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Geovisual Methods and Techniques for the Development of Three-Dimensional Tactical Intelligence Assessments

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Preface

This thesis is the result of my work in the InnoProfile research group '3D Geoinformation'. It would never have materialised as it has without the support of the following people.

First of all I would like to thank Hartmut Asche for the support he has given me. His never-ending readiness to talk, his analytical expertise as well as his numerous valuable suggestions and tips played a crucial part in the success of this work. I would like to thank him for his efforts regarding the financial support for my trips to (inter-)national conferences, workshops and symposia.

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Finally my wife, Anja, deserves a huge thank-you. Without her backing and her support, especially during my frequent trips in Germany and abroad this thesis could never have been realised in this manner. In closing I dedicate this thesis to my little Anna Paulina.

Abstract

This thesis presents methods, techniques and tools for developing three-dimensional representations of tactical intelligence assessments. Techniques from GIScience are combined with crime mapping methods. The range of methods applied in this study provides spatio-temporal GIS analysis as well as 3D geovisualisation and GIS programming. The work presents methods to enhance digital three-dimensional city models with application specific thematic information. This information facilitates further geovisual analysis, for instance, estimations of urban risks exposure. Specific methods and workflows are developed to facilitate the integration of spatio-temporal crime scene analysis results into 3D tactical intelligence assessments. Analysis comprises hotspot identification with kernel-density-estimation techniques (KDE), LISA-based verification of KDE hotspots as well as geospatial hotspot area characterisation and repeat victimisation analysis. To visualise the findings of such extensive geospatial analysis, three-dimensional geovirtual environments are created. Workflows are developed to integrate analysis results into these environments and to combine them with additional geospatial data. The resulting 3D visualisations allow for an efficient communication of complex findings of geospatial crime scene analysis.

Kurzfassung

Diese Arbeit präsentiert Methoden, Techniken und Werkzeuge für die Entwicklung dreidimensionaler Lagebilder. Zu diesem Zweck werden Verfahren der Geoinformatik mit solchen der raumbezogenen Straftatenanalyse kombiniert. Das Spektrum der angewandten Methoden und Techniken umfasst raumzeitliche GIS-Analysen ebenso wie 3D Geovisualisierungen und GIS-Anwendungsprogrammierung. Um komplexe geovisuelle Analysen auf Basis virtueller 3D-Stadtmodelle zu ermöglichen, werden Datenbanken digitaler Stadtmodelle um anwendungsspezifische Fachinformationen ergänzt. Dies ermöglicht weiterführende Analysen, zum Beispiel zur räumlichen Verteilung urbaner Risiken. Weiterhin präsentiert die Arbeit Methoden und Verfahren zur Integration der Ergebnisse komplexer raumzeitlicher Straftatenanalysen in dreidimensionale Lagebilder. Die durchgeführten Analysen umfassen die Identifikation von Brennpunkten spezifischer Delikte mittels Techniken der Kerndichteschätzung, die Verifikation dieser Hotspots durch LISA-Statistiken, GIS-basierte räumliche Charakterisierungen von Brennpunkten sowie Analysen zur wiederholten Viktimisierung. Zur Visualisierung der Ergebnisse komplexer raumzeitlicher Analysen werden dreidimensionale geovirtuelle Umgebungen erzeugt. Um weitere raumbezogene Daten ergänzt, werden sämtliche Analyseergebnisse in diese Umgebungen integriert. Die resultierenden 3D-Visualisierungen erlauben eine effiziente Kommunikation der Ergebnisse komplexer raumbezogener Straftatenanalysen.

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1

Introduction

This thesis discusses a set of methods and techniques for the creation of three-dimensional tactical intelligence assessments for urban areas. Applying methods from geoinformation science (GIScience) the study combines GIS and VIS techniques to analyse and visualise crime scene distribution patterns with three-dimensional geovirtual environments. The use case of geospatial crime scene analysis is adopted to develop new application fields for 3D geovisualisation. The investigation demonstrates how three-dimensional city models and complex interactive geovirtual environments are used as a medium to analyse and communicate the findings of complex geospatial crime scene analysis. The audience targeted by 3D tactical intelligence assessments are crime mapping analysts and decision makers at security agencies. Especially the latter group must gather and interpret complex information rapidly before a particular decision is made. The thesis focuses therefore on the development of methods and techniques that enable the development of easy-to-comprehend 3D visualisations of specific purpose. The study presents a framework of GIScience-related methods, techniques and tools to construct three-dimensional representations.

1.1   Motivation and Hypothesis

A strong motivation for this PhD thesis is to transfer methods and concepts from the 3D geovisualisation field of research into the crime mapping research community and vice versa. Methods from geoinformation science are combined with crime mapping techniques and 3D geovisualisation approaches. The thesis presents a systematic framework describing how to couple 3D geovisualisation approaches with crime mapping techniques to visualise and analyse crime and crime-related tasks with interactive three-dimensional geovirtual environments. The underlying hypothesis of this study is expressed as follows: three-dimensional visualisations are an appropriate method to communicate the findings of geospatial crime scene analysis to crime mapping analysts and decision makers at security agencies. This hypothesis encourages the development of methods and tools that facilitate constructing urban three-dimensional tactical intelligence assessments (3D-TIA). These support an accelerated decision-making progress – especially for decision-makers who are frequently untrained in reading and interpreting complicated maps.

1.2   Structure of this Thesis

The study is divided into five chapters. Chapter 1 outlines the motivation for this study as well as the underlying hypothesis. A short definition of the term 3D-tactical intelligence assessments is given and the scientific background is introduced. Furthermore the peer-reviewed research papers that represent the scientific core of the thesis are briefly introduced. Chapter 2 presents these four research papers. The scientific contribution of each paper is discussed in Chapter 3. To evaluate the application potential of the developed 3D tactical intelligence assessments, a survey is conducted among police officers, analysts and decision makers. As these results have not yet been published, a brief interpretation of this

survey is presented in Chapter 4. Chapter 5 gives a conclusion and outlines possible future work.

1.3   (3D) Tactical Intelligence Assessments: Definition and Study Area

According to Jacobsen (2001) the expression tactical intelligence assessment[1] is used in this thesis to denote a documented description of police-relevant issues related to a specific situation[2]. It marks the basis for further analyses and evaluation processes. The so-called situation assessment[3] identifies particular measures to take to react on a specific situation (cf. Jacobsen 2001, p. 73). In this thesis tactical intelligence assessments are defined as a representation of spatial and temporal distributions of security-relevant features relating to a specific date and a specific area; they build the basis for subsequent identification, analysis and prediction of police-related incidents (Jacobsen 2001, p. 75).

Consequently, 3D tactical intelligence assessments are perceived in this thesis as three-dimensionally enhanced representations of geospatial and temporal distributions of specific offences. The base data for geospatial crime scene analyses and 3D visualisations, respectively, was provided by Cologne police headquarters. The datasets exported from the police-internal transaction-processing-system[4] describe location, time and applied modus operandi of two different offences: robberies and residential burglaries for the period January 1, 2007 to December 31, 2007. To facilitate further in-depth analysis and 3D visualisation, these datasets are complemented with various other geospatial datasets, such as, a 3D city model of the city of Cologne, high resolution aerial photography, a digital terrain model, a digital cadastral map, a city map and additional vector-based datasets including, e.g., the road network, rivers and administrative boundaries. These datasets are used for analysis as well as for creating the three-dimensional geovirtual environment.

To design these three-dimensional visualisations this thesis links digital processing and analysis of spatially-related crime data with easy-to-comprehend 3D visualisations. Specific workflows have been developed that link both the GIS and VIS related tasks. For geospatial data managing and analysis ESRI's Geographic Information System ArcGIS was used while the Autodesk (former 3D Geo) LandXplorer system was used for 3D visualisations[5] (VIS). As

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[1] German "Lagebild"

[2] German "Lage"

[3] German "Lagebeurteilung"

[4] German "Vorgangsbearbeitungssystem"

[5] Apart from major performance advantages, a specific motivation for applying the LandXplorer system is due to the fact that the author of this thesis is a member of the INNO-Profile research group "3D Geoinformation – modelling, processing and system integration". This group is based at the Department of Geography of the University of Potsdam and the computer graphic systems group of Prof. Dr. J. Doellner at the Hasso-Plattner-Institute at Potsdam University (HPI). The development of the LandXplorer system originated here.

this methodological framework addresses automation issues of frequently-used analysis functions, the development of GIS-based tools and applications is an integrative part of this study as well. Frequently-used GIS functions are encapsulated in programmed GIS plug-ins (Dynamic Linked Libraries, DLL and Executables, EXE) by using ESRI's ArcObjects and Microsoft Visual Studio 2005 .NET.

To encourage the use of 3D for representing tactical intelligence assessments, the following section gives a brief overview of the ongoing scientific debate of applying 3D in cartography and GIScience.

1.4   Scientific Framework

This thesis deals with methods from the research disciplines of (3D) geovisualisation and crime mapping. The key themes and issues of geovisualisation are outlined by MacEachren and Kraak (2001). They define geovisualisation as the integration "of approaches from visualisation in scientific computing, cartography, image analysis, information visualisation, exploratory data analysis and geographic information systems to provide theory, methods, and tools for visual exploration, analysis, synthesis and presentation of geospatial data" (Kraak 2001, p. 1). Based on their conceptual framework Slocum et al. (2001) discuss a research agenda on cognitive and usability issues in geovisualisation. A definition of the term geovirtual environments (GeoVE) can be found in MacEachren et al. (1999). Such three-dimensional environments are an integrative part of this thesis. MacEachren et al. describe these as particularly immersive, information intense, interactive and intelligent. 3D geovisualisation is a highly multidisciplinary science, using analogies from GIS, virtual reality and human computer interaction techniques (Nielsen 2004, p. 1).

The underlying assumption of this thesis, namely that three-dimensional visualisations promote an intuitive perception of geospatial phenomena, is subject to broad scientific discussions in recent cartography. Buziek (2003), among others, states that three-dimensional visualisation techniques are extremely vivid and enable a rapid and distinct visual transmission of geospatial information even to untrained map readers. Jobst (2008) assesses optimisation strategies for the cartographic communication with 3D by developing a semiotic cartographic model for the deployment of 3D visualisation techniques. Pursuant of principles of communication theory he states that 3D visualisations are easy to understand – due to the fact that humans learn to comprehend their three-dimensional environment since the very first beginning of being (Jobst 2008, p. 112). Also Piaget (2003), cited in Jobst (2008, p. 44), underlines that the environment in which humans develop their cognitive skills is "affected from the third dimension since the three-dimensional space is the basis for human learning, processing and memorising from the very first moment of brain activity". Due to this and the fact that every movement in space is registered "in three coordinates by the sense organs" (Jobst 2008, p. 44), three-dimensional geovisualisations are considered "easy-to-understand, at least as intuitive representations of three-dimensional space" (Jobst 2008, p. 56). According to Jobst (2008) this increased compre-

hensibility of three-dimensionally represented geospatial information is an advantage of 3D geovisualisations. 3D elements can be read "with less individual knowledge as abstract two-dimensional coded information, for instance, a 2D topographic map" (Jobst 2008, p. 10). According to Jobst (2008) these advantages of 3D facilitate a better understanding of complex geospatial information. The map readers' mental effort is reduced, because the process of transforming 3D real world features into 2D map features and their respective decoding into 3D is not necessary (Jobst 2008, p. 48). Related to cartography and geovisualisation, 3D visualisations are "meaningful for communicational tasks" (Jobst 2008, p. 169).

Consequently, three-dimensional geovisualisations are suitable to represent complex geographical features and relationships in an intuitive way. They promote an instant and intuitive grasp of complex geospatial phenomena and thus make map comprehension more intuitive. Kraak (2003) highlights that modern geovisualisation helps to "stimulate visual thinking about geospatial patterns, relationships and trends". He emphasizes the advantage of three-dimensional visualisations that allow for an "additional variable to be displayed in a single view and, as such, give the user a direct insight into the relationship between these variables". Meng (2002) expresses that the user can easily interpret spatial relationships of three-dimensionally presented geo-objects without having to consult a key. A similar argument is put forward by Buziek (2003) who states that 3D visualisations contain a high cartographical potential especially for presenting and that they support a gain of knowledge.

According to Häberling (2002), the term 3D geovisualisation or 3D cartography respectively, relates to several kinds of 3D "maps". One can distinguish between "new perspective representations [which] include images and annotations presented on two-dimensional media" and "true 3D representations that can only be visualised interactively using special equipment" (Häberling 2002, p. 12). The interactive three-dimensional representations of tactical intelligence assessments developed in this study depend on perspective representations; applications of true 3D in cartography can be found, among others, in Buchroithner (2007, 2005) and Rase (2009). An example of creating paper-based three-dimensional representations of crime scene distributions by means of applying auto-stereoscopic visualisation techniques on the basis of lenticular plates (virtual-lenticular-rendering-method, VLR-method) is given by Stendel and Wolff (2010).

To create interactive three-dimensional representations of crime scenes, methods from 3D geovisualisation science are coupled with crime mapping techniques. An introduction to the principal theories of crime mapping is given by Chainey and Ratcliffe (2005). Since each crime occurs in a specific place, the corresponding scene can be located in space, even in cyberspace (via its Internet Protocol [IP] address). GIS-based geospatial analysis of crime scenes is therefore an integral part of crime analysis since the emergence of GIS in the 1960s (Chainey and Ratcliffe 2005). While crime analysis is a set of analytical processes that provide timely information about crime patterns and crime trend correlations, crime mapping is defined as "the process of using a geographic information system to conduct spatial

analysis of crime problems and other police-related issues" (Boba 2005). To document and communicate the findings of geospatial crime scene analysis, maps are created. Most frequently these maps show feature- or pattern distributions, e.g., spatial variation of crime hotspots related to specific offences. Depending on the map topic and anticipated audience, these maps can be difficult to comprehend.

To create easy-to-comprehend visualisations this thesis couples techniques of geospatial crime analysis with 3D geovisualisation methods. The thesis aims at developing situation representations that are preferably easy-to-"read". Taking the high potential of three-dimensional visualisations for the communication of specific crime-related geospatial information into account, this study therefore also outlines benefits for a cartography-oriented design of three-dimensional landscapes of security and insecurity. The 3D representations of urban tactical intelligence assessments result from combining methods and techniques from geoinformation science, crime mapping and 3D geovisualisation. The urban context is taken into consideration by integrating crime scene positions into complex three-dimensional city models. This thesis shows how city models are used to communicate specific geospatial crime-related analysis results.

The different methods and techniques are discussed in a number of research papers which represent the core of this thesis. The following section gives a short overview of how these papers are structured.

1.5   Overview of Included Research Papers

The methods, techniques and tools applied for the development of 3D tactical intelligence assessments have been presented at international conferences devoted to the domains of GIScience and computer science respectively and published in four peer-reviewed research papers.

The first paper describes basic methods to enhance and process 3D city models for their particular application in civil security and situation assessment, respectively. The second paper presents an introduction into 3D crime mapping methods. The third paper deals in detail with further aspects of specific geospatial analysis and 3D visualisation tasks. The last paper focuses primarily on introducing methods for temporal analysis and visualisation of the spatio-temporal aspects of crime scene data. Table 1-1 gives a brief summary of the papers. Figure 1-1 gives an overview of the main methods and functions applied in theses papers. A more detailed discussion of these papers can be found in Chapter 3.
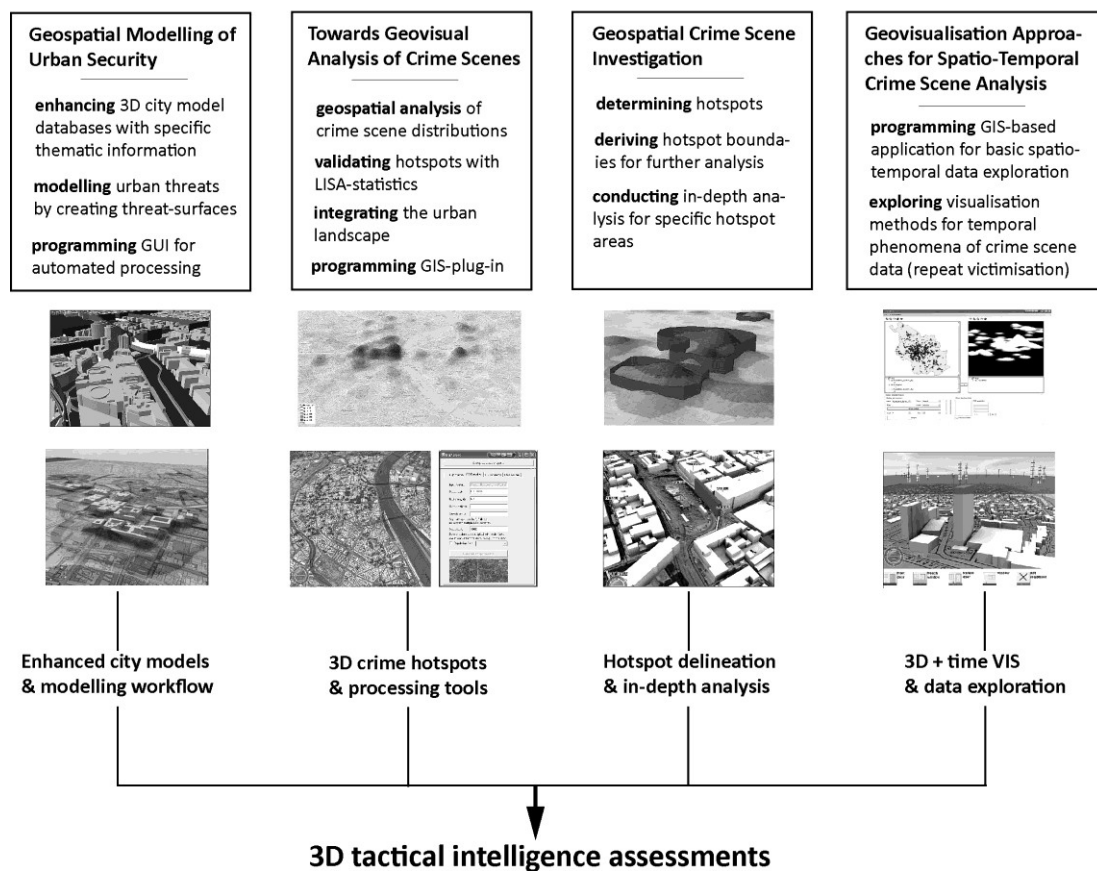

Fig. 1-1. Development of three-dimensional tactical intelligence assessments resulting from the range of methods and functions published in the four included papers. The focus of each paper is listed in the boxes above the pictures; the main findings are listed below the pictures.

Table 1-1. Peer-reviewed papers included in this thesis

ID	TITLE	AUTHOR	SUMMARY
1	Geospatial Modelling of Urban Security: A novel approach with Virtual 3D City Models; Computational Science and Its Applications - ICCSA 2008. Springer Lecture Notes in Computer Science (LNCS), Volume 5072, pp 42-51	**M. Wolff**, H. Asche	Based on methods of geoinformation science, this paper presents an innovative approach to identify particularly vulnerable urban regions. Using the 3D city model of the German capital Berlin as an example, the potential of such models for mapping, analysis and assessment of different threat levels in urban environments is demonstrated. The geovisual and analytical potential of 3D city models is instrumental for decision makers working in security agencies for both threat assessment and intuitive cartographic communication of spatial phenomena related to urban security issues.
2	Towards geovisual analysis of crime scenes – A 3D crime mapping approach. Proc. 12th AGILE Conference. Hannover/Germany, 2-5 Jun 2009. Springer Lecture Notes in Geoinformation and Cartography (LNGC): Berlin. pp. 429-448.	**M. Wolff**, H. Asche	This paper presents an approach to facilitate geovisual analysis of crime scenes by introducing three-dimensional crime mapping techniques. Robbery scenes are analysed and integrated into a virtual three-dimensional environment using up-to-date methods of 3D geovisualisation. For this purpose crime data as well as numerous geospatial data are integrated into a three-dimensional model of the German city of Cologne. Visualising the results of crime data analysis in geovirtual environments eventually leads to 3D situation awareness in a civil security context. A GIS plug-in is developed to allow for an easy transferability of methods and functions used in this approach.
3	Geospatial crime scene investigation – From hot-spot analysis to interactive 3D visualisation. Computational science and Its applications – ICCSA 2009 Yongin. Seoul/Korea, 2009. Springer Lecture Notes in Computer Science (LNCS), Volume 5592. Berlin. pp. 285-299.	**M. Wolff**, H. Asche	This contribution presents an approach to combine geospatial crime scene analysis with three-dimensional geovisualisation methods. Crime scene analysis in this paper focuses on GIS-based hotspot identification of robbery scenes. To complement this investigation, methods are presented to extract individual spatial properties of hotspot areas that might help to understand observed density patterns. Against this background in-depth analysis tries to reveal specific correlations between urban features and robbery offences. Further analysis correlates the quantity of robbery scenes with pedestrian frequencies. Spatiotemporal analysis of hotspot patterns finalises the presented set of spatial crime scene analysis.
4	Geovisualisation Approaches for Spatio-Temporal Crime Scene Analysis – Towards 4D Crime Mapping. 3rd International Workshop on Computational Forensics - IWCF 2009. The Hague/ Netherlands, 2009. Springer Lecture Notes in Computer Science (LNCS), Volume 5718. Berlin-Heidelberg. pp. 78-89.	**M. Wolff**, H. Asche	This paper presents a set of methods and techniques for analysis and multidimensional visualisation of crime scenes in a German city. As a first step the approach implies spatio-temporal analysis of crime scenes. Against this background a GIS-based application is developed that facilitates discovering basic trends in spatio-temporal crime scene distributions for a GIS untrained user. Based on these results further spatio-temporal analysis is conducted to detect variations of specific hotspots in space and time. These findings of crime scene analysis are integrated into a geovirtual environment. To analyse and visualise spatio-temporal robbery scene distributions the concept of the space-time cube is adopted. Using the example of repeat burglary victimisation further analysis- and visualisation strategies are demonstrated. Since this analysis requires incorporating temporal elements into virtual 3D environments, basic methods for 4D crime scene visualisation are outlined in this paper.

2

Research papers

A Geospatial Modelling of Urban Security: A novel Approach with Virtual 3D City Models[*]

Abstract. Complex urban structures are exposed to a variety of security risks. Especially concerning man-made hazards, cities can be considered particularly vulnerable. Due to their high concentration of population, technical and social infrastructure, as well as their importance in politics, culture, economy and finance, metropolitan areas, in particular, can be considered vulnerable environments. Since not every part of an urban area is exposed to the same level of potential security threats, it is assumed that this level differs regionally in a metropolis. Based on methods of geoinformation science, this paper presents an innovative approach to identify particularly vulnerable urban regions. Using the 3D city model of the German capital Berlin as an example, the potential of such models for mapping, analysis and assessment of different threat levels in urban environments is demonstrated. The geovisual and analytical potential of 3D city models is instrumental for decision makers working in security agencies for both threat assessment and intuitive cartographic communication of spatial phenomena related to urban security issues.

Keywords: GIS, 3D city models, geovisualisation, civil security.

A 1 Introduction

This paper presents a method which couples GIS-based analysis with the visualisation potential of virtual three-dimensional city models. Taking the virtual 3D city model of the German capital Berlin as an example [4], selected geoanalysis methods are discussed that targeted at data integration and vulnerability mapping of metropolitan regions. This geoanalytical method is then applied to investigate selected issues in the field of civil security. This approach requires the integration of application-specific thematic information into the database of existing city models. This is accomplished by using a Geoinformation System (GIS) to manage large, heterogenous spatial data. Virtual representations of complex three-dimensional urban environments are constantly gaining popularity among both the scientific community and the wider public. To cater for these requirements a workflow is

developed for extending, analysing, visualising and combining existing 3D city models with related thematic data of special interest within the domain of civil security.

This workflow as well as the extension of the database with frequency and socio-demographic data is presented in section A 2. Based on these database enhancements an innovative method to map and analyse regions with different degrees of exposure is presented in section A 3. It is shown, that investigating urban environments for increased security risks reveals an uneven distribution of threat levels over metropolitan space. Thus different urban regions are characterised by different levels of exposure, resistance and resilience compared to possible security threats. The end result is different levels and spatial distributions of vulnerability. In this context a GIS-based tool is presented which allows for an automated processing the input data and thus facilitates an easy repeatability of the analyses. Section A 4 contains a short summary and introduces some perspectives.

A 2 Augmenting existing geodatabases for geovisual analysis

Three-dimensional city models are more and more available, with various cities possessing their own digital 3D representations. Compared to the traditional medium for communication of geographical data – the two-dimensional map – virtual three-dimensional city models facilitate in-depth analysis and presentation of spatial data. Furthermore, from a cartographic point of view, three-dimensional geovisualisation can reveal "patterns that are not necessarily visible when traditional map display methods" [9] are used. Applying methods and functions of visual analytics facilitates to "detect the expected and discover the unexpected" [11] as by means of visual data mining [5]. Thus, complex spatial situations like planning scenarios, noise and pollutant dispersal patterns are increasingly analysed and visualised by the use of 3D city models [3].

Typical datasets included in such databases contain, e.g., cadastral and topographic information as well as information relating to buildings, such as use or function, dimensions, height, etc. What is, however, widely lacking with these databases is application-specific thematic content linked to the different topographic and 3D data layers. To augment existing city model databases with thematic information required to conduct special-purpose geoanalysis in the field of civil security a workflow is developed to perform such operations in a systematic way (cf. figure A-1). In this workflow different methods of GIS-based analysis are used to extend the database. As an example, pedestrian-frequency information (cf. section A 2.1) is added by linking this data to road segments. The GI-system database then provides the basis for further analysis and allows to generate different types of visualisations. Conceptually speaking, GIS serves as the centre for non-graphic data analysis. The 3D geovisualisation system serves as the visualisation front end, facilitating graphical analyses by interpreting spatial relationships in a three-dimensional environment. Applicationwise a commercial GIS package, namely ESRI ArcGIS, and the LandXplorer 3D visualisation software system [6] is used.

To investigate the geoanalytical potential of this combined GIS/VIS system, it has been applied to model urban risks in the centre of the German capital Berlin. The study area covers a 13 km by 6 km strip of the city centre inside the inner metropolitan train ring between Westkreuz and Ostkreuz S–Bahn stations. This transect contains the "Western Centre" (Kurfuerstendamm boulevard) of the city as well as its "Eastern Centre" (Alexanderplatz Square).
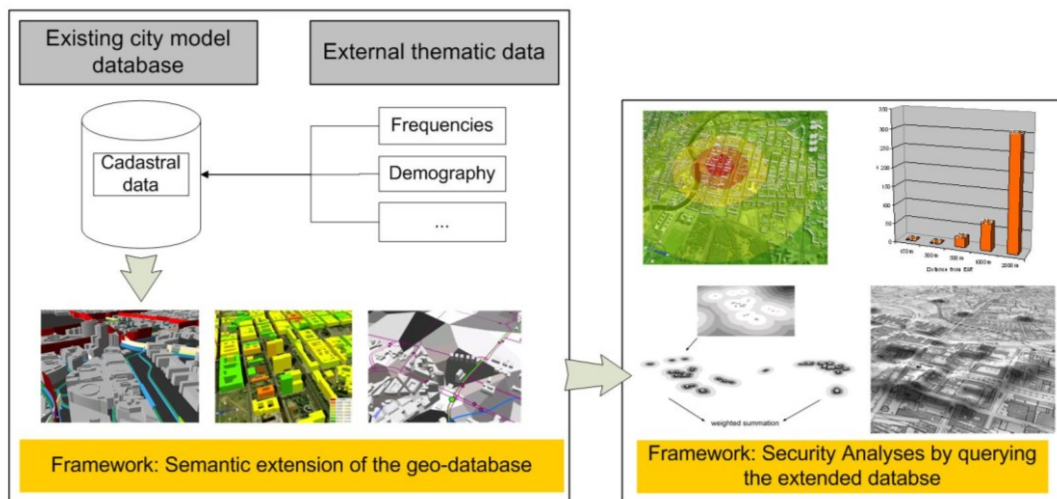
Fig. A-1. Workflow for augmenting typical city model databases with application-specific thematic information. Added thematic information allows for visualisation of pedestrian flows, public transport data and demographic parameters (left-hand box). In addition, querying the expanded database, facilitates, e.g., vulnerability analysis (right-hand box).

