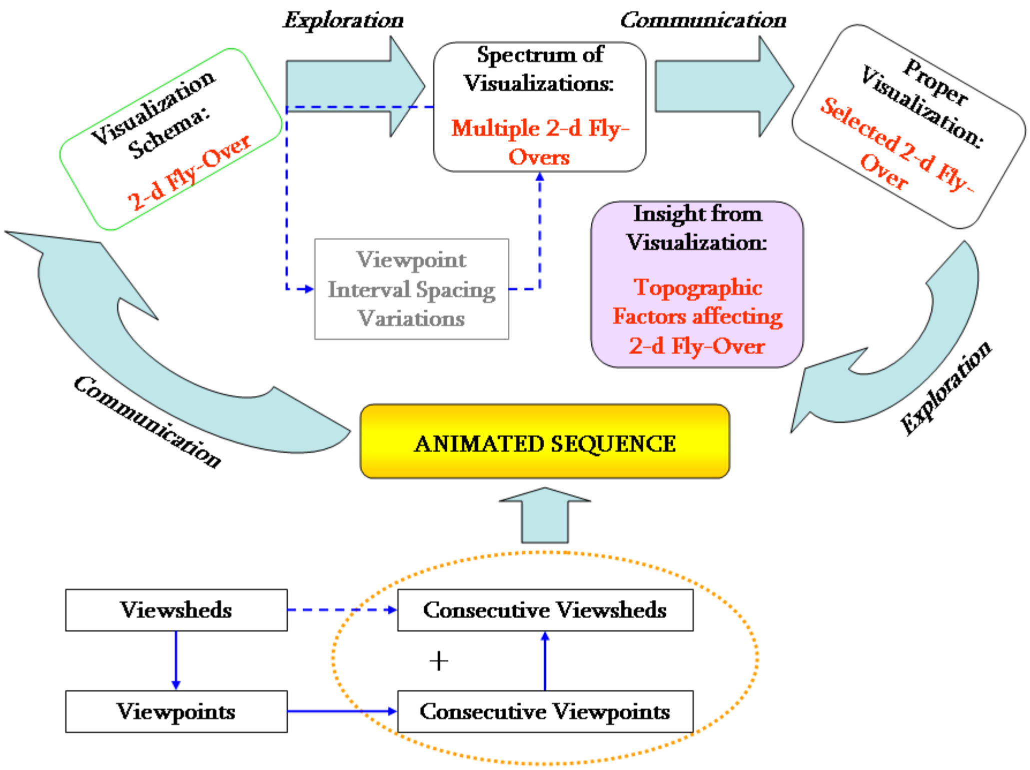


Figure 65: Insight gaining from geo-visualization of dynamic, animated viewsheds attained as a succession of communication/ exploration tasks. Note: the 2-d fly over 'schema' substantially facilitates this succession.

7.3. FURTHER RESEARCH (FOLLOW-UP)

Given that a thesis' extent is limited and that its goal and objectives are well-defined, not all the pertinent research issues can be addressed. Nevertheless, in our thesis several such issues latently emerge by the presentation of the previous sections of this chapter. Herein we adumbrate some of the most notable ones that can carry the research a step further. More precisely we refer to:

- ***Harnessing varying grid cell sizes and fuzzy viewsheds***: The resolution (i.e. the one aspect of scale) of the DTM's and viewshed's grids could be investigated; to elucidate, one could employ animation to visually explore the effect of varying cell-sized (e.g. 1-m, 2-m, 4-m, 8-m etc) viewsheds. This task could result to multi-resolution visualizations (yet within a certain resolution range for the same geographic extent); thence, for one group of viewpoints their respective frames' viewshed resolution could equal a finer (e.g. 2 m) resolution, whereas for another group of viewpoints their frames could be of a larger cell size (e.g. 4 m). In a similar way, one might utilize fuzzy viewsheds as animation frames instead of discrete viewsheds and subsequently make comparison of viewshed changes between the two types of viewsheds harnessed.
- ***Over-sampling or sub-sampling the series of viewpoints to visualize non-homogeneous viewroutes***: It appears legitimate to detect the (viewpoint) planimetric locations at which the consistency of visualscape animation is broken in order to reduce the viewpoint spacing interval and 'exaggerate'. In other words, at viewpoint transitions where the pertinent visibility patterns tend to scatter substantially the tweening/ morphing technique may not yield a smooth, apprehensive animation, and a larger number of computed frames (i.e. frames which are outputs from GIS viewshed analysis) may be required. This means that micro-steps provided by animation might not be adequate, and closer/ denser, 'real-steps' are needed. Nonetheless, this type of exaggeration is not to be reckoned as a 'temporal zoom in', since the rate of change remains the same, even though interpolated (tween) frames are substituted by real (computed) frames. Besides, this strategy has been actually employed in this thesis to compare different visualizations. But, other than this, what we explicitly suggest here is that a variable step should be inflicted on different segments of a route. Such is the case where a route entails a mixture of linear topographic features – e.g. a ridge-line succeeds a course-line; still, what about the transition from ridge to valley with regard to its step?
- ***Visualizing moving intersected viewsheds:*** In this thesis we have employed a normalized index of intersection of viewshed triads – viewsheds emanating from three consecutive viewpoints –, the DIVI, in order to ultimately appreciate the continuity of viewshed transitions with the DCVI. Then, what if we visualized the intersected viewsheds instead of the single ones? Could animations with varying viewpoint spacing intervals be evaluated readily by

visualizing their intersected viewshed evolving patterns? And what about the cognitive apprehension potential, especially in the case that we would attempt to superimpose dynamic intersected viewsheds to mere dynamic viewsheds?

- ***Identifying a priori critical points or segments (on a topographic profile graph) which carry the potential of being associated with significant viewshed pattern spatial shifts***: It has been shown that conspicuous visualscape alterations occur in correspondence to slope changes and curvature local maxima/ minima on the elevation profile. Several researchers have promoted such morphological indicants as critical points for cartographic line simplification (generalization) either in relation to the line's length, its morphology and its sampling, or with reference to the eye movement analysis (i.e. human gaze tracking in a 'sequence between fixations and saccades') (e.g. Buttenfield, 1985; Nakos and Mitropoulos, 2005; Bargiota et al., 2013). Herein, slope and curvature are acknowledged as indicants for dynamic visualscape propagation as well. In practice, one could resort primarily to the cross-section of the route – taking in parallel into consideration the pertinent topographic feature – in order to decide for the election of the required viewpoints; in such an *a priori* approach one may not need to thoroughly explore the respective visibility patterns so as to elect the most proper viewpoint configurations but could appeal to a more cognitive-driven approach which enables such critical points/ segments.
- ***Embedding some additional geographic information for explaining/ 'forecasting' the occurring shift of visibility patterns (with reference to the abovementioned):*** The topographic cross-section (in each visualization) offers an amount of understanding about what happens to viewsheds, or about what is expected to happen to them. But, the typical algorithmic procedure for (RSGs) viewshed computation by definition imposes the LoS on a range of cross-sections radiating from each viewpoint; so, especially when the route is a straight line (planimetrically), the topographic profile on display is in fact embedded as one of the multitude of profiles required to implement the algorithmic process; that is why, in part, profiling possesses such a 'forecasting' value – since it is, 'circularly' explaining itself[80] to some extent. As a consequence, the decision to involve the profile not only is justified, but it also encourages us to expand its usefulness in other ways. So, aside from just displaying the geometry/ morphology of the feature's/ route's profile, two other elements could be of assistance, enabling more mindful and successful geo-visualization experimentations (regarding viewsheds): i) the slope aspect for the vicinity of each viewpoint or ii) the topographic profile that lies perpendicularly to the route line at each location of the moving point[81]. By calculating or inferring the previous ones and by finding congruent and

[80] …in the same manner that a circular definition uses the terms being defined as a part of the definition.

[81] In the generic case that the line is not straight, but curviform, the perpendicularity of the cross-section could apply to each segment of the line, locally.

effective manners of embedding (displaying) those in geo-visualizations one can enrich their explanatory/ predictive potential.