As a database the official Berlin city model is used. It includes the following data sets:

- Built-up area of 57,096 buildings, with height data and building function
- Street network, compiled primary for car navigation issues (from Teleatlas)
- Public transport network: Metropolitan train (S-Bahn), underground, tram and bus routes
- Geotopographic data, namely topographic map K5 (scale 1:5,000), digital terrain model (resolution 25m), high resolution aerial photography (HRSC, resolution 20cm)

A 2.1 Modelling outdoor bustle: Enhancing the building dataset with frequency information

An important factor in analysis of security related issues is detailed information on the activity flows in a city. With this information, areas, streets and single buildings in a city model can be identified which are daily frequented by many or few people. This kind of information is to date not included in the Berlin city model database. That is why data from the FAW Frequency Atlas of the German Association for Outdoor Advertising (FAW) are integrated into the 3D city model database. This atlas, originally developed for the advertising industry, has been compiled also for the city of Berlin and is based on Teleatlas road segments. The atlas data allow for an in-depth evaluation of pedestrian, car, and public trans-

port frequencies. Frequencies are calculated as average values per hour on a working day basis for the years 1999 to 2005 [7]. Technically speaking, for each road segment one FAW point exists with the corresponding frequency values. Based on its geocoded coordinates this dataset is imported into the existing Berlin city model. This point-based FAW information is then referred to the corresponding road segments via its unique segment-ID. By this each segment of the street network dataset is supplemented by new attributes: The number of pedestrians, cars and public transport carrier that frequent any given street segment per hour of an average working day (cf. figure A-2).
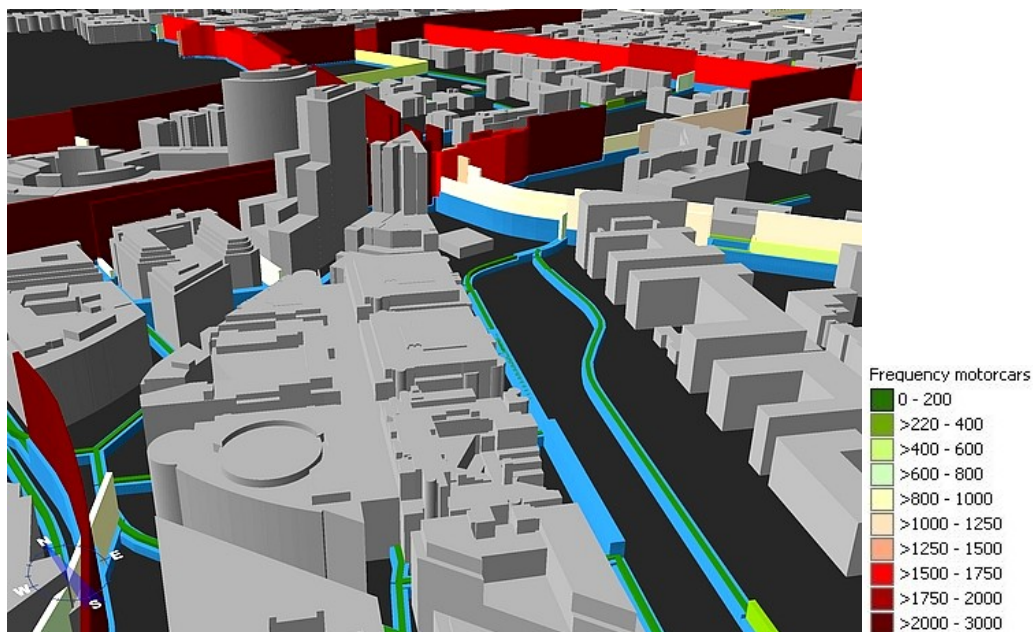
Fig. A-2. 3D visualisation of street segments according to their frequency information for cars (green to red coloured walls) and pedestrians (blue coloured walls). Segment height and colour indicate the respective frequency values. Area shows Potsdam and Leipzig Squares (centre, centre right) in central Berlin. Frequency data provided by FAW.

In addition to frequency data referred to street segments similar information for buildings along streets can be relevant for civil security issues which are often relating to single potentially vulnerable buildings. For that purpose frequency values have been assigned to adjacent buildings by analysing distances from buildings to street segments (cf. figure A-3). First, centroids of each building are calculated. Second, new points are created along the road segments for every 30 meters. Third, the four nearest segment points, based on each centroid, are identified. Finally, an average value is calculated from their frequency values. This is assigned to the whole building. As a result, such "smart" buildings can be queried for their frequency data.
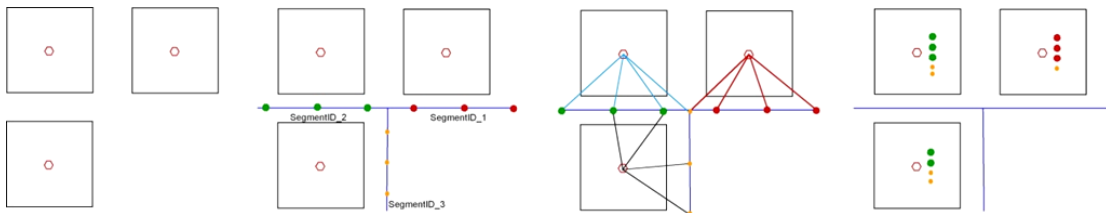
Fig. A-3. Schematic representation of algorithm application to transfer frequency values from road segments to adjacent buildings.

A 2.2 Modelling building-related population parameters: augmenting the building dataset with socio-demographic data

To identify and analyse potentially vulnerable city regions additional socio-demographic data on a building block basis is required. Such data are, e.g., population density, family income or purchasing power. Knowledge of these patterns enables one to draw conclusions from exposure, resistance and resilience concerning a possible hazardous event. To map vulnerability patterns in an urban region, additional population data of the German Society for consumer research (GfK) are also integrated into the existing city model database. Here such data are only available for the central Berlin postal code zones 10115 and 10117, respectively. This is an area of 6 km² stretching from Brandenburg Gate in the west to Hackescher Market in the east, Bundesrat building in the south and Schwarzkopfstrasse underground station in the north.

This area is both suitable and interesting for security related analysis since numerous embassies, consulates and government buildings, as well as highly frequented touristic sites, such as, Friedrichstrasse street, Unter den Linden boulevard, Gendarmenmarkt square, are located here. In addition, this area will house from 2011 the new headquarters of the German intelligence service (Bundesnachrichtendienst, BND) which will be located on the former World Youth Stadium (Stadion der Weltjugend) site.

As with processing of FAW frequency data, GfK data are imported using GIS functions. The available source dataset of 2006 includes numerous socio-demographic features, such as, population data, household size, household net income, building structure, building use, purchasing power. For data privacy reasons data are, however, not available for single buildings but for all buildings along a given street segment. Spatial reference of these point based data is by coordinates. Reference of those points to the appropriate buildings is verified by the matching of street names of GfK data points and belonging buildings, respectively. Therefore an algorithm is applied which searches for each building (its centroid) the nearest GfK point with the same street name. Attributes of this point are transferred to the building. Figure A-4 is a 3D visualisation showing purchasing power related to each building block.
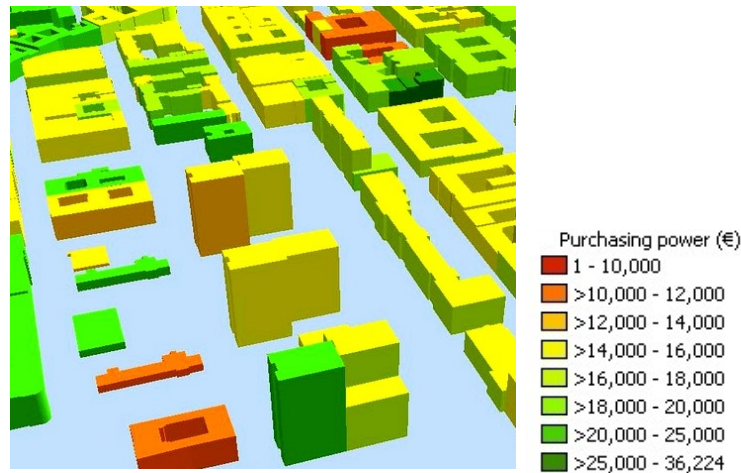
Fig. A-4. 3D visualisation of purchasing power by building blocks.

A 3 Geospatial modelling of urban risks

The augmented 3D city model database is a prerequisite for further and in-depth geoanaly-sis of urban risks. The broad range of thematic data integrated into the database allows, e.g., for further spatial analysis in the context of an urban impact assessment. Such analysis will, however, not produce any precise indication which building (the element-at-risk, EAR), e.g., is exposed to an increased threat of what nature. For evaluation of factual threat lev-els, a substantial amount of additional data would be required, many of which are not available publicly. Koonce et al. [8] state that this knowledge is „best left to the security and intelligence agencies". In this study it is therefore assumed that only buildings with specific occupancies, such as, government offices, or embassies, are particularly vulnerable to secu-rity threats.

Dealing with the nature and location of potentially hazardous events in urban environments [2, 10], an evaluation of the surroundings of a particular building exposed to a given risk is of special importance. Thus, for protection as well as for counteractive measures it is deci-sive to differentiate whether the structure is surrounded by open space or by dense urban housing. To perform distance based analysis on the city model built-up area layers, a first step requires the creation of circular impact zones, with the element at risk in its centre. In our case the radii are defined at 150m, 300m, 500m, 1,000m and 2000m intervals. In a sec-ond step the intersections of impact zones and buildings allow for statistical analysis based on the built-up-area database. This analysis shows that buildings in zones one to three (up to 500 m from the EAR) are passed by an average of 200 pedestrians. This value is decreas-ing with increasing distance. Because of the EAR location in a business district of central Berlin, the greater the distance from the EAR the more buildings have residential instead of business and administrative occupancies. As a consequence the number of potentially af-fected pedestrians is decreasing while the number of residents is increasing (cf. figure A-5).
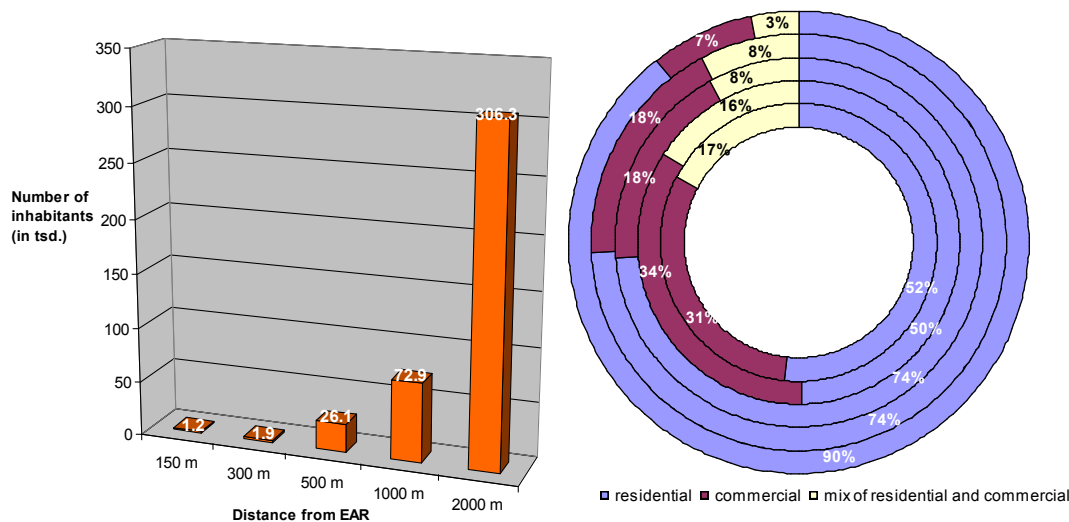
Fig. A-5. Distribution of population figures (left-hand figure) and building occupancy (right-hand figure) per impact zone.

A 3.1   Modelling the distribution of exposure levels in urban environments

In the following a method is presented to identify urban regions characterised by different degrees of exposure of a potential impact. The underlying assumption of this investigation is that not every area of an urban environment is equally exposed to the same level of potential threat. Rather a regional variation of threat levels can be found, as buildings potentially exposed to an increased security risk are not evenly distributed in city space. In this study the term "highly increased" threat is assumed for buildings housing embassies, consulates and government offices. An "increased" threat is assumed for the following buildings: Shopping centres, petrol stations (danger of explosion), police posts, power or transformer stations (critical infrastructure) etc. The following analysis is based on the buildings dataset of these categories (=exposed buildings). It can, however, be expanded to any user-defined set of buildings in a city model.

To map regionally different exposure levels the city model is first overlaid with a user-defined grid. Second, the distance of each grid cell to the closest exposed building is calculated. The resulting grid pattern is composed of cells each of which contains one distance value of the respectively closest exposed building. The grid can be further differentiated by building occupancy. The embassy grid, e.g., contains distance cell values of the closest buildings used as embassies or consulate offices. This set of exposure grids generated by proximity analysis forms the basis to identify different levels of threat exposure. For that purpose, each function-specific grid is reclassified in relation to proximity: Thus, grid cells closer to an exposed building are assigned a higher exposure level than cells with greater distance (cf. Table A-1).

Table A-1. Reclassification of distance based values

distance from basis building [m]	exposure level
0 to 25	1
>25 to 50	0.5
>50 to 100	0.2
>100 to 200	0.1
>200	0

GIS-based grid analysis, as used here, allows for convenient overlays and combinations of areal data by using map algebra functions. Hence all function-specific exposure grids generated are combined into one single "exposure grid" by summation of their respective pixel values. It has been mentioned that different building uses can be assigned different levels of threat exposure. Thus summation is performed by weighting the respective grids according to their threat exposure: The embassy offices grid (embassies, consulates) and the government offices grid are weighted with a factor of 4, the shopping centre grid with a factor of 2 and the service and utilities grid (police posts, petrol stations, power stations) with a factor of 1 (figure A-6).
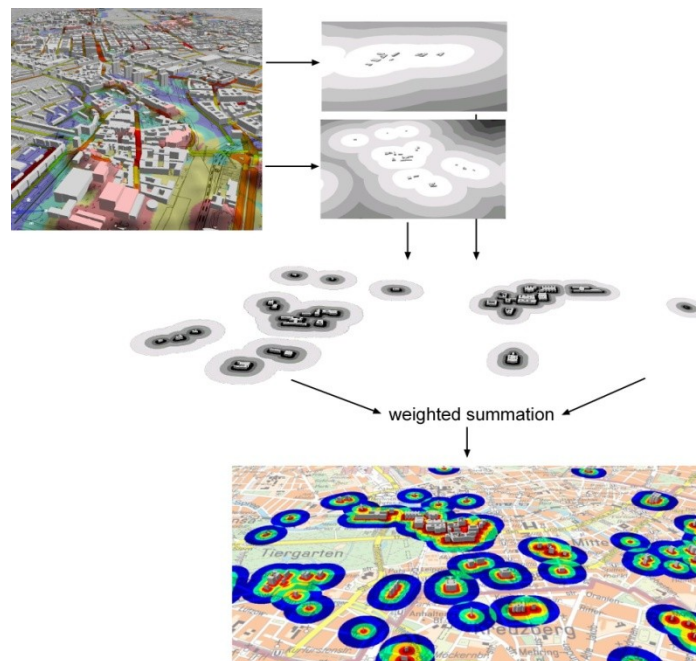
Fig. A-6. Workflow to identify different levels of threat exposure. Based on the virtual 3D city model (upper left), grids of proximity values to the closest exposed building (top centre) and a set of new grids with different regional levels of exposure is calculated by reclassification for each basis building class (centre). Combination of these grids is performed by weighted summation. The resulting grid shows combined levels of exposure with exposed buildings in the respective centre (bottom).

The workflow described here has been automated by developing a GIS tool using ESRI's ArcObjects based software development framework. Our tool facilitates an automated and fast processing of the single grids (figure A-7).
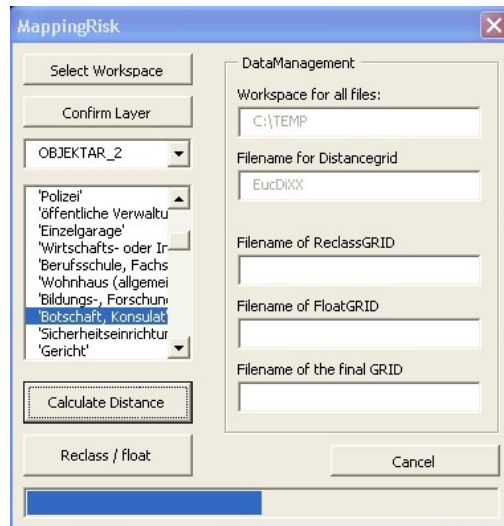
Fig. A-7. ArcObject-based GUI for an automated processing of the single grids in the GIS.

To employ this tool a buildings dataset containing information on building use and functions, respectively, is mandatory. The current version requires the user has to create an ASCII remap table according to Table A-1.

The combined weighted exposure grid can be visualised in different user-centered ways for further geoanalytical processing. Presented here is a 3D visualisation of a virtual threat surface based on the Berlin city digital terrain model (cf. figure A-8). For easy comprehension exposure grid values are exaggerated by a height factor of 10 and added to the original height values of the digital terrain model. The resulting 3D map is a graphic, easy-to-read visualisation of the spatial distribution of threats in urban environments.
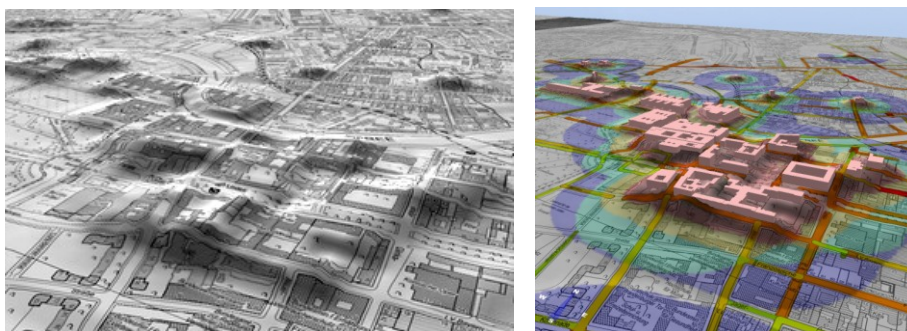
Fig. A-8. 3D visualisation of areas with increased exposure level based on the location of vulnerable buildings, area Brandenburg Gate – with (right) and without (left) periled buildings.

Intersection of the summation exposure grid with the buildings layer results in additional threat information in the built-up area dataset. As this dataset has also been augmented by socio-demographic data, a variety of geographical correlations of building occupancy, socio-demographic situation, infrastructure etc. with regional threat exposure can be mapped, visualised and analysed. For instance, all buildings located in grid cells with values of combined exposure levels greater than a given value can be selected. Also statistical analyses can be performed to distinguish between spatially varied socio-demographic feature states. As a result, it is feasible to map regions characterised by a number of inhabitants above average, significant purchasing power and high financial status (derived from net income per household).

A 4 Summary

This paper presents a method to combine GIS-based spatial analysis with innovative 3D visualisations using virtual three-dimensional city models for applications in civil security. Based on augmenting the existing spatial database of the virtual 3D city model of the German capital Berlin by a variety of parameters including building occupancy, frequency values and socio-demographic parameters, areas and objects exposed to specific levels of threat are identified. By combining function-specific grids with threat exposure levels the spatial distribution of threat levels are mapped. The resulting geographic distribution can subsequently be combined with additional socio-demographic or infrastructure data for further geovisual analysis. Perspectively some of the presented methods and functions will be modified: The ArcObjects tool presented in section A 3.2 will be extended to a larger ArcMap plug-in which also allows for an automated processing of the GIS features for the 3D-LandXplorer System. Furthermore the presented method of modelling and analysing urban security by using GIS and 3D city models will be broadened by introducing some standards of thematic 3D cartography. Thus, an efficient communication of spatial phenomena shall be ensured.

Acknowledgements

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B Towards Geovisual Analysis of Crime Scenes – A 3D Crime Mapping Approach[*]

Abstract. This paper presents an approach towards facilitating geovisual analysis of crime scenes by introducing three-dimensional crime mapping techniques. Robbery scenes are analysed and integrated into a virtual three-dimensional environment using up-to-date methods of 3D geovisualisation. For this purpose crime data as well as numerous geospatial data are integrated into a three-dimensional model of the German city of Cologne. Visualising the results of crime data analysis in geovirtual environments eventually leads to 3D situation awareness in a civil security context. A GIS plug-in is developed to allow for an easy transferability of methods and functions used in this approach.

B 1 Introduction

Digital analysis and mapping of crime events is a well-established method for law enforcement agencies. In fact a wide spectrum of generating traditional crime maps has developed over time. The methodical basis of mapping and analysis comprises a wide range of disciplines from geospatial statistics, cartography, geographic information systems (GIS) and spatial epidemiology. Digital analysis and mapping of crime offers a number of benefits, particularly in the following fields of applications: operational policing purposes, crime prevention, informing and interaction with the community, change monitoring changes in the distribution of crime over time and evaluation of efficiency of crime prevention initiatives (Hirschfield and Bowers, 2001). In addition to the semantic information of a particular crime event any crime scene has a precise geospatial location (excluding cyber-space crime possibly). Using geoinformation technology with its powerful geographic information software systems, these data can be captured and analysed. The core component, a geographic information system (GIS) is therefore widely used for spatial analysis of crime data both in academic research and in practical law enforcement (Murray et al., 2001). To document and communicate the findings of the analysis, maps are created. According to the analysis,

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[*] Wolff, M. & H. Asche (2009). Towards geovisual analysis of crime scenes – A 3D crime mapping approach. In Sester, M., Bernard, L. & V. Paelke, eds., Advances in GISciences. Proc. 12th AGILE Conference. Hannover/Germany, 2-5 Jun 2009. Springer Lecture Notes in Geoinformation and Cartography (LNGC): Berlin. pp. 429-448.

maps vary in subject, purpose, audience and map quality. In fact, cartographic visualisations can be considered the key element to communicate the results of crime analysis. Map visualisations produced by crime analysts both in the operational and academic field are generally presented in the form of traditional two-dimensional, static maps. Most frequently these maps show feature- or pattern distributions, e.g., spatial variation of crime hotspots related to specific offences. Depending on the map topic and anticipated audience, these maps can be difficult to comprehend. A common issue deals with the question how to define adequate threshold values for choropleth maps of specific hotspots. For instance it is often rather ambiguous from which value precisely hotspots can be considered "hot" (Chainey and Ratcliffe, 2005).

In this work 3D geovisualisation approaches are used to visualise crime and crime-related issues in interactive three-dimensional geovirtual environments. Consequently taking advantage of the third dimension, this contribution tries to identify benefits for a cartography-oriented design of three-dimensional landscapes of security and insecurity. As this concept links digital processing and analysis of spatially related crime data with easy-to-comprehend 3D visualisations the GIS and VIS tasks are combined in a three-step workflow specifically designed for that purpose (cf. figure B-1):

- Processing and analysis of geocoded crime scene data with GIS methods. This includes grid based analysis as well as kernel density estimation (KDE) techniques. Using local indicators of spatial association the results of this KDE analysis are tested for statistically significance.
- Creation of a three-dimensional geovirtual environment. A 3D city model is used to determine building distances to the closest crime scene. This interactive environment is modelled outside the GIS. For this purpose a specialised 3D visualisation system is used.
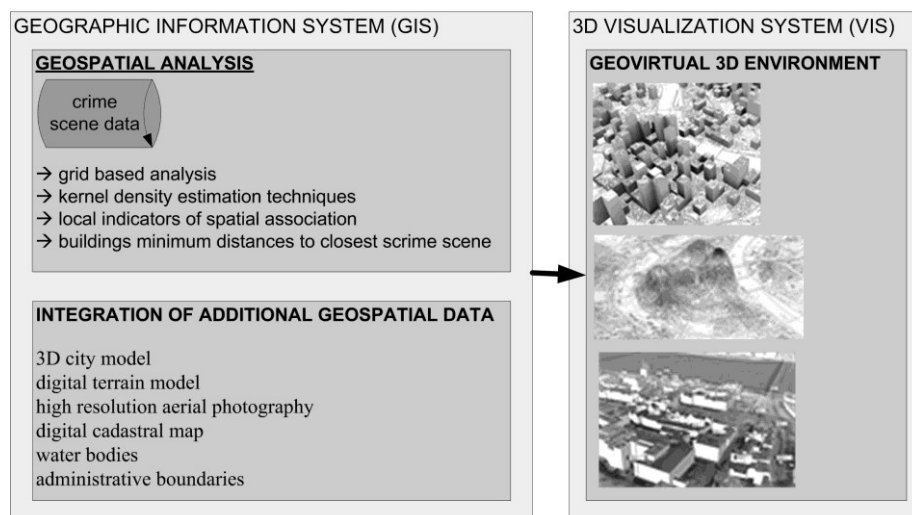- Integration of the results of spatial analysis into the geovirtual environment.

Fig. B-1. Workflow applied in this study.

After the introduction of related work (Section B 2), a scale-oriented approach is applied: at a first level 3D visualisations of crime scenes are applied on a small, citywide scale by analysing and mapping crime scene distribution patterns (Section B 3.1 and B 3.2). At a second level some alternatives for visualisation on a larger scale are presented. These focus on the building level by using the three-dimensional city model.

The combination of analysing crime data and visualising the results with methods from the field of 3D geovisualisation can help to overcome certain shortcomings of communicating complex spatial phenomena – to both, the public and responsible decision makers.

B 2   Related work

This section provides a brief overview of existing studies in the disciplines of crime mapping, 3D geovisualisation and 3D crime mapping.

B 2.1   Crime Mapping

There is a vast amount of literature addressing crime mapping applications in theory and practical application. An introduction into theories, methods and selected software systems used to document, monitor and analyse crime data is given by Chainey and Ratcliffe (2005). Since most crime analyses are based on geocoded point data of crime sites, precise geocoding is a major prerequisite for spatial analysis. McCarthy and Ratcliffe (2005) review this topic of spatial data (in-) accuracy. However, dealing with geocoded crime data, an eminent task is to detect and map spatial hotspots of specific offences. According to Ratcliffe (2004), cited in Boba (2005), a hotspot is defined as an "area with high crime intensity". In addition to Chainey and Ratcliffe (2005), an introduction into the different approaches of detecting and mapping hotspots can be found in McCullagh (2006). With "prospective hotspot mapping" a different approach is introduced by Bowers et al. (2004). Here the bandwidth parameter for calculating hotspot surfaces is not set arbitrarily but is determined empirically (as to be 400 meters). However, areas with higher crime rates than other areas should be tested statistically. Craglia et al. (2000) provide some insights addressing issues of statistical test and functions.

B 2.2   3D Geovisualisation

MacEachren and Kraak (2001) present key themes and issues of geovisualisation. Based on their conceptual framework Slocum et al. (2001) discuss a research agenda on cognitive and usability issues in geovisualisation. Adapting techniques of information visualisation to the requirements of cartography, Kraak (2002) highlights that modern geovisualisation helps to "stimulate visual thinking about geospatial patterns, relationships and trends". Furthermore he emphasizes the advantage of creating three-dimensional visualisations that allow for an "additional variable to be displayed in a single view and, as such, gives the user a

direct insight into the relationship between these variables". Meng (2002) argues that the user can easily interpret spatial relationships of three-dimensional presented geo-objects without having to consult a legend. Jobst (2007) highlights the fact that three-dimensional cartographic visualisations provide "a more intuitive acquisition of space, due to an explicit use of 3D". Both, Meng and Jobst indicate also disadvantages concerning three-dimensional visualisations as for instance the absence of a single scale in perspective views, occlusion of objects, etc. However, construction of virtual three-dimensional geovirtual environments requires dedicated software systems. The LandXplorer software is an appropriate system for visualising interactive three-dimensional maps (Döllner et al., 2006; Döllner et al., 2003).

B 2.3   3D Crime mapping

In contrast to the abundant literature on crime mapping only little works is found on the use of three-dimensionteskalender_slxal geovirtual environments in crime mapping. Though, a lot of research is carried out in the discipline of forensic three-dimensional scene reconstruction of crime sites (as for instance Se and Jasiobedzki, 2005). But there is also some work pointing in the direction of this paper. Lodha and Verma (2000) for instance present some three-dimensional visualisation techniques for crime data. Based on VRML (Virtual Reality Modelling Language) the authors present an urban crime mapping application. They create predominantly 3D bar-charts, where the number of crimes is specified on the z axis while spatial orientation is given on the x- and y axis, describing an underlying grid. However, basic 3D visualisations of surfaces calculated on the basis of crime data, as for instance hotspot surfaces, is found frequently – for instance in Harris (2000). Using Google Earth, even 3D city models can be used as an environment for presenting 2D or 3D crime maps (for instance http://www.geo-spatialtraining.com).

The method presented here allows for integrating crime data into large three-dimensional city models and extensive geovirtual environments. Its key objective is to facilitate and advance geovisual analysis.

B 3 Mapping crime in three-dimensional geovirtual urban environments

This paper focuses on analysis, integration and visualisation of crime data in three-dimensional geovirtual urban environments on different scales – from overall crime scene distributions to the building level. MacEachren et al. (1999), cited in Fuhrmann (2001) describe geovirtual environments (GeoVE) as particularly immersive, information intense, interactive and intelligent.

In a first step a three-dimensional geovirtual environment is created for the German city of Cologne. This provides the basis for subsequent urban crime data visualisation. The Cologne GeoVE consists of a digital terrain model, a 3D city model, high resolution aerial photography (25 cm/pixel), a digital cadastral map and further vector-based datasets including rivers, administrative boundaries and others (cf. Figure B-2). Here, it has to be pointed out that the GeoVE presented here as a static screenshot image is completely interactive. A commercial GIS (ArcGIS) is used to process the datasets and to prepare them for 3D visualisation. Afterwards the datasets are integrated into LandXplorer.

Fig. B-2. Virtual three-dimensional environment of the city of Cologne.

B 3.1   Identifying and visualising hotspots

Robbery crime scene data of 2007 are provided by the police headquarters of the city of Cologne. Each crime scene is described as a single point object, geocoded by x- and y-coordinates. In addition to these coordinates each point carries further thematic attributes describing time of the offence. Mapping robbery scenes with the purpose of creating first overview maps on relative small scales, one has to consider, that basic positional-based point maps do not show all of the recorded crimes since several robberies can have the same coordinates (several robberies at the same registered position at different times). Visualising large spatial point datasets with point symbols is problematic as concentration of point symbols limit the perception of each separate position. Graduated symbols, instead, provide for a better comprehension of the geographical distribution of crime scenes. The use of graduated symbols requires the classification of data values (number of robbery incidents per crime scene) as a prerequisite. One class is represented by one symbol that clearly differentiates in size from other symbols depicting other class values. Therefore the position of a symbol marks the position of a robbery scene, while its size represents the

number of robberies (cf. Figure B-3). Relating the crime scenes to a regular grid is an alternative visualisation for point or point-related data. First, the study area is overlaid with a grid of specific cell size. Specification of the cell size is not straightforward. On the one hand this value should not be too small because this might yield too many cells with no or very few crimes. On the other hand, a large cell size might produce a map which is too coarse. Taking the spatial distribution of the robbery scenes as an experimental basis, a grid cell size of 200 meters turned out to be adequate to depict the spatial structure of robbery scenes. Subsequent to the definition of cell size the resulting grid values are classified and colour-coded according to their number of crimes calculated per grid cell (cf. Figure B-4).
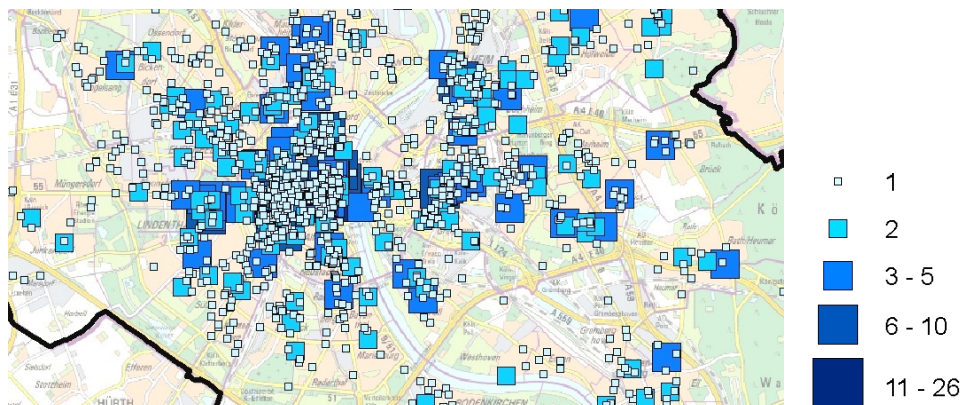
Fig. B-3. Section of a thematic 2D map showing robberies in the city of Cologne.
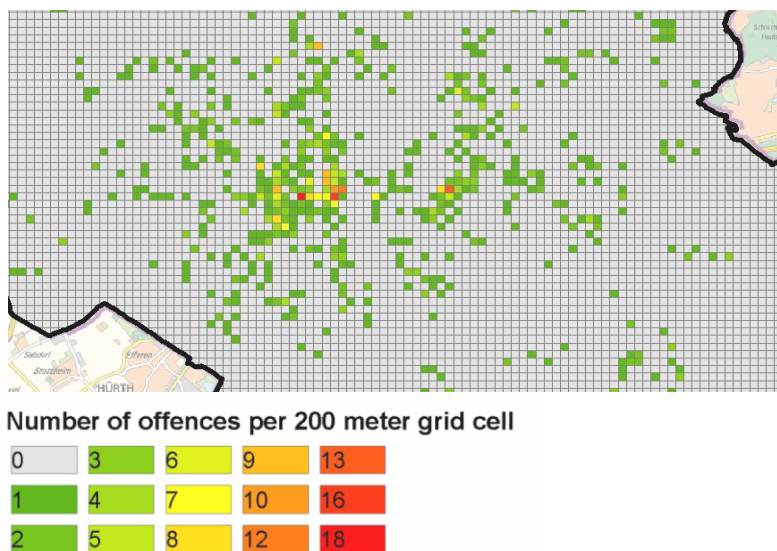
Fig. B-4. Section of a 2D map showing robberies on a grid basis.

In a 3D environment the number of crimes per grid cell is efficiently visualised by assigning grid cell values to a vertical z axis. Thus the cell height represents the number of crimes (cf. Figure B-5). The 3D environment allows for intuitive, interactive exploration and analysis of both number and distribution of crime scenes.
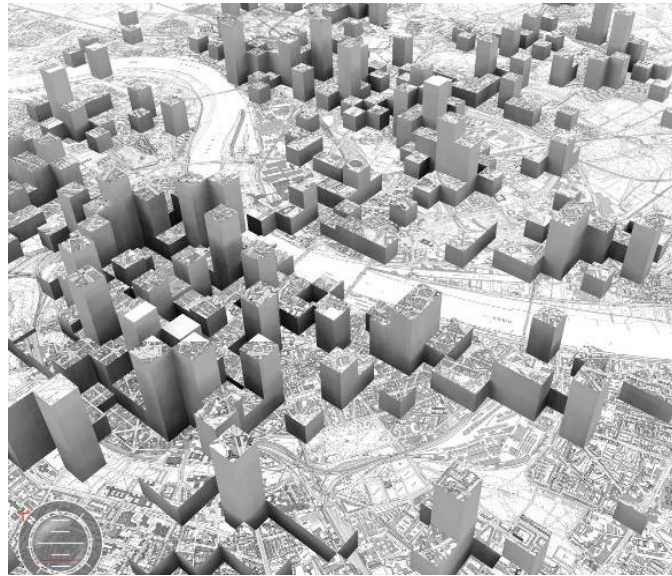
Fig. B-5. 3D visualisation of total number of robberies per grid cell.

The distribution of offences in space and time is one of the cardinal purposes of crime maps. Analysing hotspots is therefore of substantial interest for security agents as well as for decision makers in urban planning. Depending on the cell size and the vertical scale applied grid maps may reveal spatial-temporal clustering of particular crimes. To facilitate optimal analysis and communication of crime hotspots more sophisticated methods of analysis (and visualisation) have to be applied.

A well suited and commonly used method for identifying and visualising hotspots is based on calculating a continuous surface representing density values of specific offences[6]. Density mapping techniques using kernel density estimations (KDE) are one adequate method to identify and map crime hotspots. Although different kernel density functions exist (see Smith et al., 2006), each KDE algorithm eventually results in a grid whose cell values represent density values (of incidents per a defined surface unit of measure). To produce a KDE surface map the study area is first overlaid with a grid of user-defined cell size. Subsequently density values are calculated for each cell – depending on the kernel density function applied. For analysis of robbery scenes in Cologne the quadratic kernel density function implemented in ArcGIS is used:

$$g_j = \frac{3}{4} \left(1 - t^2 \right), |t| \leq$$

with $t = l_{ij} / h$, h as bandwidth

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[6] Unlike other point based data (as precipitation data for instance), crime data can not be interpolated to a continuous surface by implication.Therefore, methods, such as, inverse distance weighting (IDW) or spline interpolation algorithms are inadequate to create a continuous hotspot surface.

This function calculates for every cell of the resulting density grid g at grid location g_j, a value with distance d_{ij} from each robbery scene i. This g_j value is calculated as the sum of all applications of the kernel function over all event points in the crime scene dataset. As a result the grid generated represents density values of crimes sites related to a surface measure (for instance number of crimes sites per square kilometre). The input file for this KDE analysis is a dataset with crime scene locations. Before used as input for KDE analysis, this dataset is preprocessed: based on the robbery positions a new dataset is created that contains the total number of incidents per crime scene position as an attribute value. If there are several robberies at the same position, but at different times, these are counted and aggregated into the new dataset. The total number of robberies per identical crime scene position is written to the new datasets database as an attribute value. This dataset is used as input file for KDE analysis. Another input parameter is the cell size and the bandwidth (the search radius with distance d_{ij}). For this study a hotspot grid for the robberies 2007 is calculated using ArcGIS spatial statistics. For our study region a bandwidth parameter (search radius) of 400 meters and a cell size of 50 meters is considered appropriate. The bandwidth value has experimentally been determined at 400 meter since it represents possible hotspots as well as the general distribution of crime scenes. For visual analysis the resulting hotspot grid is integrated into the 3D geovirtual environment. Using a colourless continuous surface instead of the 2D classified and coloured grid provides an alternative representation of the KDE grid: to allow for a visual differentiation of regions with higher crime densities from regions with lower densities, predominantly traditional two-dimensional choropleth or isopleth maps are created on the basis of the hotspot grid. This requires defining adequate thresholds for the class breaks. That, in turn, leads to the issue that different maps result from different threshold definitions. However, using a three-dimensional surface no thresholds have to be defined for basic visualisation (cf. Figure B-6).
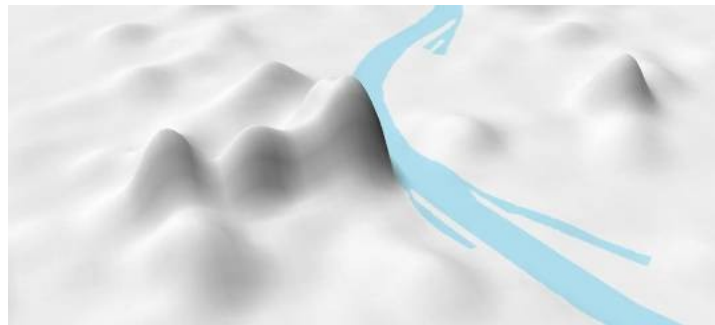
Fig. B-6. 3D visualisation of robbery hotspots based on a KDE surface without threshold classification.

Integrated in the 3D environment this thematic relief facilitates an intuitive exploration and interactive visual analysis of crime site densities on relative small and medium scale levels. In addition the surface can be overlaid with various geocoded textures – for instance with (classified) choropleth or isopleth maps of the hotspot grid or with topographic maps (cf. Figure B-7). This multiple feature coding of crime site densities is an effective visualisation method to single out specific hotspot regions – for instance to brief decision makers.

Fig. B-7. 3D visualisation of a classified KDE surface.

One disadvantage of kernel density smoothing techniques is that areas might be covered by the surface as well where no robbery can take place. For instance no robberies will be encountered in the waterbodies of Rhine river. Using 3D visualisation techniques this mistake becomes obvious. GIS functions based on map algebra allow for subtraction these areas from the KDE grid before the surface is integrated into the geovirtual environment (cf. Figure B-8).
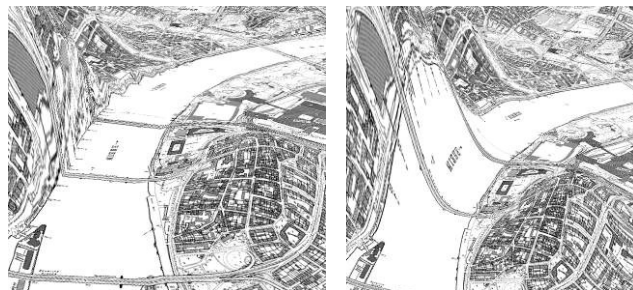
Fig. B-8. Comparison of the KDE surface with (left Figure) and without (right Figure) surface correction.

The geovisualisation techniques applied so far facilitate an basic visual exploration of crime scene distributions. This high potential for an intuitive presentation of geographic information paves the way for an instant grasp of complex spatial situations. However, to prove the existence of a specific hotspot region from a statistical point of view, further analysis should be conducted. Therefore, the crime scene distributions are tested for statistical significance using local indicators of spatial association. Eventually, those hotspots showing high levels of statistical significance are analysed more detailed on a larger scale level.

B 3.2   Validating hotspots using local indicators of spatial association (LISA)

Applying KDE techniques a smooth surface of crime densities is calculated. However, possible hotspot regions need to be verified statistically as well. This allows for differentiating hotspots relative to their significance level. Furthermore, visualising these results in a three-dimensional environment facilitates an interactive exploration of the hotspot surface while allowing the user simultaneously to check corresponding statistical significances.

To identify crime scenes that indicate an overconcentration of high (or low) robbery offences local indicators of spatial association, also known as LISA statistics are applied (Anselin, 1995). These indicators allow for analysing datasets on a local instead on a global level (for instance by using Moran's I or Geary's C) and allow for identifying differences between data values on a regional scale. From the methods of LISA statistics available (Local Moran's I, Local Geary's C) Getis-Ord (G_i^*) statistics are calculated, because this method detects areas where average values on a local level differ from those on a global level. In other words, areas can be identified by Getis-Ord (G_i^*) statistics where the number of observed crime incidents exceeds the number of observed incidents in the whole study area. G_i^* is calculated as following (Craglia et al., 2000):

$$G_i^* (d) = \frac{\sum_j w_{ij}(d) x_j}{\sum_j x_j}$$

In other words, G_i^* is the sum of weighted data values within a specific distance around an observation point i ($w_{ij}(d)$). A positive G_i^* value marks spatial clustering of high values: crime sites with high numbers of offences are surrounded by similar points (hotspot). In turn, a negative G_i^* value indicates that a crime site with few offences is encircled by crime sites showing few offences as well (coldspot). More detail on testing for spatial autocorrelation using Getis-Ords statistics can be found in Getis and Ord (1992) and Ord and Getis (1995).

To analyse the robbery dataset the Getis-Ord Gi^* statistic tool implemented in ArcGIS 9.2 is applied. Compared to (2) ArcGIS calculates Gi^* statistics in a slightly modified way (ArcGIS Desktop Help):

$$G_j^* = \frac{\sum_{j=}^{n} w_{ij} x_j - \bar{X} \sum_{j=}^{n} w_{ij}}{S \sqrt{\frac{\left[n \sum_{j=}^{n} w_{ij} - \left(\sum_{j=}^{n} w_{ij} \right)^{\wedge} \right]}{n-}}}$$

with x_j as the attribute value for each feature j

and $w_{i,j}$ as spatial weight between the features i and j

and n as the total number of features

and

$$\overline{X} = \frac{\sum_{i=1}}{n}$$

and

$$S = \sqrt{\frac{\sum_{j=}}{n} - \left(\overline{X}^2\right)}$$

The result is a z score for each location. This z score describes where features with high or low values cluster in space. To determine, whether a hotspot is statistically significant the local sum for each feature and its respective neighbours is compared in proportion to the total of all global features. If the calculated local sum differs from the expected local sum, and this difference is too large to be caused by random change, the result for that specific feature location will be a statistically significant z score. The higher the z score of a feature, the more intense is the clustering of high values in the neighbourhood of that feature (hotspot). Correspondingly, lower z scores imply more intense clustering of low values (coldspot).

Using ArcGIS is of advantage since the results (z values) are written to the input features database. Thus z values are linked to the map features. To test the KDE surface (Section B 3.1) for its statistical significance, identical robbery incidents are used for Gi^* statistics. As the input file for Getis-Ord Gi^* statistics the dataset containing the total number of robberies per identical crime scene location (cf. Section B 3.1) is used. Using the ArcGIS implementation of Gi^* statistics, a "fixed" Euclidean distance ($w_{ij}(d)$) has experimentally been determined at 200 meters.

The resulting dataset is classified according to their z scores. Subsequent class breaks are chosen to visualise significance levels of $p=0.05$ and $p=0.01$. In a final step this dataset is integrated into the three-dimensional environment. The resulting 3D visualisation allows the user to explore the KDE hotspot surface; he also can check the hotspots for statistical significance levels. Significance levels are visualised by spheres in different colour (cf. Figure B-9). This Figure shows that the hotspots in Cologne centre west of river Rhine, are also statistically highly significant.
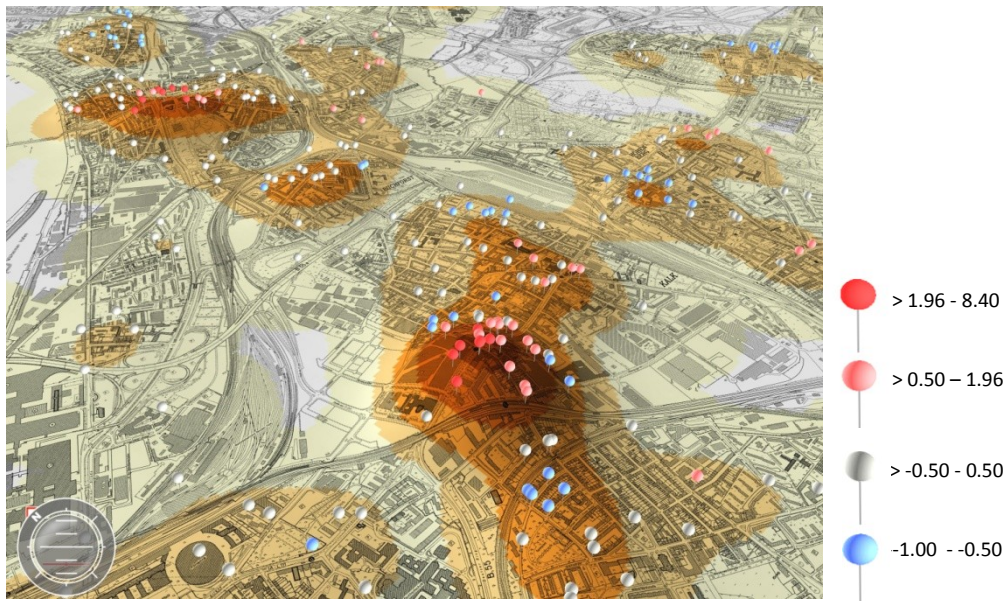
Fig. B-9. 3D visualisation of KDE surface and associated symbols showing levels of statistical significance.

At this stage the hotspot grid is still independent of administrative boundaries. However, to facilitate further visual analysis, Gi^* statistics based on specific spatial entities are calculated. Therefore offences are spatially aggregated to neighbourhood district boundaries. For this purpose the number of crimes per neighbourhood is counted. In a second step this dataset is used for Gi^* statistics. As a result each district-polygon gets a z value, that describes the clustering of high/low robbery incidents in an around a neighbourhood. This dataset is integrated into the 3D environment (cf. Figure B-10).
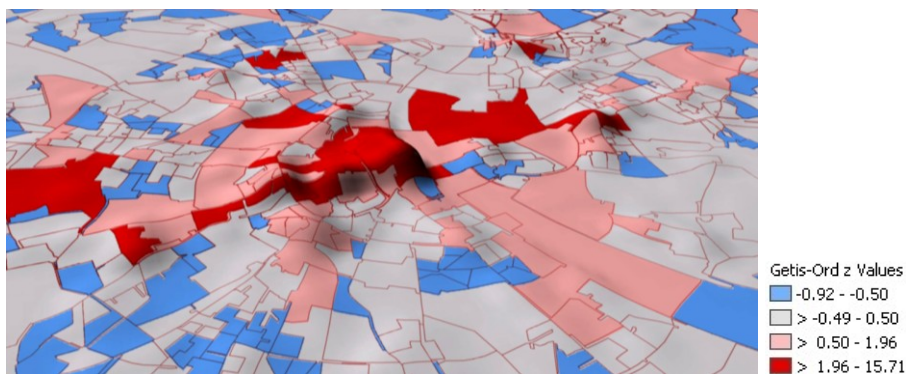
Fig. B-10. 3D LISA map: visualisation of Gi^* statistics as applied for neighbourhoods in the city of Cologne.

Figure B-10 indicates that neighbourhood districts close to the centre tend to be surrounded by neighbourhoods showing high number of offences, while father districts are predominantly surrounded by neighbourhoods representing lower number of offences. Based on suchlike visualisations, decision makers as well as urban planers are able to explore each neighbourhood district robbery rate by navigating through the virtual 3D environment.

In a further step the analysis scale is increased by focussing on particular hotspots. On that level the urban landscape with its various interdependencies is included for visual analysis by integrating a three-dimensional city model into the virtual environment.

B 3.3 Integrating the urban landscape

To allow for in-depth- analysis the virtual environment is extended by a 3D city model. The use of a 3D city model facilitates visualisations of spatial relationships at the building level in an easy to comprehend way. This analytical and geovisual potential of 3D city models can be instrumental for decision makers working in security agencies for an instant comprehension of complex spatial phenomena related to urban security issues. However, city models vary in semantic and graphic detail from those with reduced level of detail (LOD1) to completely textured LOD3 models. The latter are often complemented by interior models of single rooms to complete buildings (Gröger et al., 2005, Döllner et al., 2006). In this study a city model that consists of approximately 22,000 buildings is used. Since this model was generated form airbone-LiDAR data, roof geometries are also included (LOD2).

To facilitate geovisual analysis in terms of comparing single buildings with the robbery hotspots, the city model is overlaid with the KDE hotspot grid. Figure B-11 shows the central Cologne hotspot area with a corresponding 3D city model. To broaden this visual approach and to facilitate further analysis, the minimum distance to the nearest robbery scene is calculated for each building. Based on the crime scene dataset an Euclidean-distances-grid with a cell size of two meters is calculated. Each pixel of this grid represents the distance to the nearest crime site. This grid is combined with the city model: for each of the 22,000 buildings those pixels are detected that are included by the respective building footprint. From this set of pixels that one with the lowest value is determined – this pixel defines the minimum distance of the building to the nearest crime site. This value is added to the building database as a new attribute.
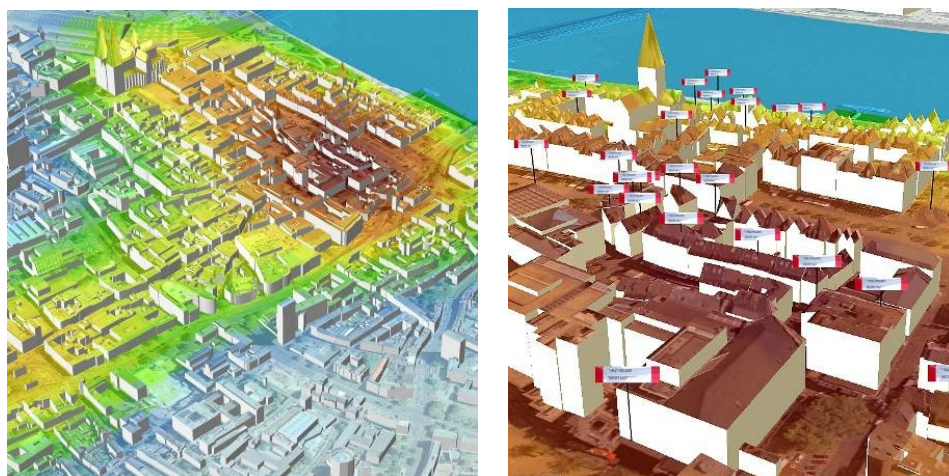
Fig. B-11. 3D city model with additional hotspot texture and crime scene positions.