- ***Inventing/ engineering proper representational structures to support the storage and instant access of related viewsheds for interactive querying and spatial analytics:*** In the previous chapters we have been familiarized with data structures and conceptual schemes that can store, manipulate and represent viewsheds with their respective viewpoints (e.g. visibility graphs, OFs). At this point, a representational scheme which could serve to the storage, manipulation, analysis and visualization of dynamic viewsheds is suggested. Simply put, by merely dragging the cursor over a DTM surface, the user-researcher should be able to interactively compute viewsheds, store them, implement queries and analytical functions – provided that we include some other geographic information layers – and visualize the outputs in a dynamic manner. So, for instance, one should be capable of: i) computing viewsheds from a view-line, ii) selecting by attribute or by spatial properties certain features or geometries, iii) implementing analytical functions (map algebra overlaying, raster data management etc.) and retrieving the pertinent dynamic spatial data and iv) producing interactive visualizations which portray visible regions in association with "what is seen" (e.g. what types of land cover or land use) each time.
- ***Utilizing (static) cartographic variables to imbue dynamic visualscapes with meaning regarding landscape character/ character assessment/ evaluation classification (LCC/ LCAC/ LEC):*** Under the previous interactive procedure we could combine dynamic visualscapes with landscape's structure, function and value. Since it has been posited that human apprehension, understanding and appreciation of a visual landscape entail active visual experience of our surroundings, these mental activities arise always in conjunction with a locomotive observer. Therefore, depending on the structure (morphology and land cover) of a landscape and the function (fruition from access to livelihoods, or recreational activities) or value (the value society attributes on a landscape because of its intrinsic (exceptional cultural, physiographic) status and the costs for its maintenance or enhancing it) attributed to it, we could promote a visualization that affords to entail landscape classifications and evaluation in a dynamic (or even interactive) manner. So, imagine a visualization that enables cartographic variables within the moving boundaries of shifting visualscapes. Transitions among viewpoints (along a route) could induce transitions from a lake's to a forest's vista; or from a parkland's to a landfill's vista. According to the purpose of classification, the area features (viewsheds can be considered as irregular polygon geographic entities) should employ a cartographic variable to portray the change in the vista's respective status. So, given that the observer is non-stationary, the moving patterns of viewsheds could change in hue, texture, value, saturation etc. For instance, the viewshed for a moving observer's changing vista from a lake to a forest should be visualized by a blue hue evolving spatial pattern turning to a green one etc. In a similar manner,

one might visualize visual landscapes for evaluative purposes. (Table 21). In this sense one should attribute not to single viewpoints but to entire routes their visual landscape classification and evaluation potential.

- ***Suitable and automated landscape photograph annotating and geo-locating***: Given the mounting supply of landscape photos by individuals, the importance of volunteered geographic information (VGI) and the potential of crowd-sourcing, Internet becomes a great depository of sources of visual information about landscape (i.e. photos). However, this information is vast, 'un-tagged' and requires geo-referencing. The approach of viewshed geo-visualization in relation to the advances in web cartography could support the landscape photos 'geo-tagging' (e.g. Brabyn and Mark, 2011) in an interactive manner. It could function in geo-locating photos in an automatic way and in landscape understanding and evaluation by harnessing the important VGI providing 'raw' empirical content (images) to landscape categories.

Table 21: Suggested cartographic variables for the geo-visualization of different classification schemes for shifting visual landscapes.

Dynamic Visual Landscape	Level of Measurement	Variable
LCC	Nominal	Hue/ Orientation/ Texture
LCAC	Nominal/ Ordinal	Texture/ Value
LEC	Ordinal/ Numerical	Value

- ***Further emphasizing the theoretical base of geo-visualization towards the explanation of spatio-temporal processes:*** What is of utmost importance for the geo-visualization of dynamic visualscapes lies in its exploration/ explanatory potential; by observing animated sequences we want to gain insight of the process and the factors leading to the propagation of visibility patterns. This potential is not to be compromised and one should be aware that technological innovation – powerful computing analytical functions and sophisticated rendering – can be as much as facilitating as misleading too. The exploratory benefits from these geo-visualizations are to be considered at the intersection between the ontological origination of and human cognitive limits about the viewshed evolving processes. And it is our conviction that heuristics and creative ways of 'dressing-up' and interpreting such processes under study can become extremely disorientating – when what really matters is to obtain greater theoretical base for explanation. In this sense, cartographic visualization should expand and enhance its theoretical background – if it is to support knowledge derivation from exploration.