Afterwards, the building dataset is classified and coloured according to these minimum distance values. The subsequent 3D visualisation allows for exploring particular buildings of urban districts affected by a high number of robberies in their neighbourhood (cf. Figure B-12). Since the distance values are stored in the buildings database, the creation of specific selection set of buildings for further analysis is supported.

minimum distance to closest crime site (in m)

up to 5	up to 100	up to 400
up to 25	up to 150	up to 503
up to 50	up to 200	
up to 86.2 (mean distance)	up to 300	
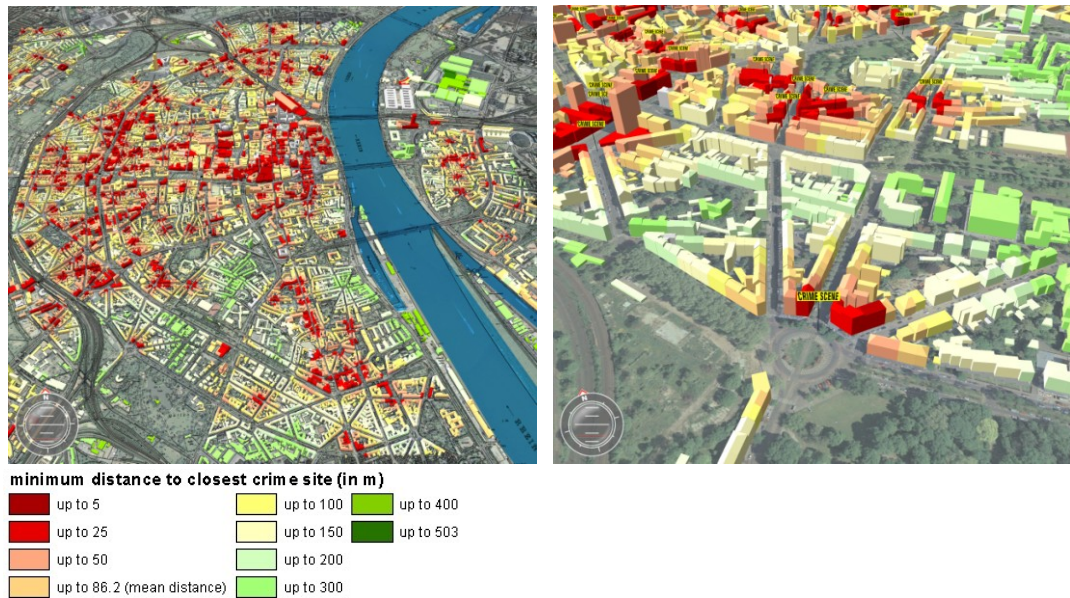
Fig B-12. Minimum distances of each building to the nearest robbery crime scene as overview visualisation and with a smaller camera distance.

This visualisation facilitates an intuitive geo-communication about the distances of each building from the nearest crime scene.

In addition an alternative visualisation is created, visualising the "skyline of crime". For this kind of illustration the minimum distances to the nearest crime scene is used as building height information (cf. Figure B-13). However, this kind of visualisation is suitable only for a small number of crime scenes. The higher the number of crime scenes, the more irregular the distribution of building heights and the less intuitive the graphic is.
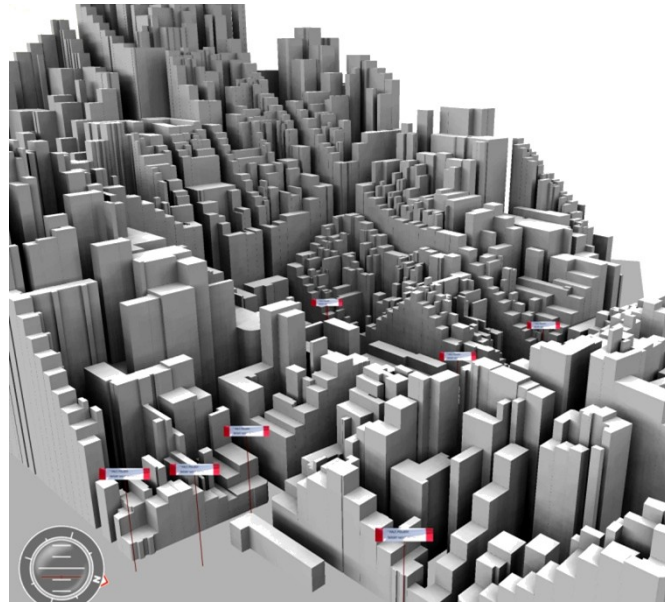
Fig. B-13. The skyline of crime: the minimum distance value is used as new height information for each building. The higher the building, the greater is the distance to the nearest crime scene.

To facilitate maximum transferability of some of the presented city model applications a GIS plug-in is programmed. With this tool the user can easily create the proximity grid and calculate the minimum building distances to the nearest crime site. Furthermore the creation of new database entries for each building regarding the membership to a distance class is supported (for instance: "distance to nearest crime site >200 and <300 meters"). Colouring the buildings according to this crime site distance is straightforward by using these field values. Moreover the tool allows for creating hotspots based on KDE algorithms as well. To enhance the usability of hotspot mapping, the possibility to calculate several hotspot grids with different bandwidth distances in one pass is integrated. Therefore the user does not have to spend much time with the tedious procedure of running the same GIS function many times using different distance values. This ArcGIS plug-in is programmed as a dynamic link library (DLL) using ESRI's ArcObjects and Microsoft .Net framework with visual basic as the programming language. Figure B-14 shows the dialogues of this plug-in.
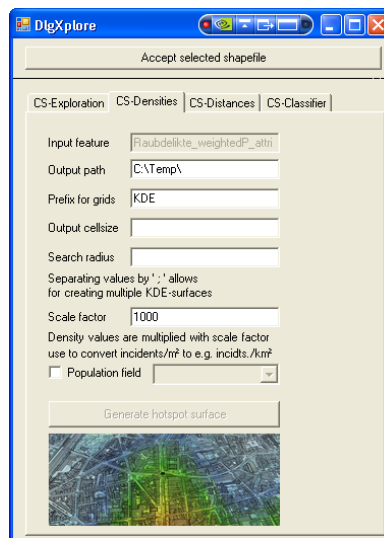
Fig. B-14. Developed plug-in for ArcGIS.

B 4 Conclusion

This paper presents several methods and functions for analysing and visualising crime data with three-dimensional geovirtual environments by the example of the city of Cologne. For this purpose methods of analysing crime data are combined with innovative 3D geovisualisation techniques. Starting on an overview scale, crime scenes are aggregated to a grid dataset. A second step includes the calculation and 3D visualisation of statistical surfaces based on kernel density estimation. Afterwards the analysis scale is increased by focussing on particular hotspots and by including the urban landscape via integrating a three-dimensional city model into the virtual environment. In the end a GIS plug-in for the purpose of a user friendly execution of several of the applied techniques is provided. However, for further studies the 4th dimension should be included in further analysis. Therefore next steps in this project will comprehend time related analysis of hotspot patterns. Further innovative three-dimensional visualisation styles will have to be developed for displaying these issues with a cartographic yet appealing way.

Acknowledgements

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C Geospatial Crime Scene Investigation – From Hotspot Analysis to Interactive 3D Visualisation*

Abstract. This contribution presents an approach to combine geospatial crime scene analysis with three-dimensional geovisualisation methods. The crime scene analysis carried out in this paper focuses on GIS-based hotspot identification of robbery scenes. To complement this investigation, methods are presented for extracting individual spatial properties of hotspot areas which might help to understand observed density patterns. Against this background, in-depth analysis tries to reveal specific correlations between urban features and robbery offences. Further analysis correlates the quantity of robbery scenes with pedestrian frequencies. Spatio-temporal analysis of hotspot patterns finalises the presented set of spatial crime scene analysis. To facilitate an instant grasp of complex spatial phenomena, the respective results of crime scene analysis are visualised using three-dimensional geovirtual environments. This combined approach contributes to an intuitive comprehension of complex geospatial information for decision makers in security agencies as well as for authorities engaged in urban planning.

Keywords: crime mapping, 3D geovisualisation, GIS

C 1 Introduction

Geographic information systems (GIS) are a widely used tool in the discipline of crime mapping. Because it is possible to virtually locate crime scenes in space almost precisely (inside or outside of a building), a GIS is an adequate tool for the managing and analysing of crime data. Both in academic research and in practical law enforcement, GIS are applied for the analysis and the mapping of crime data [1]. Among the various benefits of geospatial crime scene analysis, the following applications can be considered the most important ones: operational policing purposes, crime prevention, informing and interacting with the community, monitoring changes in the distribution of crime over time and evaluating the effectiveness of crime prevention initiatives [2].

Subsequent to the geospatial analysis of a given (crime) dataset, the results have to be communicated to a broader audience. For this purpose, thematic maps are created. Therefore, cartographic visualisations can be considered a key element in the communication of the outcomes of crime analysis. This paper focuses on providing easy-to-comprehend visualisations for decision makers working in security agencies. The method presented in this paper is based on the geospatial analysis of robbery scenes (Section C 2). Robbery scene distributions are analysed in order to discover regional clusters of crime, so-called hotspots (Section C 2.1). Series of monthly hotspot patterns are calculated in order to show the temporal evolution of hotspot areas. These form the basis for an animated movie sequence (Section C 2.1). Once identified, in-depth analysis of the hotspot areas is performed (Section C 2.2).

For the purpose of analysing spatial correlations of robbery scenes in context with their particular neighbourhood, the semantic information of road segments is updated with pedestrian frequency values. Afterwards, robbery crime scene positions are analysed regarding their distances to the updated road segments. Further in-depth analysis is carried out to characterise hotspot regions based on the existence of specific urban features. Another method identifies urban facilities located nearest to robbery scenes. These methods help an analyst to interpret why precisely crime scenes tend to cluster in particular areas.

To support decision makers with easy-to-comprehend geovisualisations, the findings of the crime scene analyses are visualised by using a three-dimensional geovirtual environment. While a GIS is used for all kinds of spatial analysis, the interactive environment is modelled with a 3D visualisation system. The workflow applied in this work (cf. Figure C-1) begins with the transformation of discrete point distributions of crime scenes into an isodensity surface that represents crime hotspots (cf. Figure C-1, "hotspot analysis"). This surface together with other findings is integrated into a three-dimensional geovirtual environment (cf. Figure C-1, "3D VIS"). Additionally, in-depth analysis is carried out for identified hotspot areas (cf. Figure C-1, "in-depth analysis").
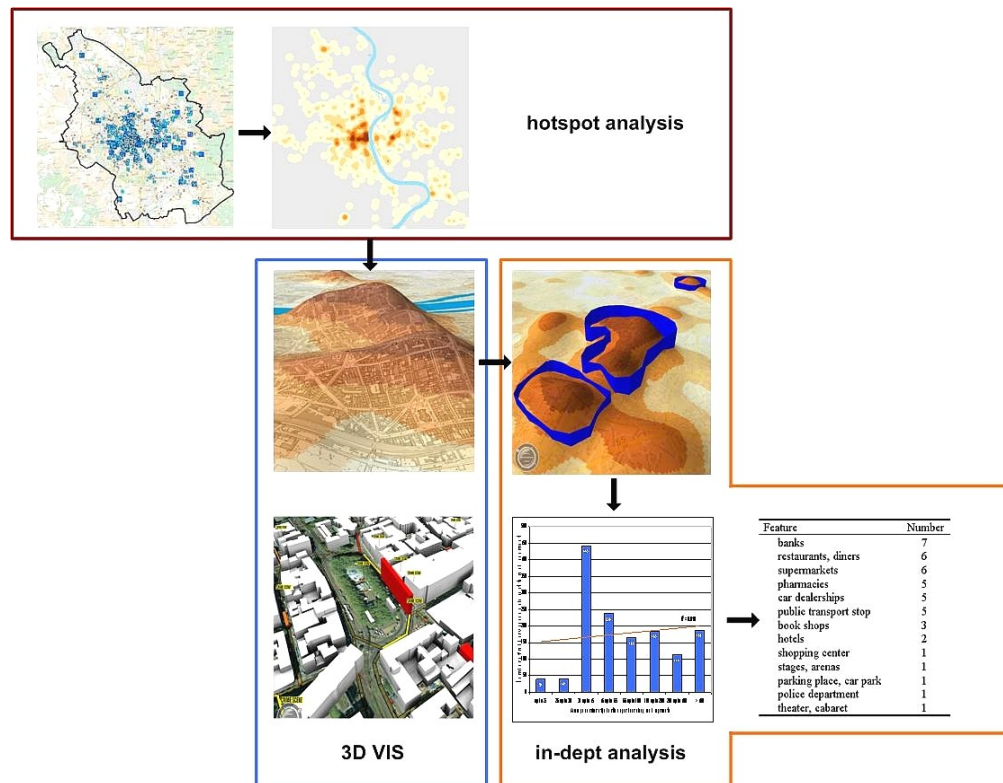
Fig. C-1. Workflow scheme as applied in this study.

C 2 Discovering robbery hotspots

This section deals with the geospatial analysis of robbery crime scene data. An approach is presented that outlines how methods of geoinformation science are applied to process crime data and to reveal spatial clusters of crime. Furthermore, particular features are identified that help an analyst to explain why a robbery hotspot exists in its given boundaries. For analysis, the ESRI ArcGIS system is used, while the interactive environment is build with Autodesk (former 3D Geo) LandXplorer. To facilitate an instant grasp of complex geospatial relationships, a three-dimensional representation is created for the study area. This geovirtual environment consists of a digital terrain model, a 3D city model, high resolution aerial photography, a digital cadastral map and further vector-based datasets including rivers, administrative boundaries and other information (cf. Figure C-2). Using GIS, all datasets are processed for 3D visualisation. Afterwards the datasets are integrated into the LandXplorer software, which is an appropriate system for interactive three-dimensional visualisations [3] [4]. Once all these data are integrated into the geovirtual environment, the user is able to interactively explore the cityscape and its crime scene positions as well as crime scene densities (cf. Section C 2.2). Although it has not been proven that 3D visualisations allow for a more intuitive communication of complex geospatial phenomena than a 2D map does, it can be stated that they do facilitate an instant and intuitive grasp of spatial information, especially for decision makers untrained in the reading and interpretation of maps.

Fig. C-2. Virtual three-dimensional environment of the study area.

In contrast to the abundant literature on crime mapping and geovisualisation, there is only little work to be found on the use of three-dimensional geovirtual environments in crime mapping. The authors of [5] for instance present some three-dimensional visualisation techniques for crime data. Based on VRML (Virtual Reality Modelling Language), the authors develop an urban crime mapping application. They predominantly create 3D barcharts. Here, the number of crimes is specified on the z axis, while spatial orientation is given on the x- and y axis. Rather straightforward 3D visualisations of crime scene based surfaces (e.g. hotspot surfaces) can be found in [6].

C 2.1 Determining the hotspots

The base dataset for analysis is obtained from the police headquarters of the German city of Cologne. The dataset represents robbery crime scenes for the year 2007 where each robbery scene is represented as an individual point, geocoded by x and y co-ordinates. Beyond these co-ordinates, each point has further attributes describing the time of the offence. Hotspot analysis is conducted in order to identify areas in the city of Cologne characterised by a higher density of robberies than other areas (cf. [7] [8] and [9] cited in [10], [11]).

For hotspot analysis, the discrete point distribution is transformed into a continuous surface of crime scene densities by using kernel density estimation (KDE) techniques [12] [13] [14]. For the analysis presented in this paper, the ArcGIS system, version 9.2, is used. Based on an input point dataset, the KDE technique produces a grid whose cell values represent density values related to a specific surface measure (for instance the number of crimes scenes per square kilometre). For this purpose, KDE algorithms first overlay a study area with a grid of user definable cell size. In a second step, density values are calculated for

each grid cell. Two parameters are crucial for this analysis: cell size and bandwidth. The cell size parameter defines the resolution of the resulting grid, the bandwidth parameter specifies the size of the search radius, i.e. how many crime scene locations (points) are used to calculate the grid of crime scene densities. A large bandwidth includes a larger area and therefore more points for analysis than a smaller bandwidth. Hence, a bandwidth that is too large might hamper the identification of smaller hotspots, while a bandwidth that is too small might result in many small clusters of crime. For the KDE analyses conducted in this paper, a cell size of 20 meters and a bandwidth of 400 meters are considered appropriate. However, the lack of rules and standards concerning a reliable hotspot bandwidth parameterisation prompts Smith et al. to conclude that bandwidth selection "is often more an art than a science" [12]. The decision for the 400 meter search radius is a result of experimental studies: the resulting hotspot grid reveals inner-city hotspot-regions while preserving the overall representation of crime scene distribution. For additional visual analysis of hotspot areas, the hotspot grid is further processed and integrated as a three-dimensional surface into the 3D geovirtual environment and overlaid with additional geocoded information (cf. Figure C-3).
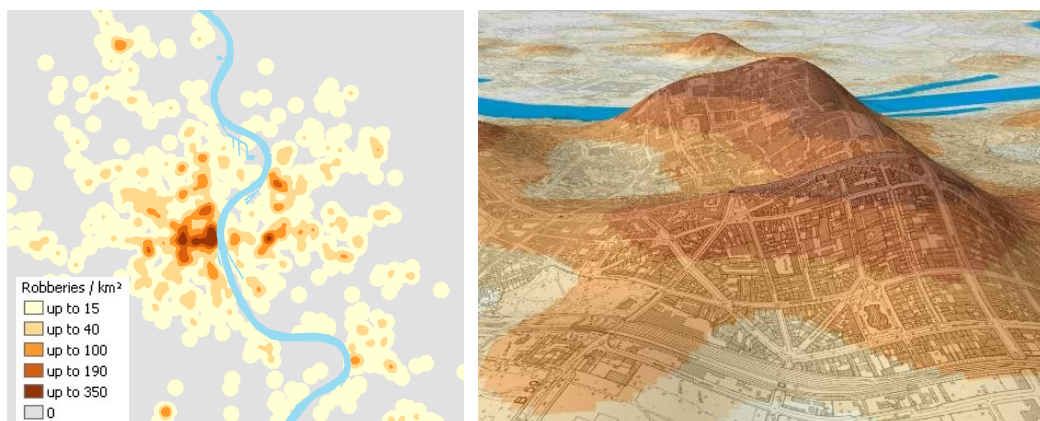
Fig. C-3. 2007 hotspot grid with robbery densities defined as number of incidents per square kilometre – represented as a 2D thematic map (left-hand image) and as a three-dimensional "information landscape" (right-hand image).

To provide an overview visualisation of temporal changes of specific hotspot regions, the dataset is divided into twelve subsets, each set representing the offences of one month. These twelve individual 3D hotspot surfaces are calculated by using the KDE parameters as specified above (cf. Figure C-4).
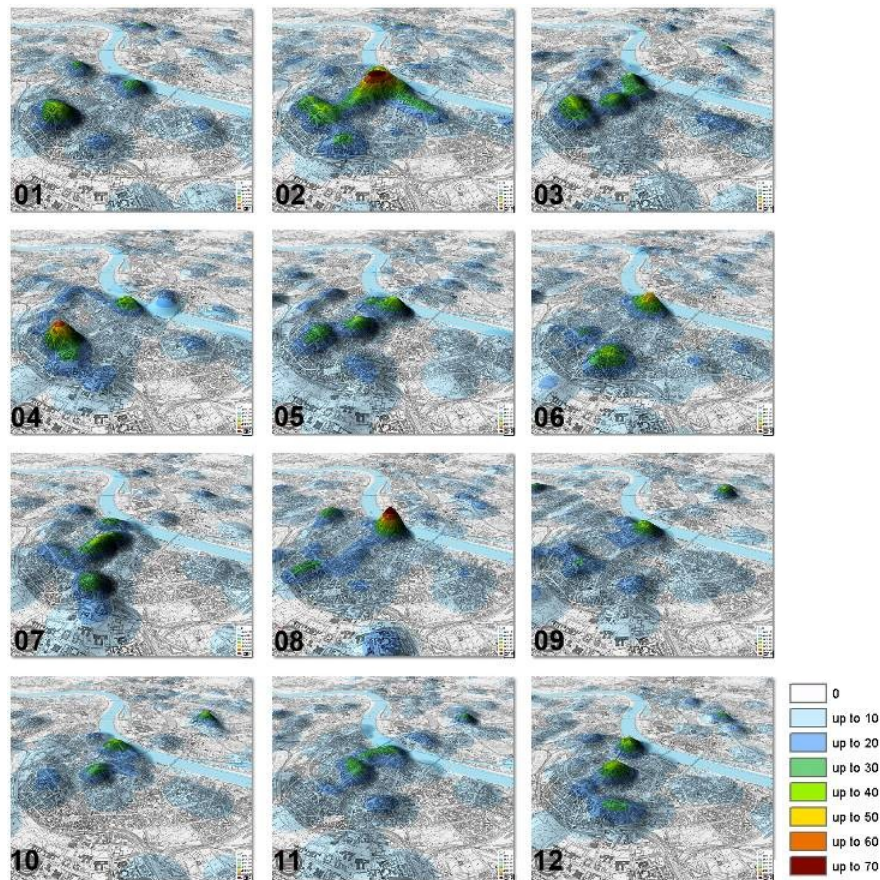
Fig. C-4. Hotspot surfaces providing monthly key frames for a movie sequence visualising temporal changes of hotspot areas during one year (committed robberies per km²).

To allow for further analysis, the virtual environment is extended by a 3D city model. Using such a model allows for including particular buildings into analysis and visualisation. In this study, a city model is used that consists of approximately 22,000 buildings. To facilitate geovisual analysis in terms of comparing single buildings with the robbery hotspots, this city model is overlaid with the KDE hotspot grid. Figure C-5 shows the central Cologne hotspot area with a corresponding 3D city model.
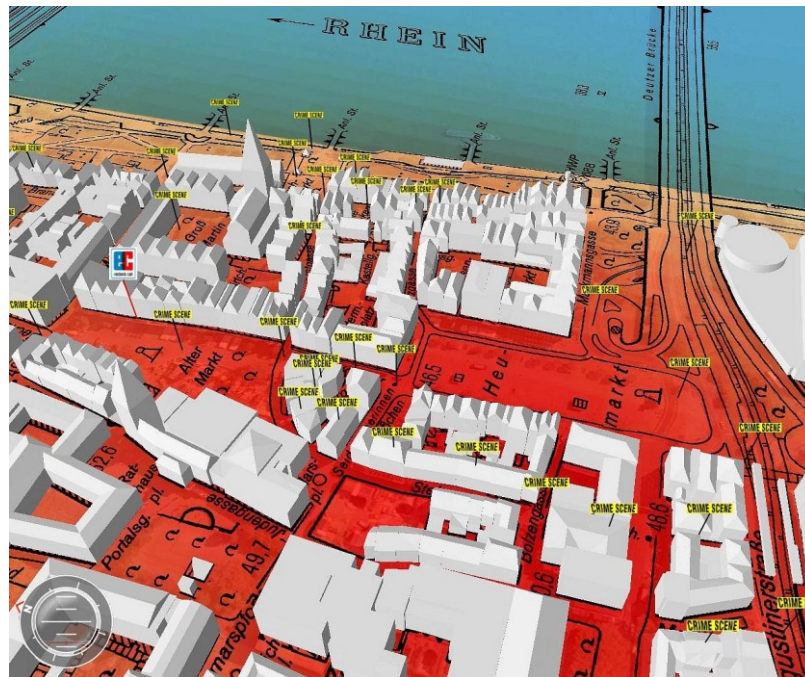
Fig. C-5. 3D city model with hotspot texture and crime scene positions.

Further in-depth analysis of specific hotspot regions requires the identification of these areas in a first step. This can be performed by visual or by data-based methods. To obtain discrete hotspot boundaries from the KDE grid, a data-based method is applied. The method implemented here is based on focal neighbourhood statistics. This method compares each pixel's value of the KDE grid to the values of its neighboured pixels and calculates the respective standard deviation values. The number of neighbour cells to be included in this analysis is set to a rectangle of 7 x 7 pixels. Thus, each grid cell is compared to its 7 x 7 neighbourhood and the respective standard deviation is calculated. The result is a new grid, whose cell values represent standard deviation values of robbery scene densities.

Applying this method leads to a grid of density-gradients. The higher the grid values, the higher the "robbery gradient" of a particular cell to its neighbours. This value is used to detect hotspot boundaries. Based on visual exploration, a standard deviation value equal to 15 is set as the threshold value for defining the boundaries. Subsequently, the standard deviation grid is reclassified. Grid values of zero represent cells with standard deviations lower than 15, grid values equal to one represent standard deviations equal to 15. This grid is afterwards vectorised and the resulting polygons are simplified manually. The resulting polygons, eventually, represent the boundaries of the three largest hotspots (cf. Figure C-6).
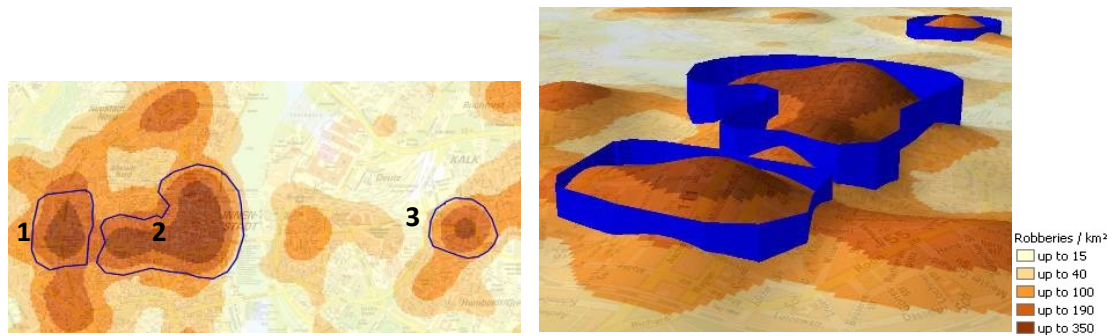
Fig. C-6. KDE surface with three derived hotspot boundaries represented as 2D map (left-hand image) and integrated into the geovirtual environment (right-hand image).

C 2.2   In-depth analysis of particular hotspots

Based on the three hotspot areas identified with focal neighbourhood analysis, this section presents methods for further analyses of robbery scenes located explicitly inside the boundaries. These methods facilitate a GIS-based characterisation of particular hotspot regions that do not require any expert- or geographic knowledge of these regions. In a first step some overall characteristics of these regions are identified with GIS methods. For that purpose, the distribution of several urban facilities (schools, restaurants, clubs, sights, banks, etc.) is analysed for each hotspot region. Tables C-1 to C-3 depict the absolute number of registered facilities inside the boundaries of each hotspot area.

Table C-1. Number of specific features in hotspot region one

Feature	Count
restaurant, diner	94
bank	12
club	9
public transport stop	8
parking place, car park	7
hotel	7
book shop	7
pharmacy	7
supermarket	4
theatre, cabaret	3
cinema	2
sight	1
school	1
consulate	1
church	1
shopping centre	1

Table C-2. Number of specific features in hotspot region two

Feature	Count
restaurant, diner	151
hotel	46
parking place, car park	24
bank	23
public transport stop	21
sight	16
pharmacy	14
museum	12
church	10
book shop	9
theatre, cabaret	7
shopping centre	6
supermarket	5
car dealership	3
club	3
stage, arena	3
railroad station	2
indoor swimming pool	2
bus terminal	1
tourist information	1
consulate	1
post	1
town-hall	1
school	1
petrol station	1

Table C-3. Number of specific features in hotspot region three

Feature	Count
bank	7
restaurant, diner	6
supermarket	6
pharmacy	5
car dealership	5
public transport stop	5
book shop	3
Hotel	2
shopping centre	1
stage, arena	1
parking place, car park	1
police department	1
theatre, cabaret	1

This analysis reveals differences between the three hotspot regions. Except for restaurants and diners (these facilities are frequently found in all three areas), hotspot area one with its

many clubs can be characterised as a nightlife district. In the adjacent hotspot area two, tourism plays a major role, as can be seen in the high number of hotels, parking places, museums and sights. The existence of many banks, supermarkets, pharmacies and car dealerships in hotspot area three, on the other hand, points to a housing area. Overlaying the hotspot boundaries with a city map (cf. Figure C-7) reveals that hotspot area number one indeed covers an area that is well-known for its nightlife ("Rudolfplatz" and "Friesen-platz"). Hotspot area two covers the city centre of Cologne, an area that is heavily frequented by tourists (Cologne cathedral) and for shopping along the many pedestrian zones. Hotspot area three is located in the district of Cologne-Kalk, which is a former industrial location with comparatively high unemployment rates.
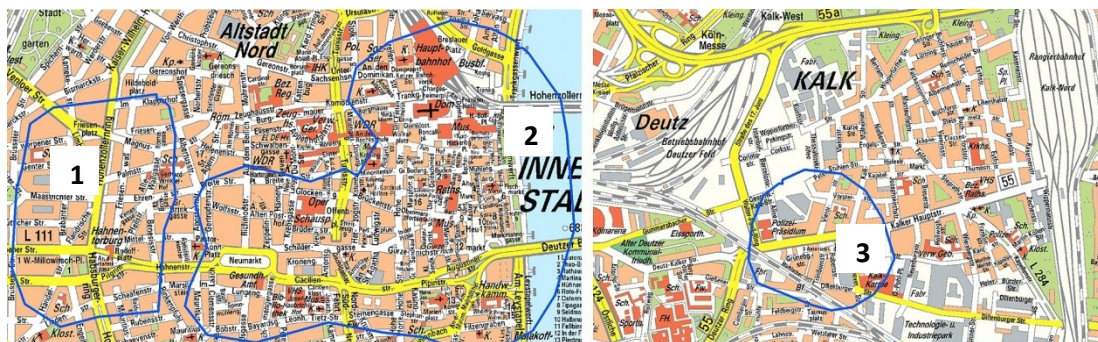
Fig. C-7. Hotspot regions one, two (left-hand image, blue outlines) and three (right-hand image).

Since one hotspot covers the extensive area of inner-city pedestrian zones, further analysis explores correlations between pedestrian quantities and robbery scene positions. Statistical analysis is conducted to determine whether robbery scenes with high (low) numbers of offences are located near streets frequented by many (few) people. To allow for such analysis, data of pedestrian frequencies is used to update the Cologne road network. This data is obtained from the FAW Frequency Atlas of the German Association for Outdoor Advertising (FAW). In this atlas, frequency values are calculated as average values per hour on a working day basis for the years 1999 to 2005 (Data description FAW-frequency-Atlas 2006). Based on its geocoded coordinates, this point-based FAW information is referred to the corresponding road segments via its unique segment ID. Afterwards, the distances between robbery scenes and roads segments are analysed. In a first step, the nearest road segment is identified for each individual robbery scene. In a second step, the number of offences per crime scene is assigned to the nearest road segment as a new attribute value. However, since frequency values are based on a working day basis, weekend crimes are excluded from the dataset for analysis. Eventually, the road network is updated with the average frequency of pedestrians frequenting this segment per hour and with the total number of nearest located robberies. Finally, robbery scenes and pedestrian frequencies are tested for correlation. For the whole city of Cologne, a weak but significant positive correlation between the number of offences and the number of pedestrians is identified (Pearson's rank correlation coefficient = 0.178, significant for p=0.01). Only a small number of robberies is registered near segments frequented by a small number of pedestrians.

However, most robbery scenes are not located close to segments frequented by the highest number of pedestrians (>400 per hour). Instead, most robberies are committed close to segments frequented by up to 45 pedestrians per hour (cf. Figure C-8).
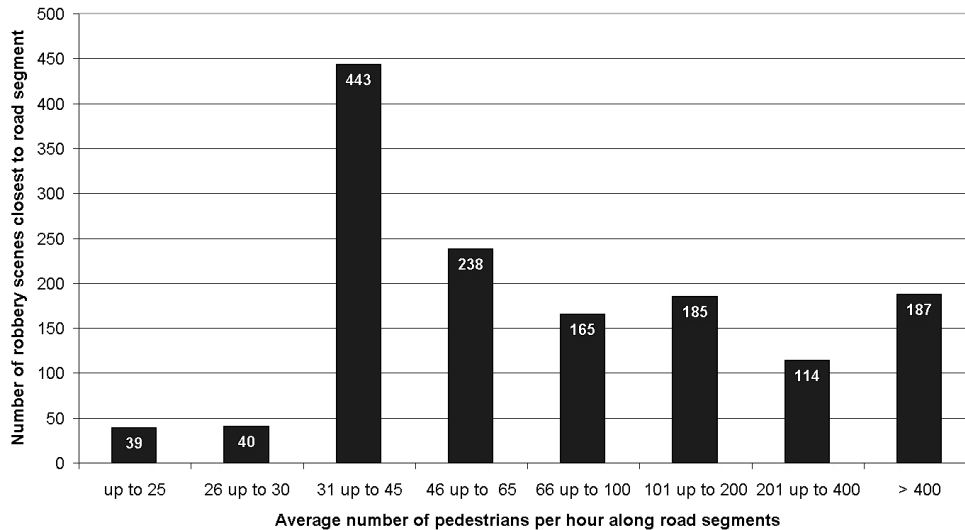
Fig. C-8. Number of offences compared to pedestrian frequencies on road segments for the city of Cologne.

Afterwards, corresponding analysis is conducted for the subset of robbery scenes and road segments encircled by the hotspot boundaries. Figure C-9 shows that in most instances, the nearest street segment to a robbery scene is frequented by 400 and more pedestrians per hour. However, roughly half of all road segments with pedestrian frequencies equal to 400 and more pedestrians are located in the hotspot boundaries (296 out of 588 segments).
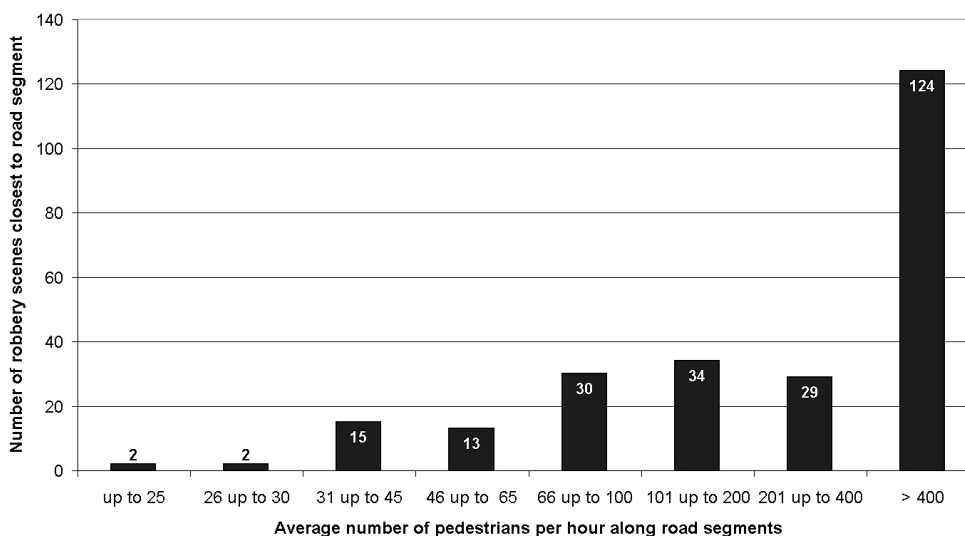
Fig. C-9. Number of robbery offences compared to pedestrian frequencies on road segments for hotspot areas.

To facilitate an intuitive communication of these findings, the enhanced road network is integrated into the geovirtual environment. While x and y coordinates are used to represent the position of the road segments, z coordinates are used to visualise the number of offences related to the respective segments. The segment colour represents pedestrian frequencies (Figure C-10).
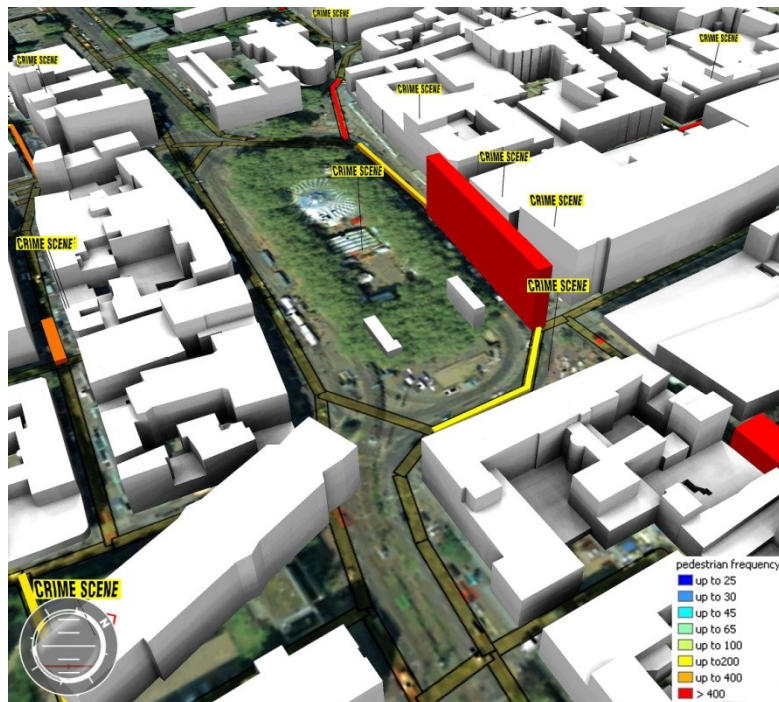
Fig. C-10. Robbery scenes aggregated to nearest road segments. The higher the segments, the more offences are related to it.

A further step of in-depth hotspot analysis is to automatically detect specific spatial characteristics of hotspot regions. Analysing the quantity and distribution of urban features inside the hotspots helps an analyst to explain why precisely robbery scenes tend to cluster in those specific areas. The dataset representing the position of specific facilities (cf. Tables C-1 to C-3) is used for analysis. GIS methods are applied to identify precisely the facility located nearest to each individual robbery scene. Subsequently, separate tables are generated for each of the three hotspot regions. These tables list summarised frequencies for those facilities identified as being the nearest one to a robbery scene inside the particular hotspot area (cf. Table C-4 to C-6). In hotspot region number one for instance, a restaurant is identified 57 times as being the nearest facility to a robbery scene (therefore restaurants are depicted as rank no. 1). For another 13 robberies, a stop of public transport is identified as being the nearest facility (therefore rank no. 2). The tables also list minimum and average distances. Regarding the 57 robberies in which a restaurant is being identified as the nearest facility, e.g., the shortest distance is calculated as being 6.1 metres away from a crime scene, while they are on average located 24.6 meters away.

The overall number of facilities identified as to be the nearest one to a particular robbery scene depends on the absolute frequency of this facility in the particular hotspot region. Table C-4 shows, for instance, that 94 restaurants are counted in hotspot region one (hence, restaurants depict "rank freq. absolute" = 1). This qualifies the high frequency of restaurants identified as to be the closest facility to robbery scenes. From this, a ratio is calculated (57/94 = 0.61). Considering this ratio, parking places and public transport stops become more relevant than restaurants: although only seven parking places are registered in hotspot region one, a parking place is identified seven times as being the nearest facility to a robbery scene (cf. Table C-4 to C-6).

Table C-4. Facilities identified as to be the closest to a robbery scene in hotspot area one

Facility	Absolute freq. of facility in hotspot area	Rank freq. abs.	Freq. facility being nearest to robbery scene	Ratio freq. closest/ absolute	Minimum dist. to nearest scene	Average dist. to nearest scene
restaurant, diner	94	1	57	0.61	6.1	24.6
public trans- port	8	4	13	**1.63**	3.6	10.9
parking place	7	5	7	**1.00**	25.7	36.6
book shop	7	5	5	0.71	11.4	24.2
bank	12	2	4	0.33	21.4	24.6
club	9	3	3	0.33	10.5	27.6
pharmacy	7	5	2	0.29	25.1	26.6
supermarket	4	6	1	0.25	19.6	19.6
hotel	7	5	0	0.00	-	-
theatre, cabaret	3	7	0	0.00	-	-
cinema	2	8	0	0.00	-	-
sight	1	9	0	0.00	-	-
school	1	9	0	0.00	-	-
consulate	1	9	0	0.00	-	-
church	1	9	0	0.00	-	-
shopping centre	1	9	0	0.00	-	-

Table C-5. Facilities identified as to be the closest to a robbery scene in hotspot area two

facility	Absolute freq. of facility in hotspot area	Rank freq. abs.	Freq. facility being nearest to robbery scene	Ratio freq. closest/ absolute	Minimum dist. to nearest scene	Average dist. to nearest scene
restaurant, diner	151	1	74	0.49	1.6	33.0
public transport	21	5	61	**2.90**	1.5	36.8
parking place	24	3	26	**1.08**	5.5	43.4
hotel	46	2	25	0.54	4.8	39.0
museum	12	8	21	**1.75**	7.6	22.7
pharmacy	14	7	7	0.50	3.0	26.2
supermarket	5	13	6	**1.20**	9.4	19.5
shopping centre	6	12	5	0.83	2.8	2.8
church	10	9	5	0.50	31.1	45.2
theatre, cabaret	7	11	5	0.71	59.9	60.6
sight	16	6	3	0.19	28.1	53.1
bank	23	4	2	0.09	12.6	18.3
stage, arena	3	14	2	0.67	39.8	46.9
school	1	16	2	**2.00**	10.5	10.5
book shop	9	10	1	0.11	16.8	16.8
indoor swimming pool	2	15	1	0.50	17.6	17.6
car dealership	3	14	0	0.00	-	-
club	3	14	0	0.00	-	-
railroad station	2	15	0	0.00	-	-
bus terminal	1	16	0	0.00	-	-
tourist information	1	16	0	0.00	-	-
consulate	1	16	0	0.00	-	-
post	1	16	0	0.00	-	-
town-hall	1	16	0	0.00	-	-
petrol station	1	16	0	0.00	-	-

Table C-6. Facilities identified as to be the closest to a robbery scene in hotspot area three

facility	Absolute freq. of facility in hotspot area	Rank freq. abs.	Freq. facility being nearest to robbery scene	Ratio freq. closest/ absolute	Minimum dist. to nearest scene	Average dist. to nearest scene
public transport	5	3	19	**3.80**	23.9	55.8
bank	7	1	11	**1.57**	20.0	78.5
restaurant, diner	6	2	6	**1.00**	20.1	54.5
pharmacy	5	3	5	**1.00**	13.5	37.0
supermarket	6	2	3	0.50	13.2	35.9
book shop	3	4	2	0.67	67.6	91.4
hotel	2	5	2	**1.00**	103.8	130.0
stage, arena	1	6	1	**1.00**	96.9	96.9
parking place	1	6	1	**1.00**	150.9	150.9
police department	1	6	1	**1.00**	121.2	121.2
car dealership	5	3	0	0.00	-	-
shopping centre	1	6	0	0.00	-	-
theatre, cabaret	1	6	0	0.00	-	-

This method allows even a non-local analyst to prepare overall characterisations of confined hotspot areas. However, this analysis depends on the amount and quality of data representing the particular urban facilities. The more the geocoded facilities, the more reliable the analysis is. Further analysis, such as an explanation of why precisely many robberies in hotspot area number three are committed close to public transport stops, cannot be conducted here. This would require more detailed information on offenders and victims, respectively. Criminological interpretation of specific analysis findings is left to the respective experts. The findings presented here depict a basis for further analysis in the corresponding police departments.

C 3 Conclusion

This paper presents an approach for exploring robbery hotspots by coupling in-depth geospatial crime scene analysis with 3D mapping methods. For this purpose, the spatial distribution of robbery scenes is analysed in a first step. This results in density grids. These grids are used in a next step to identify hotspot areas by extracting vector-based boundaries. Based on these boundaries, in-depth-analysis of hotspot areas is conducted. Further methods of geoinformation science are applied to characterise these regions by analysing the distribution of specific urban facilities and by correlating pedestrian frequencies with robbery offences. However, temporal analysis has not been included in the analysis so far. Therefore, the presented approach should be expanded by including spatio-temporal problems in further analysis.

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D Geovisualisation Approaches for Spatio-Temporal Crime Scene Analysis – Towards 4D Crime Mapping[*]

Abstract. This paper presents a set of methods and techniques for analysis and multidimensional visualisation of crime scenes in a German city. As a first step, the approach applies spatio-temporal analysis of crime scenes. Against this background, a GIS-based application is developed which facilitates discovering basic trends in spatio-temporal crime scene distributions for a GIS-untrained user. Based on these results, further spatio-temporal analysis is conducted in order to detect variations of specific hotspots in space and time. These findings of crime scene analysis are integrated into a geovirtual environment. The concept of the space-time cube is adopted in order to analyse and visualize spatio-temporal robbery scene distributions. Using the example of repeat burglary victimisation, further analysis- and visualisation strategies are demonstrated. Since this analysis requires incorporating temporal elements into virtual 3D environments, basic methods for 4D crime scene visualisation are outlined in this paper.

Keywords: 3D crime mapping, geovirtual environments, GIS, spatio-temporal

D 1 Introduction

In contrast to traditional crime mapping analysis, which predominantly results in two-dimensional static maps, the presented approach allows for creating interactive four-dimensional map applications. The paper focuses on combining methods of geospatial crime scene analysis with innovative spatio-temporal (4D) geovisualisation techniques. As this concept links digital processing and geospatial analysis of crime data with easy-to-comprehend 3D and 4D visualisations respectively, the GIS (geographic information system) and VIS (visualisation system) tasks are combined in a specific workflow designed for that purpose.

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[*] Wolff, M. & H. Asche (2009). Geovisualisation Approaches for Spatio-Temporal Crime Scene Analysis - Towards 4D Crime Mapping. In Gerads, Z. J. M. H., Franke, K. Y. & C. J. Veenman, eds, 3rd International Workshop on Computational Forensics - IWCF 2009. The Hague/Netherlands, 13-14 Aug 2009. Springer Lecture Notes in Computer Science (LNCS), Volume 5718. Berlin-Heidelberg. pp. 78-89.

After a short review of relevant work (Section D 2), brief spatio-temporal exploration of crime scene data is conducted (Section D 3.1). For that purpose a GIS-based application is programmed that focuses on straightforward spatio-temporal crime scene exploration. To make this application as easily operable as possible, the tool is designed as a standalone application using ESRI's ArcGIS Engine development framework. Since its functionality focuses on brief exploration of temporal and spatial trends in crime scene distributions, the user does neither have to be familiar with ArcGIS nor with any other GIS.

The findings of this analysis facilitate further in-depth analysis (Section D 3.2). Identified hotspots of specific crimes are analysed in more detail regarding their variation in space and time. A method is presented to visualise repeat residential burglary victimisation. Another method visualises temporal patterns of robbery offences by applying 4D visualisation techniques. To generate advanced visualisations, analysis results are pipelined to a sophisticated 3D visualisation system (Autodesk LandXplorer Studio Professional). Depending on the analysis, this system is used to design distinct 3D and 4D visualisations.

D 2 Related work

This section provides a brief overview of existing studies in the disciplines of crime mapping and 3D geovisualisation.

D 2.1 Crime Mapping

Among the various publications addressing crime mapping applications in theory and practical application [1] give an introduction into theories, methods and selected software systems used to document, monitor and analyse crime data. Because most crime analyses are based on geocoded crime scene data, precise geocoding is a major prerequisite for spatial analysis. Reference [2] reviews this topic of spatial data (in-) accuracy. However, dealing with geospatial crime scene data, an eminent task is to detect and map spatial hotspots of specific offences. According to [3] cited in [4], a hotspot is defined as an "area with high crime intensity". In addition to [1], an introduction into the different approaches of detecting and mapping hotspots can be found in [5]. With "prospective hotspot mapping", a different approach is introduced by [6]. However, areas with higher crime rates than other areas should be tested statistically. Reference [7] provides insights addressing issues of statistical test and functions. Reference [8] gives both an overview of existing studies in the field of spatio-temporal crime mapping and applicable methods and techniques for visualising space and time related issues in crime patterns.

D 2.2 3D Geovisualisation

Key themes and issues of geovisualisation are presented by [9]. Based on their conceptual framework [10] discuss a research agenda on cognitive and usability issues in geovisualisation. Adapting techniques of information visualisation to the requirements of cartography, [11] highlights that modern geovisualisation helps "stimulat[ing] visual thinking about geospatial patterns, relationships and trends". The author furthermore emphasises the advantage of creating three-dimensional visualisations that allow for an "additional variable to be displayed in a single view and, as such, gives the user a direct insight into the relationship between these variables". Reference [12] argues that the user can easily interpret spatial relationships of three-dimensional presented geo-objects without having to consult a legend. Reference [13] highlights the fact that three-dimensional cartographic visualisations provide "a more intuitive acquisition of space, due to an explicit use of 3D". Both [12] and [13] also indicate disadvantages concerning three-dimensional visualisations, such as for instance the absence of a single scale in perspective views, occlusion of objects, etc. However, construction of virtual three-dimensional geovirtual environments requires dedicated software systems. The adopted LandXplorer software is an appropriate system for visualising interactive three-dimensional maps and is introduced by [14] [15].

D 3 Using geovirtual environments for visualising spatio-temporal analysis findings

This section describes the application of the research framework by using crime scene data registered in the German city of Cologne. Data representing robberies and residential burglaries during the year 2007 is provided by the police headquarters of the city of Cologne. Each crime scene is described as a single point object, geocoded by x and y coordinates. In addition to these coordinates, each point has further thematic attributes. First of all, crime scenes are analysed regarding their overall patterns of distributions in space and time (Section D 3.1). Based on these findings, further in-depth analysis is conducted (Section D 3.2). All results of spatio-temporal analysis are pipelined to a 3D visualisation system. This leads to 3D and 4D visualisation. This combination of spatio-temporal crime scene analysis with methods from the field of 3D/4D geovisualisation facilitates an instant grasp of complex spatial phenomena and relationships, primarily for decision makers in security agencies untrained in the reading and interpretation of maps.

D 3.1 Exploring spatio-temporal characteristics

Prior to in-depth analysis of specific crime hotspots, the first step of analysis comprises the identification of overall spatio-temporal trends in crime scene datasets. An application is programmed allowing untrained GIS users as well as GIS experts to explore fundamental spatio-temporal trends in crime data. Using the ESRI ArcGIS Engine software development framework, this application is developed as a standalone application (.exe). ArcGIS Engine is

used for software development since this allows for an easy integration of (Arc-)GIS functions into custom applications via ArcObjects programming. However, since proprietary ArcGIS functionality is addressed, the end user needs the ESRI ArcGIS Engine runtime library or a licensed ArcGIS to be installed on the local machine. Besides loading and viewing of geospatial crime scene datasets, the application basically allows for two kinds of spatio-temporal analysis (cf. Figure D-1):

- Generation of charts depicting the number of offences during a specified period.
- Hotspot analysis by computing kernel-density-estimation (KDE) based surfaces of crime scene densities for specified periods.
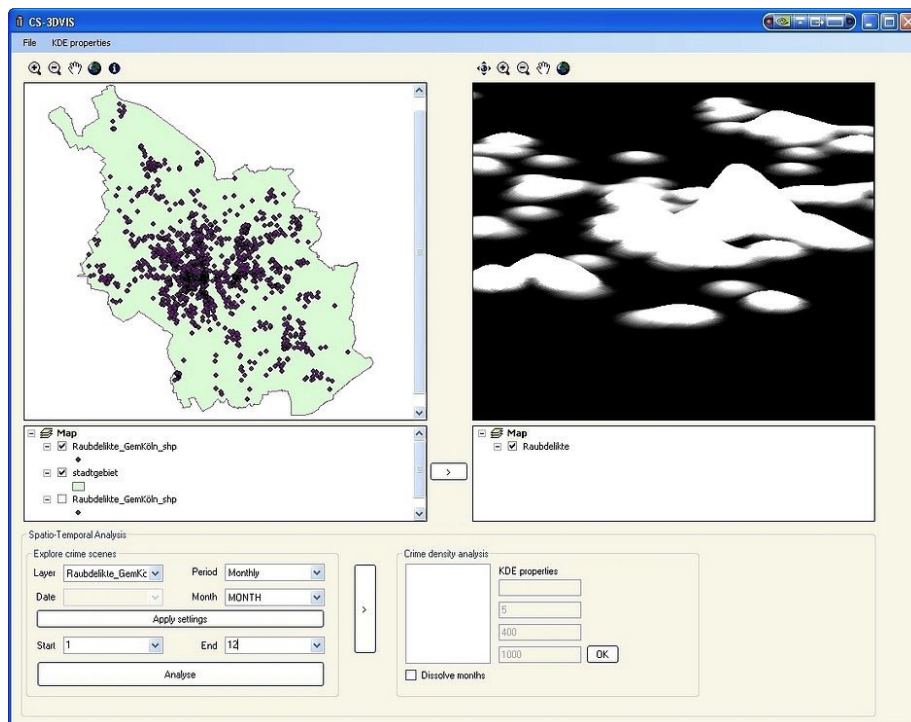
Fig. D-1. GUI of programmed GIS application providing spatio-temporal data exploration. The left-hand window displays 2D map features, the right-hand window displays hotspot grids as three-dimensional surfaces.

The process of analysis presented in this paper begins with conducting overview analysis of general temporal distributions of specific crimes (residential burglaries and robberies). In a first step, the monthly sums of robberies and burglaries, respectively, are calculated using the application's temporal query functions (Figure D-2).
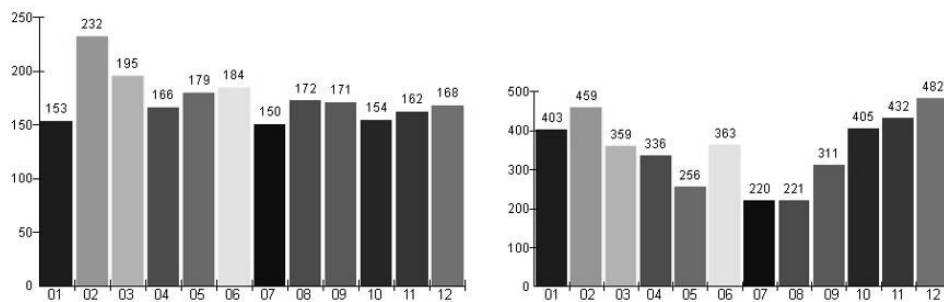
Fig. D-2. Frequencies of robbery (left-hand figure) and residential burglary crimes (right-hand figure) in 2007.