EPILOGUE

If a person – with an average level of familiarity with computers and graphics – was (randomly) chosen to be asked: 'What level of elaborate information would suffice for a faithful and effective visualization', then he/ she would probably reply: 'The level that optimally verges on visual (or augmented) reality'; similarly, to a question such as: 'Which data resolution should be employed', or 'At which space interval should the viewpoints be selected' the replies would be probably: 'The finest available' and 'At the closest possible' respectively. Nevertheless, this obsession with enriched, informative graphics and refined rendering (high resolution and frame rate) reflects a tendency which refers not only to people outside the domain of scientific visualization. Notwithstanding this trend – which is rather more prominent for scientific communities which do not abide by the principles of (cartographic) abstraction and generalization – when one is dealing with geo-visualization, such principles cannot be neglected, for the potency of all kinds of maps lie in their abstraction.

It is an unquestioned fact that efficient computer models employing elaborate graphics offer a great potential for scientific visualization. Nonetheless, increased computing power and enhanced graphics are capable of deluging and overwhelming us with a false and deceptive sense of (optimal approximation of) geographic reality, when what really matters is the emergence of the substantial – depending on the purpose whereof a visualization has been created in the first place. When Galileo was conducting its 'mental experiments', he had expelled the influence of phenomena occurring in the everyday experience of moving objects (such as friction), and had reduced the exuberant material world and space to an Euclidean, abstract geometric space. Thence, on the one hand, neither all of the 'digital reconstructions' of reality require visual or augmented realism, nor all of the graphical subtleties of the latter are cognitively apprehensible; on the contrary, the information congestion owing to such plethora of subtleties can severely constraint the understanding of the 'visualized' (i.e. the referent). On the other hand, though, a rigid 'traditionalism' can beget equally plaguing consequences, entailing that only the old, tested and verified 'worldviews', methods and techniques – those of the 'beaten track' – are valid, meaning that we should stubbornly cling to a static and obsolete means of conceptualizing, representing and understanding the geographical reality. This kind of obstinacy might be justified if it stems from some short of naivety and resistance to change, or from an adhesion to some metaphysical principle (e.g. simplicity); but this not the case when there are utilitarian incentives motivating such conservative approaches by groups or communities of science who purport to 'protect' science and its evolution (as if it were their property) for their own interest. Apparently, this also applies to those who propose 'scientific fashions' only for their techno-philia to find an opening to the market, and establish their 'dominion' by raising 'dire technological necessities'.

In this age of the vastness of readily available data and information, what we really need are theoretical, conceptual and methodological cues to enable us to navigate through their maze in order to keep making sense and acquiring replete with meaning knowledge. Computers and other devices such as tablets, iPads and smartphones entail a prodigious potential both for the approximation (data collection, manipulation, representation, analysis, modeling) and digital reconstruction (information geo-visualization) of phenomena and processes of the geographical reality, and for the diffusion (through the Web) of their derivatives even in near-real-time. But, what we all should consider are: Does this enormous accumulation of data and information and their swiftness in response and dissemination leads to a more intelligible image of geographic reality (even this postulates what Henri Poincaré would call a 'realism of 'relations'' that are grasped in terms of approximate laws), or are we merely (unconsciously or deliberately) scratching the surface of this very reality by promoting/ accepting technical applications that are primarily directed at creating 'alternative realities'? And what are the implications of these advancements in (geo-spatial) information and in 'technological suggestions' on our human, biological, cognitive, social and cultural substance, especially if the latter – alternative realities – will tend to dominate?

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SUPPLEMENTARY MATERIAL

I: The geo-visualizations (animated viewshed maps) are stored in four CDs – attachments.

- The 1st CD includes the nine initial geo-visualizations (without the topographic profile) per viewpoint space interval – 40 m, 20 m, 10 m:
    - three Pass Route Geo-Visualizations:
    - three Ridge Route Geo-Visualizations
    - three Valley Route Geo-Visualizations
- The 2nd CD contains the 20-m Pass Route Geo-Visualization + Profile
- The 3rd CD contains the 10-m Ridge Route Geo-Visualization + Profile
- The 4th CD contains the 20-m Valley Route Geo-Visualization + Profile

II: The totality of the initial numerical values and the calculated indices for each viewpoint, being categorized according to space interval and topographic feature are presented in the Table below (if you are reading this thesis from the hard copy version, please refer to the digital, soft copy version, available: i) in CD1 or ii) at DSpace at NTUA, http://dspace.lib.ntua.gr).