As Figure D-2 shows, most robberies in 2007 occurred during February (232 offences, left-hand image), while most residential burglaries are committed in December (482 offences, right-hand image). Against this background, further analysis is conducted to examine these two months more detailed. Temporal resolution for analysis is increased by using the application's option "daily" for data exploration. This analysis reveals that most robberies which took place in February are conducted on Feb. 15th, which was Women's Carnival, the start of Cologne Carnival. Most residential burglaries in December on the other hand were committed on December 31st – New Year's Eve (cf. Figure D-3).
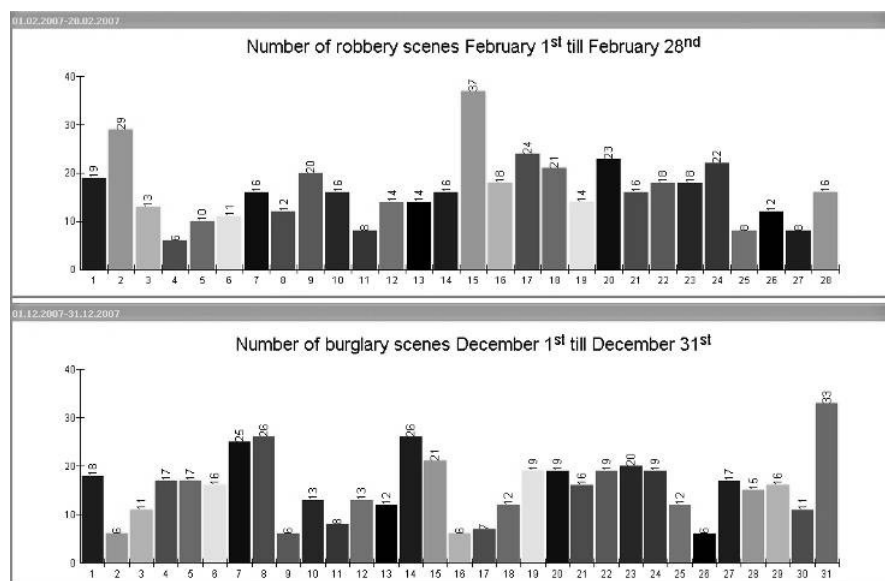
Fig. D-3. Daily frequencies of robbery (upper figure) and residential burglary crimes (lower figure) in February and December 2007.

Knowing these basic trends of temporal distributions during the year 2007, a second step of data exploration implies the identification of spatial crime scene distributions. For this purpose, the application's KDE module is used. To allow for further temporal analysis of KDE surfaces, the application supports the calculation of KDE surfaces for specified periods. KDE surfaces can be created, for instance, on the basis of single years, of individual months or on a daily basis. By using kernel density estimation techniques for hotspot analysis, the discrete point distribution of crime scenes is transformed into a continuous surface of crime

scene densities [16] [17] [18]. Based on the selected crime scene dataset, the implemented KDE module computes a grid in which cell values represent density values related to a specific surface measure (for instance the number of offences per square kilometre). Density values for each cell are calculated depending on the implemented kernel density function [16]. Since the application is based on ArcGIS functionality, the implemented KDE routine is based on the ArcGIS quadratic kernel density function. To conduct KDE analysis, the user has to specify the bandwidth and the output cell size for the KDE grid. Specification of bandwidth is crucial since this parameter describes the size of the search radius, i.e. how many crime scene locations (points) are used to calculate crime scene densities. To allow for convenient bandwidth-experimentation, the implemented KDE module supports multiple bandwidth specifications. To create, for instance, multiple KDE surfaces with bandwidths of 50, 100, 150, 200, 250, 300, 350 and 400 meter, the user may enter these different values separated by a semicolon into the corresponding bandwidth-specification field. Afterwards (visual) analysis of the created grids helps to identify the appropriate bandwidth setting.

By using the KDE module (bandwidth = 400 m, cell size = 20m), a single grid of robbery scene densities is calculated for the year 2007. These grids are post processed, pipelined to the 3D VIS LandXplorer and combined with other geocoded textures (as for instance with an aerial photography or a topographic map, cf. Figure D-4).

Fig. D-4. 3D representation of a robbery hotspot surface for the year 2007.

Because Figure D-2 reveals temporal variations of robbery offences during the year, monthly distributions of crime scenes are analysed in a next step. For this purpose, 12 individual hotspot grids are computed for each month. The analysis reveals that robbery hotspots in the city of Cologne vary clearly in time and space. Characteristic hotspots, for instance, are identified in February and August (Cologne Carnival and summer holidays, respectively).

In addition to robberies, residential burglary crime scenes are also analysed for spatial clustering by conducting KDE analysis. Unlike parameterisation for robbery analysis, KDE bandwidth for burglaries is specified with 800 meters. Figure D-5 depicts the 3D hotspot surface for residential burglary crime scenes.

Fig. D-5. 3D representation of a residential burglary hotspot surface for the year 2007.

D 3.2   Methods of 4D spatio-temporal crime scene visualisation

In the previous section, methods for discovering general trends in the spatio-temporal distribution of crime scenes were presented as well as selected 3D visualisation methods. This section describes additional techniques for further time related analysis and 3D/4D visualisation, respectively. Since previous analysis revealed February 15th as the day with the highest number of robberies in 2007, further in depth-analysis is applied to this specific date. For this purpose, the resolution of temporal analysis is increased. For further analysis the offence's time of day is used.

Regarding high-resolution spatio-temporal analysis, the concept of the space-time cube is applied. In 1970 Hägerstrand introduced his fundamental concept of the so-called space-time cube [19], which was adopted in a number of studies and applications (e.g. [20] [21]). Taking this concept into account, the chronology of robberies is visualised by using 4D geo-visualisation techniques. Taking the offences' time of day as additional information, the

vertical axis of the environment is used for representing time (cf. Figure D-6). The figure depicts two issues: the spatial distribution of robberies during February 15th (visualised by poles) and the temporal chronology of robberies, also referred to as space-time paths (visualised as coloured line segments that connect the robberies). The greater the z values (the higher the line is above ground), the later on February 15th the offence occurred. The longer the space-time paths, the more time elapsed between two robberies.
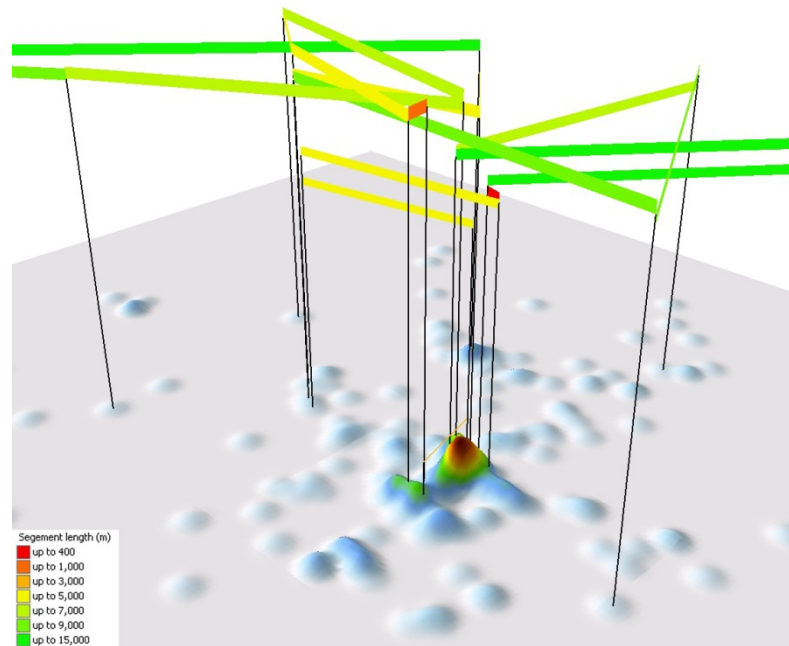
Fig. D-6. Representation of space-time paths for robberies on Feb. 15th in the city of Cologne.

This kind of visualisation facilitates interactive exploration of complex temporal issues in geospatial crime scene analysis. It provides information about possible connections be-tween specific offences. A short line segment between two offences, for example, may point to a possible link between these robberies (Figure D-6 shows two short segments in red colour). Since such offences are situated closely together in time and space they may be committed by the same offender. However, this hypothesis has to be verified by taking further offence-related information into account. For detailed geoprofiling, additional po-lice information is necessary.

Further potential for applying the space-time related issues bears the visualisation of re-peat victimisation. According to [22], repeat victimisation is defined as "where the same offence occurs a number of times against the same victim (be this a person or an entity like a house)". However, [23] cited in [24] emphasise that repeats can also be "unconnected" with the initial occurrence. According to [23], an additional specification for the definition above is "connection", i.e. if two burglaries, for instance, are not only committed in the same building but also with the same modus operandi employed [23].

Since this definition contains

- spatial (where does the offence occur?)
- temporal (when and how many times?) and
- thematic (which modus operandi?)

phenomena, the design of an intuitive visualisation is challenging. To visualise this issue, an extensive geovirtual environment for the city of Cologne is created. According to [25] cited in [26], geovirtual environments (GeoVE) are defined as to be particularly immersive, information intense, interactive and intelligent. This GeoVE consists of a digital terrain model, a 3D city model, high resolution aerial photography (25 cm/pixel), a digital cadastral map and further vector-based datasets including rivers, administrative boundaries and others. Figure D-7 shows the GeoVE including an aerial photography, a 3D city model and the position of crime scenes (burglaries in 2007).

Fig. D-7. 3D GeoVE with 3D city model, aerial photography and crime scenes.

To allow for visual analysis of repeat residential burglary victimisation, time related information is integrated into the geovirtual environment. Figure D-5 shows two fundamental hotspots of residential burglary (one located eastern, the other south-eastern of Cologne city centre). For further geovisual analysis, the burglary scenes in the south-eastern hotspot are used. Time and modus operandi are subject for analysis and visualisation (cf. Figure D-8).

Each symbol in Figure D-8 represents a single residential burglary in the city of Cologne. A pole points to the burgled 3D building. The applied modus operandi is illustrated by a symbol representing the registered modus operandi, with the possibilities of "front door", "terrace door", "French window", "window" and "not registered". These symbols are stacked vertically according to the working day the burglary is committed. The symbol at the lower end of the pole represents a burglary committed on a Monday, the second lowest represents a Tuesday and so on, while the symbol on the top of the pole represents a burglary committed on a Sunday. To alleviate readability and comparability of different stacks, an optional layer (cf. the dark blue transparent layer in Figure D-8) marks the temporal "basement" (i.e., a Monday).
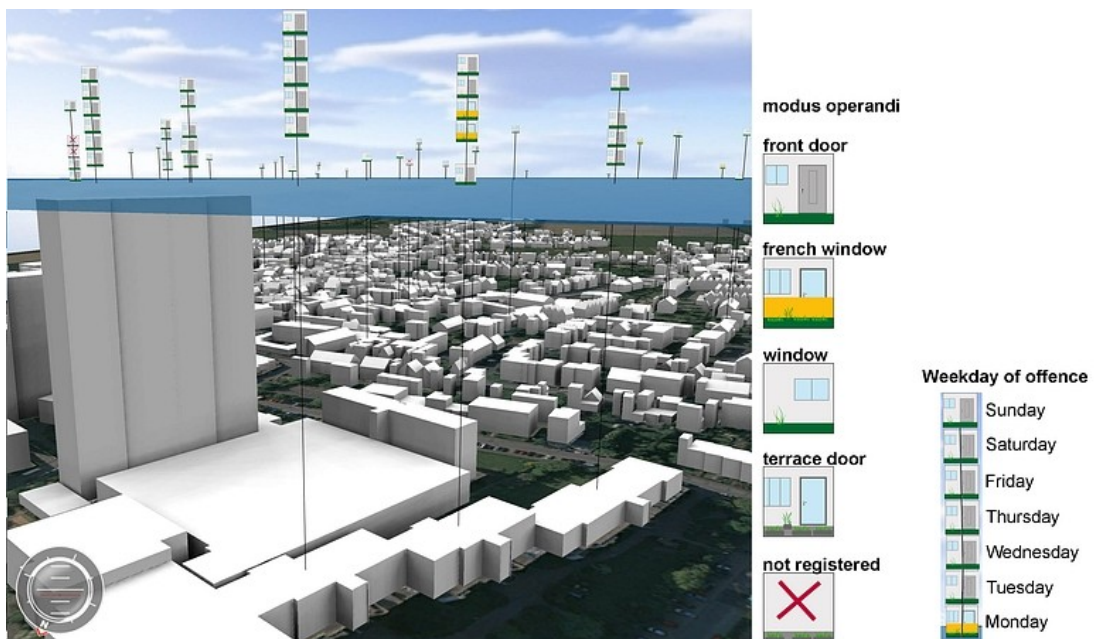
Fig. D-8. Repeat residential burglary victimisation and applied modus operandi visualised with a geovirtual environment. Temporal dimension is visualised by on the z axis by classifying burglary scenes regarding its weekday of perpetration.

Using this interactive visualisation, a crime analyst can explore three entities simultaneously: 1st the spatial distribution of burglary offences in the study area, 2nd the temporal resolution and 3rd the employed modus operandi. The combined visual analysis of these elements allows for a convenient evaluation of repeat victimisation. Although the figures are presented as static screenshot images, it has to be emphasised that the environment is completely interactive.

D 4 Conclusion

This paper presents a set of methods for combining geospatial crime scene analysis techniques with the multidimensional visualisation potential of geovirtual environments. The methods focus on the one hand on spatio-temporal data analysis, while facilitating intuitive

visualisation of complex spatio-temporal issues on the other hand. A GIS-based application allows GIS-untrained analysts the basic exploration of spatio-temporal features of geo-coded crime scenes. Subsequent to this analysis, hotspots and their variations in space and time are analysed. The results are pipelined to a 3D visualisation system. The issue of re-peat burglary victimisation is analysed exemplarily to illustrate the potential of geovirtual environments for the multidimensional representation of complex situation analysis.

Acknowledgements

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3

Results and discussion

Within this chapter the four scientific papers[7] as well as their major research objectives are discussed. Each research paper includes several related major research objectives (cf. Figure 3-1).

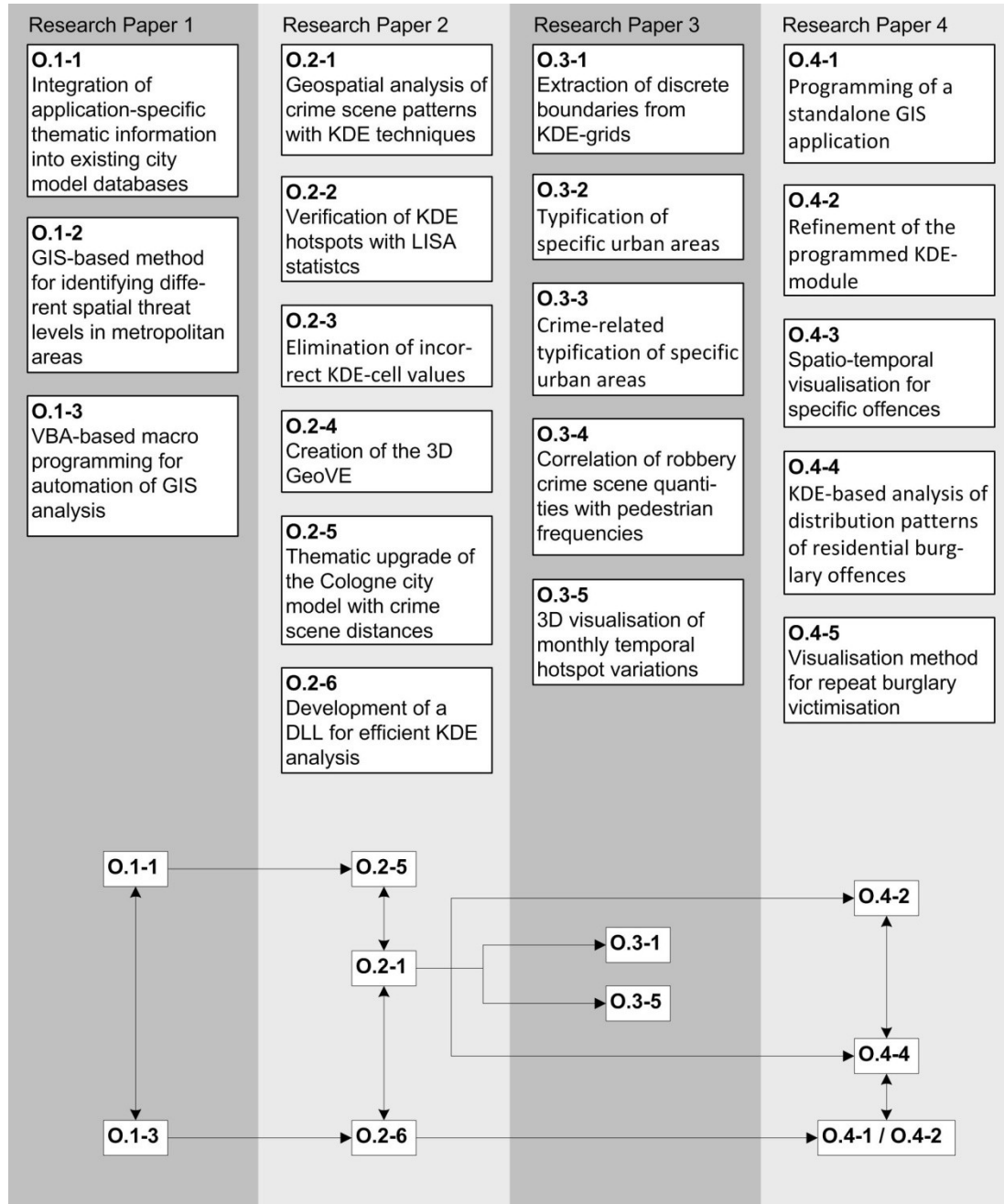| Research Paper 1	Research Paper 2	Research Paper 3	Research Paper 4
O.1-1 Integration of application-specific thematic information into existing city model databases	**O.2-1** Geospatial analysis of crime scene patterns with KDE techniques	**O.3-1** Extraction of discrete boundaries from KDE-grids	**O.4-1** Programming of a standalone GIS application
O.1-2 GIS-based method for identifying different spatial threat levels in metropolitan areas	**O.2-2** Verification of KDE hotspots with LISA statistcs	**O.3-2** Typification of specific urban areas	**O.4-2** Refinement of the programmed KDE-module
O.1-3 VBA-based macro programming for automation of GIS analysis	**O.2-3** Elimination of incorrect KDE-cell values	**O.3-3** Crime-related typification of specific urban areas	**O.4-3** Spatio-temporal visualisation for specific offences
	O.2-4 Creation of the 3D GeoVE	**O.3-4** Correlation of robbery crime scene quantities with pedestrian frequencies	**O.4-4** KDE-based analysis of distribution patterns of residential burglary offences
	O.2-5 Thematic upgrade of the Cologne city model with crime scene distances	**O.3-5** 3D visualisation of monthly temporal hotspot variations	**O.4-5** Visualisation method for repeat burglary victimisation
	O.2-6 Development of a DLL for efficient KDE analysis		

Fig. 3-1. Papers and major research objectives. The lower part of the figure shows how major research objectives are connected to several other objectives.

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[7] All research work in the papers presented was carried out by the author of this thesis.

3.1   Discussion of Research Paper 1

Wolff, M. & H. Asche (2008). Geospatial Modelling of Urban Security: A novel approach with Virtual 3D City Models. In Gervasi, O., Murgante, B., Laganà, A., Taniar, D., Mun, Y. & M. L. Gavrilova, eds., Computational Science and Its Applications – ICCSA 2008, Springer Lecture Notes in Computer Science (LNCS): Volume 5072. Berlin-Heidelberg. pp. 42-51.

In the first paper methods and techniques are discussed to integrate specific civil-security related information into existing city model databases. Apart from representing the geometry of buildings, 3D city models are applied to visualise specific information that is subsequently used for visualisation or analysis purpose. To emphasise the potential of enhanced city models for mapping and analysing different levels of potential threat, distinct methods of GIScience are applied.

Objectives

This paper deals with the overall topic of analysing and visualising different levels of potential threats in metropolitan areas. For the investigation this topic has been subdivided into the following objectives.

Objective O.1-1: Integration of application-specific thematic information into the database of existing city models by applying different methods of GIS-based analysis. The database of the Berlin city model is enhanced with pedestrian-frequency information and socio-demographic data.

Objective O.1-2: Development of a GIS-based method to identify different spatial threat levels in a metropolitan area. Based on building occupancies the Berlin 3D city model is used to determine individual exposure grids. A virtual threat surface is calculated by combining these grids. The resulting surface serves as an easy-to-read visualisation of geospatial threat distributions in a metropolitan area.

Objective O.1-3: Automation of GIS analysis. Using ESRI's ArcObjects a GIS-based tool is developed that enables an automated processing of the single exposure grids and their reclassifications according to specific exposure values.

Discussion

This research work presents a method to model and analyse urban security issues by using virtual 3D city models. 3D city models are particularly suitable for geovisual analysis tasks in the field of civil security as they facilitate analysis and graphic presentation of complex geospatial phenomena. To allow for specific analysis on the basis of 3D city models the semantic content of these models has to be thematically augmented (objective O.1-1). A method is conceptualised and implemented to enhance the Berlin city model database with specific information that makes further (in this case security-related) analysis possible: to represent

urban activity flows and patterns, respectively, frequency values of pedestrian flows are integrated into the geovirtual city model. This enables, e.g., querying specific buildings according to the number of pedestrians frequenting this building. To improve the building dataset with this information, road segments are updated with frequency information. This information is transferred to the adjacent buildings. By integrating the enhanced road segments into the geovirtual environment, activity flows are visualised on the basis of the street network. Combined with the 3D city model this allows for an identification of urban districts that are characterised by high (by low) activity flows.

To perform further civil security analysis, such as, urban vulnerability assessments, additional socio-demographic data is integrated into the city model. A GIS-based method is developed to identify different spatial threat levels on the basis of a city model (objective O.1-2). Knowledge of population patterns (as well as knowledge of, e.g., household sizes, household net income, building structure, building use and purchasing power) facilitates further estimations of urban risks exposure. To achieve this objective, a workflow is developed to create a combined 3D threat surface representing different geospatial exposure levels (cf. Figure A-6, p. 28). This surface results from specific hypotheses and is therefore characterised as a hypothetical threat surface (particular building occupancies are assigned specific threat levels and specific exposure levels are assigned to individually defined building distances). For a flexible calculation of combined threat-surfaces, a GIS plug-in is programmed to facilitate the calculation of the respective exposure-grids for untrained GIS users (objective O.1-3). This plug-in specifies individual building occupancies as well as different distance values and exposure levels, respectively. The plug-in customises the process of calculating different threat surfaces and facilitates the creation of both well-founded threat-surfaces and educated guess calculations. Such a tentatively derived threat surface can be combined with a second surface resulting from further geostatistical analyses. Specific methods to calculate such surfaces are described in the following section.

In summary the GIS-based methods, workflows and automations presented allow for a thematic enhancement of city models and geovirtual environments. Updated models and environments serve as a valuable instrument to communicate specific building-related geospatial information not only in civil security-related fields but also in further GIScience-related fields (e.g. in urban planning). The methods and techniques used are applicable to every digital city model. With respect to the development of 3D tactical intelligence assessments, the presented methods and techniques simplify the preparation, processing and enhancement of three-dimensional city models and geovirtual environments for applications in a civil security-related context.

3.2   Discussion of Research Paper 2

Wolff, M. & H. Asche (2009). Towards geovisual analysis of crime scenes – A 3D crime mapping approach. In Sester, M., Bernard, L. & V. Paelke, eds., Advances in GISciences. Proc. 12th AGILE Conference. Hannover/Germany, 2-5 Jun 2009. Springer Lecture Notes in Geoinformation and Cartography (LNGC): Berlin. pp. 429-448.

The second paper discusses methods of creating geovirtual three-dimensional intelligence assessments for use in geospatial crime scene analysis. It outlines related research work and presents methods to couple techniques of geospatial crime scene analysis with 3D geovisualisation approaches. The paper comprises fundamental methods for applying geovirtual environments to communicate complex crime-mapping related phenomena.

Objectives

This paper deals with the overall topic of coupling geospatial crime scene analysis with 3D geovisualisation techniques. For the investigation this topic has been subdivided into the following objectives.

Objective O.2-1: GIS-based analysis of crime scene patterns. Spatial characteristics of robbery crime distributions are analysed by using geostatistical methods of kernel density estimation techniques (KDE). Point-based information is transformed into geostatistical surfaces which represent areal density values of specific crime scenes (hotspots).

Objective O.2-2: Providing further geostatistical reliability of identified hotspots. LISA statistics are applied to prove the existence of particular KDE hotspots. Using LISA statistics with ArcGIS results in a z score added as a new database entry to each crime scene location. By classifying these z scores, significance levels are visualised.

Objective O.2-3: Elimination of incorrect KDE cell values. Using KDE functions to create continuous surfaces of crime scene densities can produce grid cells with density values greater zero where actually no crime takes place (e.g. no residential burglaries in the river Rhine).

Objective O.2-4: Set up an extensive three-dimensional geovirtual environment of the study area. Different raster- and vector-based information is processed, projected, merged and integrated to represent the study area three-dimensionally. This 3D environment serves as an integration platform for geodata and analysis findings. Geospatial crime scene analysis results are integrated into this environment for presentation and communication purposes.

Objective O.2-5: Assignment of crime scene minimum distance values to individual buildings of a LOD2 city model. This allows for further building-related analysis. As the city model is used to communicate particular semantic information this objective is in relationship with objective O.1-1 (integration of application-specific thematic information into the database of existing city models). To augment the city model with crime scene distance values, the

respective minimum distance to the nearest robbery crime scene is calculated for each individual building and added as a new entry into the city model database. The set of buildings is classified according to these distance values.

Objective O.2-6: Programming of a dynamic link library (DLL) and customisation of some of the applied methods. The DLL provides an increased usability for calculating KDE raster with different bandwith/cellsize-parameter combinations.

Discussion

This paper discusses the fundamental scientific motivation and the methodical framework for combining geospatial crime scene analysis with 3D geovisualisation methods. The paper lays the foundation for communicating the findings of geospatial crime scene analysis by using interactive three-dimensional geovirtual environments (GeoVEs). This encourages an accelerated decision-making progress – particularly for decision makers who may be untrained in reading complex maps. The developed method allows for geospatial processing and visual analysis of crime scenes by linking the GIS and VIS tasks (cf. Figure B-1, p. 34). This method elaborates on the benefits of integrating particular upgraded city models into three-dimensional geovirtual environments that are specifically crime-mapping oriented. Basic methods for mapping crime scene distributions are discussed and the advantages of 3D geovisualisation techniques for this specific purpose are elaborated.

To generate a three-dimensional surface of crime scene densities (objectives O.2-1 and O.2-3, respectively) KDE techniques are applied. This 3D surface of robbery crime scene densities is integrated into the GeoVE and overlaid with various geocoded textures (objective O.2-4). This is an effective strategy to visually highlight particular hotspots and to communicate the findings of geospatial analysis to, e.g. decision makers[8]. To substantiate these analyses with statistical significances, LISA statistics are applied. This allows for testing identified KDE hotspots statistically and provides further knowledge on statistical significances.

In addition to density surfaces, 3D city models can be used as a valuable tool to communicate crime scene distributions on a building level. Based on the methods of improving city models with application-specific information (cf. objective O.1-1), each individual building of the Cologne city model is enhanced with the minimum distance value to the respectively nearest crime scene (objective O.2-5). This allows for visually analysing particular buildings and their neighbourhood with regard to nearby crime scene positions and existing hotspot areas, respectively. To provide a flexible calculation of these minimum distance values as well as to support straight-forward calculations of KDE surfaces with different bandwith/cellsize parameter combinations, a second GIS plug-in is programmed (objective O.2-6). Compared to the plug-in already described (objective O.1-3), this one supports the cal-

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[8] To evaluate the usability of the developed interactive intelligence assessments a survey was conducted during a crime mapping symposium. Results are presented in Chapter 4.

culation of minimum crime scene distances to each individual building. The method imple-mented, firstly creates a raster based on Euclidean distances of each crime scene. Secondly, this raster is overlaid with the building footprints. Unlike the plug-in presented before (O.1-3), the DLL is programmed with Visual Basic using the .NET framework. Since the plug-in is compiled to a DLL the source code is not accessible to the user. These functions can be fur-ther improved by extending the limited KDE methods of ArcGIS. As mentioned before (cf. Section B 1.3), KDE grids are calculated in this work by using the quadratic kernel density function implemented in ArcGIS. This software-based limitations can be overcome, for in-stance, by coupling ArcGIS with the free software environment for statistical computing, R. The GIS plug-in can be updated by this means through referencing the R DCOM server and by gaining access to sophisticated R functionality, such as, different kernel functions for KDE calculations.

In summary, this second paper reviews the current state of scientific research and presents methods for combining geospatial crime scene analysis with 3D geovisualisation tech-niques. The methods presented facilitate specific analysis and allow for creating easy-to-comprehend 3D visualisations of crime scene distributions. According to the hypothesis the presented methods provide the fundamental scientific framework of this thesis. The meth-ods and techniques developed clarify the benefits of integrating upgraded city models into a specific crime mapping oriented context and define the framework for 3D crime-mapping.

3.3   Discussion of Research Paper 3

Wolff, M. & H. Asche (2009). Geospatial crime scene investigation – From hotspot analysis to interactive 3D visualisation. In Gervasi, O., Murgante, B., Laganà, A., Taniar, D., Mun, Y. & M. L. Gavrilova, eds., Computational Science and Its Applications – ICCSA 2009 Yongin. Seoul/Korea, 29 Jun-2 Jul 2009. Springer Lecture Notes in Computer Science (LNCS), Volume 5592. Berlin-Heidelberg. pp. 285-299.

The third research paper extends the scope of the previous paper. It overlaps with the second by starting with an introduction into hotspot identification followed by a brief presentation of the Cologne 3D geovirtual environment. The key concepts of this paper imply further geospatial analysis of identified hotspot areas. To facilitate hotspot identification, a data-based method is presented that supports the extraction of vector-based polygonal boundaries from a KDE grid. These boundaries are used for further analysis, for instance, to characterise the individual hotspot areas by analysing different distribution of particular urban facilities in each hotspot area.

Objectives

This paper deals with the overall topic of characterising identified hotspot areas by conducting geospatial analysis. For the investigation this topic has been subdivided into the following objectives.

Objective O.3-1: Extraction of discrete boundaries from a hotspot KDE grid. This enables data-based identification of particular hotspots and permits further vector-based analysis that distinguishes between hotspot- and non-hotspot areas.

Objective O.3-2: General typification of specific urban areas (hotspot areas). To characterise urban (hotspot, respectively) areas, the distribution of specific urban facilities is analysed for each hotspot area. Position and quantity of, e.g., restaurants, banks, clubs, schools, sights, etc. are exploited to distinguish, for instance, tourism or nightlife districts from residential areas.

Objective O.3-3: Crime-related typification of specific hotspot areas by analysing crime scene distributions within the individual hotspots. For each robbery crime scene registered, urban facilities are identified with GIS methods that are located nearest to the particular scene. This allows for identifying individual buildings with a comparatively high number of nearby crime scenes.

Objective O.3-4: Correlation of pedestrian frequencies with position and number of robbery offences; augmentation of the Cologne road network with pedestrian frequency values (cf. objective O.1-1). For each crime scene the nearest road segment is identified and thematic information of each road segment is updated with the number of offences assigned to that segment.

Objective O.3-5: Visualisation of basic temporal changes of hotspot patterns. Based on the identification of hotspot areas with KDE techniques (cf. objective O.2-1) a set of twelve KDE grids (one grid per month) is calculated and visualised with analogous classification schemes.

Discussion

This paper discusses methods to facilitate in-depth analysis of identified hotspot areas. To detect a hotspot, generally two methods can be applied: firstly, by visually distinguishing areas with high crime scene densities from areas with low crime scene densities, and, secondly, by applying data-based methods. As, e.g., the process of generating vector-based hotspot boundaries can be parameterised and automated, it is advantageous to use a data-based method to identify hotspots. This identification of areas located inside or outside a crime hotspot is primarily relevant for the planning of specific operative measures or for further analysis of these particular areas. In either case discrete boundaries are required. To facilitate data-based hotspot area identification a method is developed that utilises the concept of focal neighbourhood statistics (objective O.3-1): by moving a rectangular filter over the KDE grid, the standard deviation (std) of each pixel to a predefined number of neighbourhood KDE pixel values is calculated. This results in a new grid of KDE standard deviations. By defining a specific standard deviation value a binary grid is generated (values equal to zero: std < threshold value, not a hotspot). This grid provides the basis for deriving polygonal hotspot boundaries. Although the method works well for the main hotspots of the study area, further improvements are possible (e.g. an interactive definition of the threshold value).

Based on these boundaries, further geospatial in-depth analysis of the encircled areas is carried out. Characterising the different hotspots by analysing the distribution of particular urban facilities (objective O.3-2) allows, e.g., non-local analysts to assess the urban character of distinct hotspot areas. Applied to the hotspot grid of the study area, this method reveals different urban functions in each area:

- hotspot number one: a nightlife district

- hotspot number two: an area predominantly characterised by tourism

- hotspot number three: a residential area.

This geospatial characterisation of hotspot areas is further refined by identifying the building occupancy of buildings located closest to a crime scene (objective O.3-3). This analysis reveals, for instance, that only one school is located in hotspot area number two. This school, however, is detected twice as being the nearest facility to a robbery scene. In another case 21 museums are identified in hotspot area number two. 12 times, however, museums are identified as the nearest facility to a robbery scene. In summary, this analysis can refer to specific building occupancies that are frequently identified as being the nearest

building to a crime scene (e.g. in area x many robberies are committed close to the restaurant xyz). At this point the study at hand does not intend to deepen the analysis by trying to identify, e.g., possible root causes of robbery crime in these specific areas. Such analysis would demand more detailed information on offenders and victims, respectively. The present work rather focuses on the application of GIScience-related methods and techniques; the criminological interpretation of specific findings is left to analysts in the respective agencies.

To extend this characterisation of identified hotpot areas, pedestrian frequency information is analysed (objective O.3-4). A method to update road segments with frequency information has already been presented (cf. objective O.1-1). To upgrade the Cologne street network the same method is applied. For analysing robbery crime scene distributions more detailed, knowledge of the amount of people frequenting a specific street is an important asset in crime scene analysis. In this study this information is used to analyse whether a high/low number of pedestrians frequenting a particular street correlates with a high/low number of robbery offences in this area. Referring to the complete street network both hypotheses must be rejected: most robberies in the city of Cologne do not occur close to the most frequented nor the least frequented streets, but to segments frequented by up to 45 pedestrian per hour (cf. Figure C-8, p. 61). The analysis of road segments located inside the hotspots leads to a different result: in the hotspot areas most robberies are committed close to the most frequented road segments (cf. Figure C-9, p. 62). In contrast to the analysis for the whole road network, no statistical significant correlations can be identified here.

Since neither crime scenes nor hotspot areas persist in time, a further objective is to reveal general patterns of hotspot distributions in space and time (objective O.3-5). For this purpose a flash animation is created for the year 2007. This movie sequence is based on twelve hotspot grids, each representing a monthly KDE surface. This animation gives a brief impression of changing hotspot patterns in space and time. The changing peaks of robbery crimes can be recognised clearly. This is a rather simplistic method; more sophisticated methods for analysing and visualising time-related tasks for geospatial crime scene analysis are described in section C 3.4.

In summary, this third paper discusses the identification of hotspot areas with a data-based method. A technique is presented to automate the identification process of hotspot areas by delineating polygonal boundary structures of particular hotspots. Further methods facilitate a geospatial characterisation of hotspots ("geo-portrait") that does not require any geographic knowledge of the particular areas. The generic analysis methods presented can be adopted for any other research area. The paper presents methods and techniques to add specific geospatial intelligence to three-dimensional representations of situation awareness.

3.4   Discussion of Research Paper 4

Wolff, M. & H. Asche (2009). Geovisualisation Approaches for Spatio-Temporal Crime Scene Analysis - Towards 4D Crime Mapping. In Gerads, Z. J. M. H., Franke, K. Y. & C. J. Veenman, eds, 3rd International Workshop on Computational Forensics - IWCF 2009. The Hague/Netherlands, 13-14 Aug 2009. Springer Lecture Notes in Computer Science (LNCS), Volume 5718. Berlin-Heidelberg. pp. 78-89.

The fourth paper discusses methods and techniques for spatio-temporal analysis and visualisation of crime mapping related issues. By using datasets of residential burglary and robbery crimes respectively, GIS-based methods for temporal analysis and multidimensional visualisation are outlined. To permit, e.g., straightforward data exploration for untrained GIS users as well as for GIS professionals, a standalone GIS application is developed. The potential of multidimensional geovirtual environments for representing complex (crime-scene oriented) geospatial analysis is illustrated by the example of repeated burglary victimisation.

Objectives

This paper deals with the overall topic of developing methods for spatio-temporal analysis and visualisation of crime scenes. For the investigation this topic has been subdivided into the following objectives.

Objective O.4-1: Programming of a standalone GIS application that enables analysing general spatio-temporal characteristics of a given set of crime scenes.

Objective O.4-2: Further refinement of the programmed KDE module of objective O.2-6 and integration into the application. This new module does not only facilitate the calculation of different KDE grids with distinct bandwidth/pixel size settings but also allows for creating different temporal KDE grids (monthly and daily analysis, respectively).

Objective O.4-3: Exploration of spatio-temporal characteristics of crime scene distributions. Using the space-time cube concept a method is developed to visualise particular crime scene-based space time paths for individual days.

Objective O.4-4: KDE based analysis of distribution patterns of residential burglary offences.

Objective O.4-5: Analysis of repeat victimisation for a specific hotspot. Repeat victimisation is used as an example to emphasise the potential of multidimensional geovirtual environments to visualise complex geospatial relationships in space and time.

Discussion

This paper discusses methods for spatio-temporal crime scene analysis. By focussing on the temporal dimension of crime scene analysis, complex multidimensional geovisualisations are created to complete the geovirtual representations of intelligence assessments on the one hand and to identify potential future work of 4D geoinformation on the other hand.

To facilitate basic exploration of geospatial crime scene distribution patterns for GIS professionals as well as for non-professionals, a standalone GIS application is developed with the ESRI ArcEngine software development kit. Basic data exploration is provided by a query module that calculates the number of offences per month and day, respectively. Using this temporal query function, different bar charts are automatically generated for different periods and different offences (objective O.4-1). Knowing general temporal distributions patterns, geospatial patterns are analysed. For this purpose the KDE functionality of the DLL-plug-in described earlier (cf. objective O.2-6) is further developed to support the automated calculation of different KDE grids for individually defined periods (objective O.4-2).

To identify spatio-temporal relationships between registered crime scenes, the concept of space-time paths is applied (objective O.4-4). This method identifies crime scenes closely linked in space and time. Spatial distances between two robbery scenes are analysed and visualised as well as temporal distances between two scenes (defined as the time elapsed between two consecutive offences). The spatial dimension is represented by line segments that connect the individual positions of robbery scenes. To represent time, the z axis is used (cf. Figure D-6, p.76). Two robberies whose scenes are connected in geometrical space by a short and almost horizontal aligned line segment (i.e. scenes are closely linked in space and time) may be committed by the same offender. Due to the anonymisation of the crime scene datasets at hand, no further interpretation is possible at this point. Therefore the findings of this method should be related to further offender/victim information. The question whether two or more offences are related to each other (as a part of a serial crime, e.g.) depends on further information. Regarding repeat residential burglary crime for instance, important evidence to discover potential burglary crime series is the applied modus operandi. Objective O.4-5 is to develop a visualisation strategy for representing the applied modus operandi for buildings being repeatedly burgled. This objective tackles the phenomenon of repeat victimisation and utilises the potential of geovirtual environments to visualise this specific issue (what building precisely is being burgled how many times with which modus operandi applied).

In summary, this fourth research paper discusses methods for brief temporal data exploration as well as for visualising specific spatio-temporal related phenomena with respect to crime scene analysis. For this purpose a standalone GIS tool is developed as a further refinement of the plug-ins described earlier. Regarding spatio-temporal analysis advanced visualisation methods are presented. Applying the example of repeat victimisation, a 3D city model is used to represent the precise buildings being repeatedly burgled while a set of

vertically-stacked icons represents day and manner of applied modus operandi. However, further improvements are possible. For instance, a CityGML 3D city model can be used to precisely visualise the building element used for committing the burglary (e.g. window or door, respectively).

4

Evaluating application potential

To evaluate the application potential of the developed methods, a survey was conducted during a GIS and crime mapping symposium held at the Cologne police headquarters in October 2009. Participants of this symposium were police officers, analysts and decision makers using GIS techniques for analysing and visualising crime scene distributions during their day-to-day business. Throughout the investigation presented here a number of interviews were held with both police officers and decision makers. The majority of these persons evaluated the application potential of the three-dimensional tactical intelligence assessments positively. The survey was conducted to verify this. The results of the survey reflect experts' general opinions and trends concerning the application potential of the 3D mapping techniques. 16 participants, all of them crime mapping operators, took part in the standardised interviews via questionnaires[9].

The questionnaire (cf. Appendix) includes questions ranging from general map expertise to individual crime mapping experience and 3D mapping skills in particular. Before the questionnaires were handed out to the participants, the interactive 3D tactical intelligence assessments were presented to the participants in a live-demo.

Figure 4-1 shows that the participants' ages range from 48 to 55 years old. Most of them work in small crime mapping teams of less than three persons and spend more than one hour per workday with crime mapping and have worked for many years in this domain (up to 30 years). The majority of them know how to read maps: only one person stated to have no map reading experience. 10 out of 16 participants have created maps or map-like representations, six had no experience. Knowledge in the field of crime mapping is well-developed: 15 participants apply crime mapping techniques professionally. The majority judged their crime mapping skills as good or excellent, a minority as basic (seven persons). Seven persons "regularly" use thematic maps to visualise the outcome of crime analysis, five "occasionally" and three participants stated they had never created a map or a map-like representation so far.

In summary maps are created regularly by those participants who assessed themselves as having good and excellent knowledge of crime mapping techniques. Participants, in contrast, who quoted their crime mapping knowledge as basic, predominantly create maps occasionally (cf. Table 4-1). Altogether, a sound competence of map creation and a high competence of crime mapping can be accredited to the participants.

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[9] As mentioned earlier, this work focuses on the application of GIScience-related methods and techniques; the work does not originate in social sciences. Therefore the issue of representativeness is not discussed here in detail. Besides, it would be difficult to specify a binding threshold value for a representative sample in this specific case: is it 500 policemen, is it 500 analysts, is it 500 policewomen or is it 10 to 20 analysts and officers?
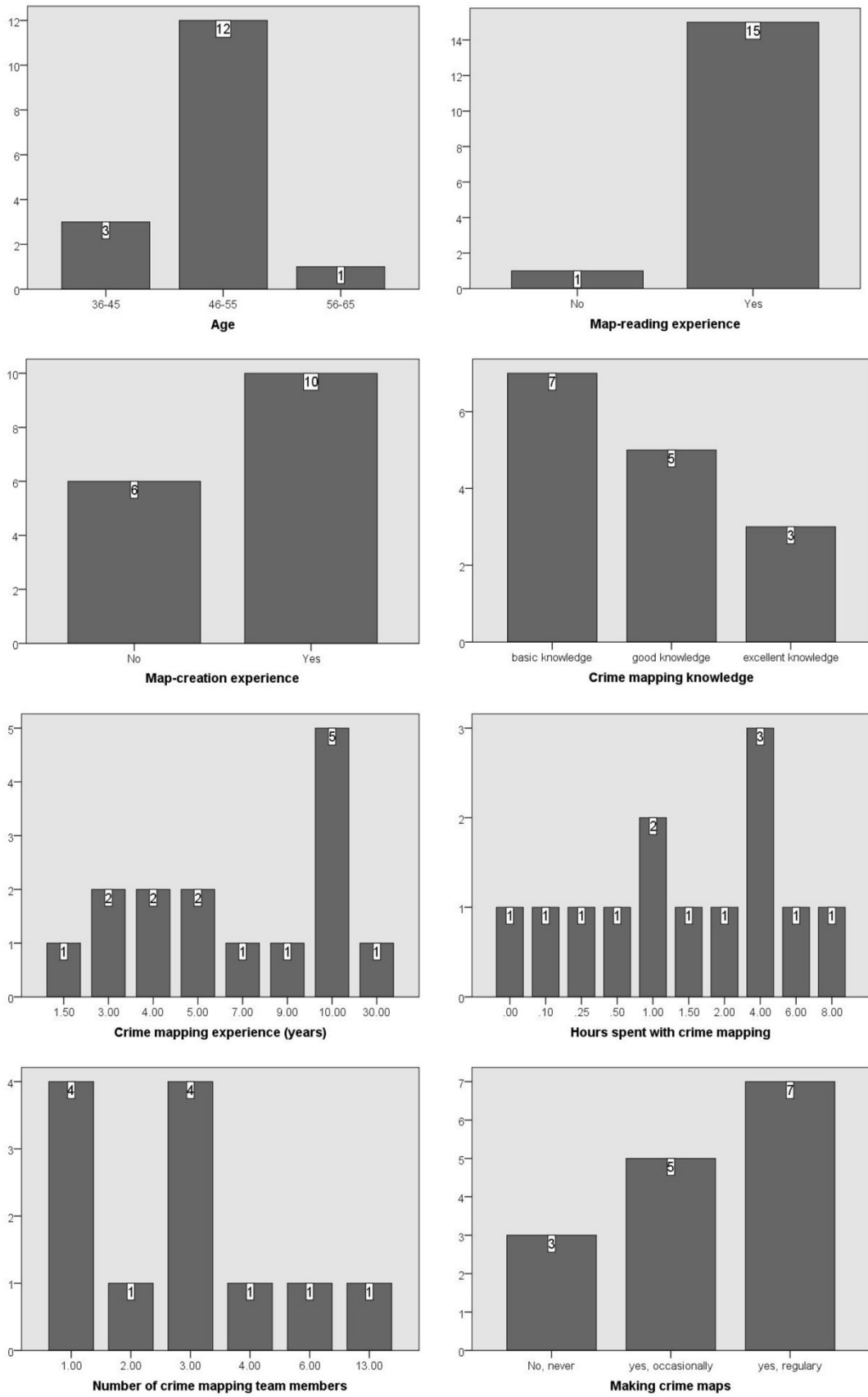
Fig. 4-1. Frequency charts, general issues.

Table 4-1. Dependencies between knowledge of crime mapping techniques and map creation experience

		Crime mapping knowledge			
		Basic	Good	Excellent	Total
Have you ever visualised the results of crime analysis by creating thematic maps?	No, never	2	0	1	3
	Yes, occasionally	4	1	0	5
	Yes, regularly	1	4	2	7
Total		7	5	3	15

The third complex of the questionnaire evaluates the potential of the developed 3D methods to represent tactical situation assessments. The first question of this section is whether the participant had already practically dealt with 3D visualisations in crime mapping. The majority of 13 persons had never dealt with 3D, only three persons had occasionally used 3D mapping techniques (cf. Figure 4-2). Interestingly, all participants with poor crime mapping knowledge expressed that they had never dealt with 3D mapping techniques. Those participants, in contrast, with good or excellent crime mapping knowledge had already dealt with 3D mapping (cf. Table 4-2). Obviously, 3D mapping techniques are perceived as a sophisticated method requiring advanced crime mapping knowledge.

Asked, as how useful the participants consider the demonstrated 3D visualisation methods for representing crime scene distributions, the majority (eight persons) denoted these methods as "useful" and "very useful" (two persons), respectively. Six persons considered them not so useful (cf. Figure 4-2).

Table 4-3 depicts that the presented 3D techniques are rated less useful by two participants who have experience with 3D mapping. Those participants who had never applied 3D crime mapping methods, in contrast, rate these techniques as "useful" (cf. Table 4-3). This may correspond with the high visual attraction of 3D (geo-) visualisations. Those participants, who had never created 3D representations for specific purposes consider these techniques rather suitable, while those who had already applied 3D mapping techniques seem to be more sceptical about their potential. Regarding the application potential of interactive 3D tactical intelligence assessments for the day-to-day business, five participants stated a high, two persons a very high potential. Eight persons, however, attested low potential for their day-to-day business (cf. Figure 4-2).
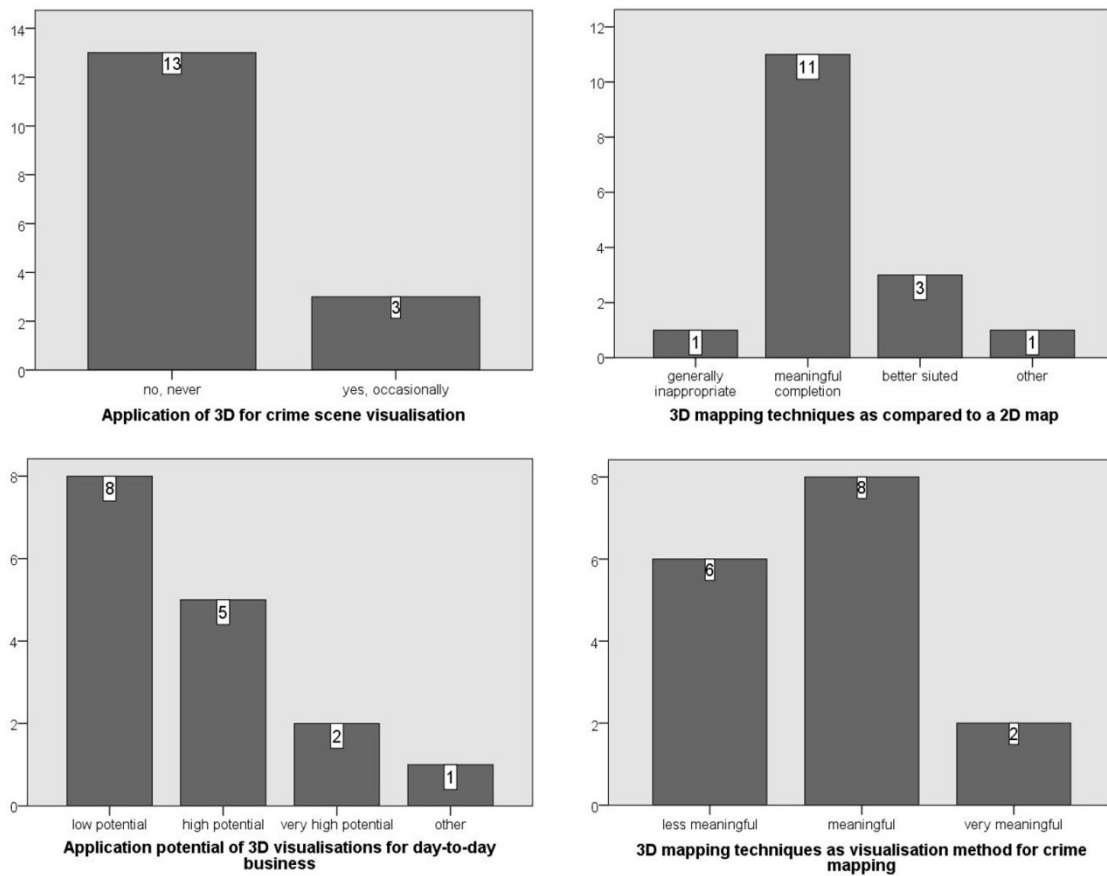
Fig. 4-2. Frequency charts, specific 3D relevant issues.

Table 4-2. Dependencies between participant's crime mapping knowledge and 3D mapping experience

		Crime mapping knowledge			
		Basic	Good	Excellent	Total
Have you already dealt with 3D visualisation issues related to crime mapping in your daily routine?	No, never	7	3	2	12
	Yes, occasionally	0	2	1	3
Total		7	5	3	15

Table 4-3. Dependencies between 3D mapping experience and judgement on 3D mapping relevance

		Ever applied 3D?		
		No, never	Yes, occasionally	Total
How useful do you consider the demonstrated 3D visualisations for representing crime scene distribution patterns?	Not so useful	4	2	6
	Useful	7	1	8
	Very useful	2	0	2
Total		13	3	16

To evaluate crime mapping experts' opinions about the communication potential of 3D visualisations, the participants were asked to judge the presented interactive 3D representations of crime scene distribution patterns in comparison to "traditional" 2D map based visualisations. As Table 4-4 shows, 11 from 18 participants judged the presented 3D visualisations as a useful addition; three persons perceived these methods as even better suited. One person classified the presented 3D crime mapping techniques as being "generally inappropriate".

Table 4-5 reveals two "3D enthusiasts". These are the two experts, who were convinced that the presented 3D applications are "better suited" to communicate analysis results than a 2D map and who at the same time characterised the presented 3D mapping techniques as "very useful" visualisation methods for representing crime scene distributions (cf. Table 4-5). Compared to these two 3D enthusiasts, one "3D pessimist" was identified as well. This person rated the communication potential of 3D crime mapping visualisations as "generally inappropriate" (compared to a 2D map) and characterised the presented 3D mapping methods as "not so useful" to represent crime scene distributions (cf. Table 4-5). At the same time, this person ascribed 3D mapping techniques only a "low" potential to day-to-day business (cf. Table 4-5).

Table 4-4. Dependencies between 3D relevance for day-to-day business and 3D communication potential

		3D relevance for day-to-day business				Total
		Low potential	High potential	Very high potential	Other	
Regarding the communication of analysis results to third parties and compared to the traditional 2D map, how would you judge the presented interactive 3D representations of crime scene distribution patterns?	Generally inappropriate	**1**	0	0	0	1
	Useful addition	6	4	0	1	11
	Better suited	0	1	2	0	3
	Other	1	0	0	0	1
Total		8	5	2	1	16

Table 4-5. Dependencies between evaluated 3D relevance compared to the 2D map and 3D crime mapping applications' potential

		3D relevance as compared to 2D map				Total
		Generally inappropriate	Useful addition	Better suited	Other	
How useful do you consider the demonstrated 3D visualisations for representing crime scene distribution patterns?	Not so useful	**1**	4	0	1	6
	Useful	0	7	1	0	8
	Very useful	0	0	**2**	0	2
Total		1	11	3	1	16

In summary a majority of the interviewed experts considers the presented 3D crime mapping techniques as useful and as a consequential addition compared to the traditional 2D map. Related to this specific survey, the hypothesis of this study (three-dimensional visualisations are an appropriate method to communicate the findings of geospatial crime scene analysis to a broad audience), is overall verified.

5

Concluding remarks and outlook

This last chapter revisits the main research objectives in the overall context of this thesis. The chapter ends with a brief outlook to possible further research work.

Conclusion

This study applies and refines specific methods and techniques from GIScience to develop methods for computing three-dimensional representations of tactical intelligence assessments. With reference to the underlying hypothesis – 3D visualisations are an appropriate method to communicate the findings of geospatial crime scene analysis to a broad audience – a research framework is elaborated that is based on methods and techniques of GIScience. This framework and its encapsulated research objectives respectively, couple specific GIS and 3D VIS techniques to enable the combined analysis and visualisation of civil security related tasks for different purposes.

For the purpose of modelling urban threat levels 3D city models are enhanced with specific thematic information mandatory for further vulnerability analysis. This method demands for extensive geospatial analysis, GIS techniques are used, e.g., to update existing city models with pedestrian frequency information and socio-demographic data. It is shown how enhanced city models allow for identifying different urban threat levels in metropolitan areas. To detect different levels of threat exposure in a metropolitan area a grid-based method is presented.

To provide methods for crime mapping related issues, officially registered crime data is used. For analysing this kind of data, specific methods are required. Further research objectives are analysing this specific data, e.g., transforming a discrete set of point-based crime scene positions into geostatistical surfaces. These surfaces make it possible to conduct intensive hotspot analysis. Spatial patterns of crime scene densities are computed by applying fundamental techniques of geospatial crime scene analysis, such as, kernel density estimation. Subsequent to hotspot mapping, further research objectives verify hotspot areas with LISA statistics, identify hotspot areas with a data-based method and create "geoportraits" of these areas with geospatial technology. These analyses complement the situation assessments with geospatial intelligence.

To enhance the existing set of methods and techniques with temporal data analysis and visualisation capabilities, particular research objectives facilitate spatio-temporal data exploration as well as space-time-path-based analysis and repeat victimisation analysis. The developed standalone GIS application further refines the GIS plug-ins by providing basic functionality for brief temporal data exploration. Using this functionality identifies the particular day with the highest number of robberies in 2007. To analyse and visualise spatio-temporal patterns of robbery crime scenes for that precise day space-time paths are constructed to connect the individual scenes. Interpretation of these geometrical segments gives first leads of possible serial crime.

To facilitate easy-to-comprehend visualisations, three-dimensional geovirtual environments are created for the study area. Serving as an integration platform, these environments ensure for an appropriate communication of the findings of geospatial (crime scene) analysis. GIS methods are applied to enable an efficient management, processing and revision of the various vector- and raster-based data integrated into these environments. The three-dimensional tactical intelligence assessments result from augmenting these environments with the main findings of geospatial crime scene analyses.

The brief evaluation of the application potential of these visualisation methods indicates that a majority of interviewed experts appreciate these 3D intelligence assessments as useful and as a consequential addition as compared to the traditional two-dimensional thematic map. The conducted survey reveals two "3D-enthusiasts" who state that the presented three-dimensional applications are "better-suited" to communicate crime mapping analysis results than a two-dimensional map. Furthermore they characterise the presented 3D mapping techniques as "very useful" visualisation methods for representing crime scene distributions. However, according to this brief survey, three-dimensional mapping techniques seem to be perceived as a kind of sophisticated methodology whose application appears to require advanced (crime) mapping knowledge.

Further research

Future research work can be dedicated to the following fields: in a first instance the survey should be further optimised and executed to a broader sample to prove or disprove the presented findings. In a next step extended usability studies can be carried out. The developed interactive versions of the 3D tactical intelligence assessments should be individually evaluated on an interactive level as well. Police officers, for instance, could test both the interactive PC-based visualisations and static two-dimensional maps with corresponding content (e.g. burglary densities). Also usability issues should be evaluated (cf., e.g., Elzakker and Wealands 2007, Fuhrmann and MacEachren 2001, Slocum et al. 2001). Based on the feedback, the strengths and weaknesses of the three-dimensional representations of tactical intelligence assessments can be anticipated in a more appropriate manner.

Further improvements are related to kernel-density analysis and the implementation of different kernels, respectively. As previously mentioned, the kernel limitations caused by ArcGIS can be avoided by coupling R with ArcGIS. For instance, the GIS plug-ins programmed can be further refined to support different kernel functions. By including R references, sophisticated statistical functions can be addressed.

Methods and techniques from the emergent but rapidly developing discipline of Geovisual Analytics (cf. Andrienko et al 2007) can be integrated into the framework of this study. A possible exploitation of approaches from Geovisual Analytics might, for instance, comprise the application and development of specific spatio-temporal data-mining techniques for exploring large crime scene datasets – e.g., related to geographic profiling. Hence, the con-

sequent advancement of techniques presented in this thesis will be the focus of future work – towards multidimensional tactical intelligence assessments.

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Selbständigkeitserklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig und nur mit den angegebenen Hilfsmitteln angefertigt sowie an keiner anderen Hochschule eingereicht habe.

Potsdam, den 15. September 2010

Appendices

Table of figures

List of Tables

Scource Code GIS Plug-In (DLL)

(section)

```vb
Public Class DlgXplore

    Dim pZonalRaster As ESRI.ArcGIS.Carto.IRasterLayer
    Dim pFeatLayerCity As ESRI.ArcGIS.Carto.IFeatureLayer
    Dim pFeatLayerLegendShape As ESRI.ArcGIS.Carto.IFeatureLayer
    Dim pFlArray As ESRI.ArcGIS.esriSystem.IArray
    Dim FlagManyKDEFiles As Boolean

    Private Sub ButtonGo_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
        Handles ButtonGo.Click

        'TabControl_Hotspot altivieren
        TabControl_Hotspot.Enabled = True

        'Evtl. Vorselektionen löschen
        ListBoxFields.Items.Clear()

        'Anzeigen aller Attribute in 1. Listbox
        Dim pImxDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
        pImxDoc = GetMxDocument(XploreData.m_application)

        Dim pLayer As ESRI.ArcGIS.Carto.ILayer2
        pLayer = pImxDoc.SelectedLayer

        'Auslesen der Tabellenfelder und -spalten
        Dim pFeatLayer As ESRI.ArcGIS.Carto.IFeatureLayer2
        Dim pFeatClass As ESRI.ArcGIS.Geodatabase.IFeatureClass
        Dim pFields As ESRI.ArcGIS.Geodatabase.Fields
        Dim pField As ESRI.ArcGIS.Geodatabase.Field

        pFeatLayer = pImxDoc.SelectedLayer
        pFeatClass = pFeatLayer.FeatureClass
        pFields = pFeatClass.Fields

        Dim numberOfFields As Integer
        Dim name As String
        numberOfFields = pFields.FieldCount()

        For i As Long = 0 To numberOfFields - 1
            pField = pFields.Field(i)
            name = pField.Name
            ListBoxFields.Items.Add(name)
        Next i

        mpImxDoc = pImxDoc
        mpLayer2 = pFeatLayer
        mpFeatLayer2 = pFeatLayer
        mpFeatClass = pFeatClass
        mpFields = pFields
    End Sub

#Region "Get MxDocument from ArcMap"

    Public Function GetMxDocument(ByVal application As ESRI.ArcGIS.Framework.IApplication) As
        ESRI.ArcGIS.ArcMapUI.IMxDocument

        If application Is Nothing Then
            Return Nothing
        End If

        Dim mxDocument As ESRI.ArcGIS.ArcMapUI.IMxDocument = (CType(application.Document,
        ESRI.ArcGIS.ArcMapUI.IMxDocument)) ' Explicit Cast

        Return mxDocument

    End Function
#End Region
    Private Sub ListBoxFields_SelectedIndexChanged(ByVal sender As Object, ByVal e As
        System.EventArgs) Handles ListBoxFields.SelectedIndexChanged

        'Aufräumen evtl. Vorselektionen
        ListBoxStat.Items.Clear()
        ListBoxUnique.Items.Clear()
```

```vb
Dim pImxDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
pImxDoc = GetMxDocument(XploreData.m_application)


Dim index As Integer
Dim feldname As String

index = ListBoxFields.SelectedIndex()
feldname = ListBoxFields.Items.Item(index)

'Unique Fields
Dim pDataStat As ESRI.ArcGIS.Geodatabase.IDataStatistics
Dim pCursor As ESRI.ArcGIS.Geodatabase.ICursor

'Für die Statistiken, Zugriff auf alle Elemente
Dim pFeatLayer As ESRI.ArcGIS.Carto.IFeatureLayer
pFeatLayer = DlgXplore.mpLayer2

'Zugriff auf Variable über shared variable des Dialoges
pCursor = DlgXplore.mpFeatLayer2.Search((Nothing), False)

pDataStat = New ESRI.ArcGIS.Geodatabase.DataStatistics
pDataStat.Field = feldname
pDataStat.Cursor = pCursor

Dim unis As Long

'Enum-Collection
Dim pEnum As IEnumerator
Dim value As Object

pEnum = pDataStat.UniqueValues
unis = pDataStat.UniqueValueCount

If unis > 1000 Then

    If (MsgBox(" There are " & unis & " unique values. Display all?",
         MsgBoxStyle.YesNo, "ManyValues") = MsgBoxResult.Yes) Then

        'WaitCursor
        System.Windows.Forms.Cursor.Current = System.Windows.Forms.Cursors.WaitCursor()

        Do While (pEnum.MoveNext())
            value = pEnum.Current
            Debug.Print("value: " & value)
            ListBoxUnique.Items.Add(value)
        Loop

        System.Windows.Forms.Cursor.Current = System.Windows.Forms.Cursors.Default()

    End If

Else

    'WaitCursor
    System.Windows.Forms.Cursor.Current = System.Windows.Forms.Cursors.WaitCursor()

    Do While (pEnum.MoveNext())
        value = pEnum.Current
        Debug.Print("value - " & value)
        ListBoxUnique.Items.Add(value)
    Loop

    System.Windows.Forms.Cursor.Current = System.Windows.Forms.Cursors.Default()

End If
```

```vb
Dim pField As ESRI.ArcGIS.Geodatabase.IField

Dim globMin As Double
Dim globMax As Double


pField = DlgXplore.mpFields.Field(index)

Debug.Print(pField.Name)
If (pField.Type = ESRI.ArcGIS.Geodatabase.esriFieldType.esriFieldTypeInteger) Or
 pField.Type = ESRI.ArcGIS.Geodatabase.esriFieldType.esriFieldTypeDouble Or pField.Type =
 ESRI.ArcGIS.Geodatabase.esriFieldType.esriFieldTypeSingle Then

    CheckBox_Graph.Enabled = True

    'LabelText anpassen
    LabelField.Text = pField.Name.ToLower

    Dim min, max, std, sum, aver As Double
    Dim cnt As Long
    Dim pStatRes As ESRI.ArcGIS.esriSystem.IStatisticsResults

    pCursor = pFeatLayer.Search(Nothing, False)
    pDataStat.Cursor = pCursor

    'WaitCursor
    Dim pMouseCursor As ESRI.ArcGIS.Framework.IMouseCursor
    pMouseCursor = New ESRI.ArcGIS.Framework.MouseCursor
    pMouseCursor.SetCursor(2) 'HourGlass

    'Statistiken
    pStatRes = pDataStat.Statistics

    cnt = pStatRes.Count
    min = pStatRes.Minimum
    max = pStatRes.Maximum
    std = pStatRes.StandardDeviation
    sum = pStatRes.Sum
    aver = sum / cnt

    ListBoxStat.Items.Add(cnt)
    ListBoxStat.Items.Add(min)
    ListBoxStat.Items.Add(max)
    ListBoxStat.Items.Add(std)
    ListBoxStat.Items.Add(sum)
    ListBoxStat.Items.Add(aver)

    globMin = min
    globMax = max

End If


If CheckBox_Graph.CheckState = Windows.Forms.CheckState.Checked Then

    'Zeichnen eines GraphicWindows
    Dim pTab As ESRI.ArcGIS.Geodatabase.ITable
    Dim pDataGraph As ESRI.ArcGIS.Carto.IDataGraph
    Dim pDataProp As ESRI.ArcGIS.CartoUI.IDataGraphProperties
    Dim pDaGrWindow As ESRI.ArcGIS.ArcMapUI.IDataGraphWindow
    Dim pDataGraphs As ESRI.ArcGIS.CartoUI.IDataGraphs

    pTab = DlgXplore.mpLayer2

    pDataGraph = New ESRI.ArcGIS.CartoUI.DataGraph
    pDataGraph.Table = pTab

    'Feld(er) zur Darstellung
    Dim strFeld As String
    strFeld = pField.Name

    pDataGraph.FieldSet1 = strFeld
    pDataGraph.UseSelectedSet = False 'Alle Datensätze benutzen

    'Achsenskalierung
    'min und max soll sich nach min und max in den Daten richten
    Dim pDataGraphAxis As ESRI.ArcGIS.CartoUI.IDataGraphAxis
    pDataGraphAxis = pDataGraph
    pDataGraphAxis.YAxisMin = globMin
    pDataGraphAxis.YAxisMax = globMax
    pDataGraphAxis.YAxisStyle =
```

```vbnet
                ESRI.ArcGIS.CartoUI.esriDataGraphAxisStyleEnum.esriDataGraphAxisStyleUserDefined

            pDataGraph.Draw()

            'Eigenschaften des Diagramms
            pDataProp = pDataGraph
            pDataProp.GraphSubtype =
            ESRI.ArcGIS.CartoUI.esriDataGraphTypeEnum.esriDataGraphTypeScatter
            pDataProp.GraphSubtype =
            ESRI.ArcGIS.CartoUI.esriDataGraphSubtypeEnum.esriDataGraphSubtypeScatter2DSimple
            pDataProp.LegendPosition =
             ESRI.ArcGIS.CartoUI.esriDataGraphLegendPositionEnum.esriDataGraphLegendPositionCR
            pDataProp.Title = "Distribution " & strFeld
            pDataProp.ShowXAxisLabels = True

            'DataGraph Fenster zeichnen
            pDaGrWindow = New ESRI.ArcGIS.ArcMapUI.DataGraphWindow
            pDaGrWindow.DataGraph = pDataGraph
            pDaGrWindow.Application = XploreData.m_application

            'Hinzufügen des Diagramms zur Datagraph Collection
            pDataGraphs = pImxDoc
            pDataGraphs.Add(pDataGraph)

            pDaGrWindow.Show(True)

        End If

    End Sub

    Private Sub ListBoxUnique_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As
         System.EventArgs) Handles ListBoxUnique.SelectedIndexChanged

        Dim index As Integer
        Dim uniquefeld As String
        index = ListBoxFields.SelectedIndex()
        uniquefeld = ListBoxFields.Items.Item(index)
        Debug.Print(uniquefeld)

        'Für selektieres Feld Anzahl der Features berechnen
        Dim query As String
        Dim feld As String
        feld = mpField

        query = "[" & feld & "=" & uniquefeld & "]"
        Debug.Print(feld)


    End Sub

    Private Sub Button_HotSpot_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
         Handles Button_HotSpot.Click

        'Berechnung der Hotspotoberfläche
        Dim pDensityOp As ESRI.ArcGIS.SpatialAnalyst.IDensityOp
        pDensityOp = New ESRI.ArcGIS.SpatialAnalyst.RasterDensityOp

        'Raster Environments
        Dim pEnv As ESRI.ArcGIS.GeoAnalyst.IRasterAnalysisEnvironment
        pEnv = pDensityOp

        'Variablen für die KDE-Analyse
        Dim temp As String
        Dim cellsize As Single
        Dim radius As Double
        temp = TextBox_cellsize.Text
        cellsize = CSng(temp)
        temp = TextBox_radius.Text  'RADIUS für die KDE-Analysen

        'Output cell size
        pEnv.SetCellSize(ESRI.ArcGIS.GeoAnalyst.esriRasterEnvSettingEnum.esriRasterEnvValue,
         cellsize)

        'Workspace Facrory
        Dim pRWF As ESRI.ArcGIS.Geodatabase.IWorkspaceFactory
        Dim pRW As ESRI.ArcGIS.DataSourcesRaster.RasterWorkspace

        'Ausgabepfad
        Dim workspace As String
        workspace = TextBox_raster.Text
```

```vbnet
pRWF = New ESRI.ArcGIS.DataSourcesRaster.RasterWorkspaceFactory
pRW = pRWF.OpenFromFile(workspace, 0)

pEnv.OutWorkspace = pRW

'Ausgaberaster
Dim pOutRas As ESRI.ArcGIS.Geodatabase.IRaster

'FeatureClass für das Eingabe-Punktshapefile
Dim pFeatureClass As ESRI.ArcGIS.Geodatabase.IFeatureClass

'Das zu Beginn gewählte Shapefile
pFeatureClass = mpFeatClass

'Zur Weiterverarbeitung ein IGeodataset anlegen
Dim pGeoDSHotSpot As ESRI.ArcGIS.Geodatabase.IGeoDataset
pGeoDSHotSpot = pFeatureClass

'FeatClassDescriptor verwenden, um ein Grid zu erzeugen
Dim pFeatClassDescr As ESRI.ArcGIS.GeoAnalyst.IFeatureClassDescriptor
pFeatClassDescr = New ESRI.ArcGIS.GeoAnalyst.FeatureClassDescriptor

'Soll ein Population-Feld berücksichtigt werden?
If (CheckBox_PopField.Checked = True) Then
    pFeatClassDescr.Create(pGeoDSHotSpot, Nothing, ComboBox_PopField.Text)
Else
    'Einen Descriptor OHNE Population Field erstellen
    pFeatClassDescr.Create(pFeatureClass, Nothing, "NONE")
End If


'Das Tool ermöglicht es, mehrere KDEs mit unterschiedlichen Radien zu berechnen,
'Hierfür können im Feld Radius mehrere Werte durch ";" getrennt eingegeben werden.
'Dieses Feld auswerten

'Anzahl der zu berechnenden KDES Surfaces mit unterschiedlicher bandwidth
Dim count As Integer
'Leerzeichen entfernen
temp = Trim(temp)

Dim i As Integer

If (temp.Contains(";") = True) Then

    'String splitten
    Dim stringArray() As String
    stringArray = Split(temp, ";")

    'Wie viele Semikolon?
    count = stringArray.GetUpperBound(0)

    For i = 0 To count
        radius = CDbl(stringArray(i))

        'Grid in diesem Fall benennen nach Prefix plus aktueller Radius
        pEnv.DefaultOutputRasterPrefix = TextBox_prefix.Text.ToUpper & CStr(radius) & "_"

        'KDE 'Scale Faktor von 1000 um auf Angaben für km² zu kommen
        pOutRas = pDensityOp.KernelDensity(pFeatClassDescr, radius, 1000)

    Next


Else    'Nur ein Radius
    radius = CDbl(temp)
    pEnv.DefaultOutputRasterPrefix = TextBox_prefix.Text.ToUpper & CStr(radius) & "_"

    'Scale Faktor von 1000
    pOutRas = pDensityOp.KernelDensity(pFeatClassDescr, radius, 1000)

    'Hinzufügen der Surface zur Map
    Dim pOutputLayer As ESRI.ArcGIS.Carto.IRasterLayer
    pOutputLayer = New ESRI.ArcGIS.Carto.RasterLayer
    pOutputLayer.CreateFromRaster(pOutRas)
    pOutputLayer.Name = "KDE of crime scenes"
    mpImxDoc.AddLayer(pOutputLayer)

End If

MsgBox("KDE surface created")
```

```vb
End Sub

Private Sub TextBox_prefix_TextChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles TextBox_prefix.TextChanged

    'Prefix nur 3 Buchstaben          If IsNumeric(TextBox_prefix.Text) = True Then
        MsgBox("Only characters allowed!")
        TextBox_prefix.Clear()
    End If

    'Prüfen, ob 3 Buchstaben
    Dim i As Integer
    i = TextBox_prefix.Text.Length()
    If i > 3 Then
        MsgBox("Only 3 characters allowed")
        TextBox_prefix.Clear()
    End If


End Sub

Private Sub TextBox_cellsize_TextChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles TextBox_cellsize.TextChanged

    If IsNumeric(TextBox_cellsize.Text) = False Then
        MsgBox("Only numbers allowed!")
        TextBox_cellsize.Clear()
    End If

End Sub

Private Sub CheckBox_PopField_CheckedChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles CheckBox_PopField.CheckedChanged

    'Pupulation Field berücksichtigen

    Dim pFieldsPopoField As ESRI.ArcGIS.Geodatabase.Fields
    Dim pFieldPopField As ESRI.ArcGIS.Geodatabase.Field
    Dim i As Integer

    pFieldsPopoField = mpFeatClass.Fields

    For i = 0 To pFieldsPopoField.FieldCount - 1
        pFieldPopField = pFieldsPopoField.Field(i)
        ComboBox_PopField.Items.Add(pFieldPopField.Name)
    Next

End Sub

Private Sub TextBox_radius_TextChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles TextBox_radius.TextChanged

    'Prüfen, ob nur Zahlen oder ; eingegeben werden
    If TextBox_radius.Text.Contains(",") Then
        MsgBox("Use ; to separate values!")
        TextBox_radius.Text = ""
    End If

    Button_HotSpot.Enabled = True

End Sub

Private Sub TextBox_distCellSize_TextChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles TextBox_distCellSize.TextChanged

    'Die Cellsize des EucDistance Rasters soll gleich der Cellsize des
    ZonalDistanceRatsers sein
    'Dieses wird intern durch die Funktoon ZonalSttistics erzeigt. Dies beinhaltet eine
    Rasterisierung des Shapefiles (des Stadtmodells)
    TextBox_ZonalCellsize.Text = TextBox_distCellSize.Text

End Sub

Private Sub TextBox_DistOut_TextChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles TextBox_DistOut.TextChanged

    'Dieser OutputPath soll Default Path sein für den OutputPath der Tabelle von
    ZonalStatisticsAsTable
    TextBox_ZonalTableOut.Text = TextBox_DistOut.Text
```

```vb
End Sub

Private Sub Button_EucDistance_Click(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles Button_EucDistance.Click

    'WaitCursor
    Dim pMouseCursor As ESRI.ArcGIS.Framework.IMouseCursor
    pMouseCursor = New ESRI.ArcGIS.Framework.MouseCursor
    pMouseCursor.SetCursor(2) 'HourGlass

    'Berechnung eines Grids euklidischer Distanzen auf Basis der Tatorte
    Dim pDistanceOp As ESRI.ArcGIS.SpatialAnalyst.IDistanceOp
    pDistanceOp = New ESRI.ArcGIS.SpatialAnalyst.RasterDistanceOp

    'Raster Environments
    Dim pEnv As ESRI.ArcGIS.GeoAnalyst.IRasterAnalysisEnvironment
    pEnv = pDistanceOp

    'Variablen für KDE-Analyse
    Dim temp As String
    Dim cellsize As Single
    temp = TextBox_distCellSize.Text
    cellsize = CSng(temp)

    'Output cell size
    pEnv.SetCellSize(ESRI.ArcGIS.GeoAnalyst.esriRasterEnvSettingEnum.esriRasterEnvValue,
     cellsize)

    'Workspace Facrory
    Dim pRWF As ESRI.ArcGIS.Geodatabase.IWorkspaceFactory
    Dim pRW As ESRI.ArcGIS.DataSourcesRaster.RasterWorkspace

    'Ausgabepfad
    Dim workspace As String
    workspace = TextBox_DistOut.Text

    pRWF = New ESRI.ArcGIS.DataSourcesRaster.RasterWorkspaceFactory
    pRW = pRWF.OpenFromFile(workspace, 0)

    pEnv.OutWorkspace = pRW

    'Ausgaberaster
    Dim pOutRasDist As ESRI.ArcGIS.Geodatabase.IRaster

    'Grid mit Prefix benennen
    pEnv.DefaultOutputRasterPrefix = TextBox_preFixDist.Text.ToUpper & CStr(cellsize) & "m_"

    'EucDistance
    pOutRasDist = pDistanceOp.EucDistance(mpFeatClass, Nothing, Nothing)

    MsgBox("Distance surface created and added to map")

    'Hinzufügen der Surface zur Map
    Dim pOutputLayer As ESRI.ArcGIS.Carto.IRasterLayer
    pOutputLayer = New ESRI.ArcGIS.Carto.RasterLayer
    pOutputLayer.CreateFromRaster(pOutRasDist)
    pOutputLayer.Name = "EucDist of crime scenes"
    mpImxDoc.AddLayer(pOutputLayer)

    'Dieses Raster als DeaultRatser für zonale Statistiken anbieten
    TextBox_ZonalRaster.Text = pOutputLayer.Name.ToString

    MsgBox("Distance surface created and added to map")

End Sub

Private Sub Button_DissLoadCityM_Click(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles Button_DissLoadCityM.Click

    'Auswählen eines City Models (Shapefieles, polygon)
    Dim pGxDialog As ESRI.ArcGIS.CatalogUI.IGxDialog
    pGxDialog = New ESRI.ArcGIS.CatalogUI.

    Dim pGxFilter As ESRI.ArcGIS.Catalog.IGxObjectFilter
    'Filter auf Shapefiles
    pGxFilter = New ESRI.ArcGIS.Catalog.GxFilterShapefiles

    'Dialog vorbereiten, Eigenschaften setzen
    With pGxDialog
        .Name = "Select Building Shapefile"
        .AllowMultiSelect = False
```

```vbnet
            .ObjectFilter = pGxFilter
            .ButtonCaption = "Select"
            .StartingLocation = TextBox_DistOut.Text.ToString
        End With

        Dim pGxObjects As ESRI.ArcGIS.Catalog.IEnumGxObject
        Dim pGxDataset As ESRI.ArcGIS.Catalog.GxDataset

        pFeatLayerCity = New ESRI.ArcGIS.Carto.FeatureLayer      'new Layer!

        'AuswahlDialog anzeigen
        pGxDialog.DoModalOpen(0, pGxObjects)

        'Die zurückgegebenen Objekte (Shapefile(s)) durchgehen
        pGxDataset = pGxObjects.Next
        'Wenn kein Shapefile ausgewählt wurde, ist pGxDataset LEER!
        If Not pGxDataset Is Nothing Then

            pFeatLayerCity.FeatureClass = pGxDataset.Dataset

            TextBox_DistInput.Text = pFeatLayerCity.Name.ToString()

            'Hinzufügen des Shapes zu Anwendung, Shape benennen für TOC
            pFeatLayerCity.Name = pFeatLayerCity.FeatureClass.AliasName
            mpImxDoc.AddLayer(pFeatLayerCity)
            'Map refreshen und content aktualisieren
            mpImxDoc.ActivatedView.Refresh()
            mpImxDoc.UpdateContents()

            'Nun die ComboBox für das ZoneField freigeschalten
            ComboBox_ZonalField.Enabled = True
            TextBox_ZonalInput.Text = pGxDataset.DatasetName.WorkspaceName.PathName.ToString &
            "\" & pFeatLayerCity.Name.ToString & ".shp"

            'ComboBoxen für die Auswahl des Dissolves und des Zone-Fieldes befüllen
            Dim pFieldsZonal As ESRI.ArcGIS.Geodatabase.Fields
            Dim pFieldZonal As ESRI.ArcGIS.Geodatabase.Field
            Dim i As Integer

            pFieldsZonal = pFeatLayerCity.FeatureClass.Fields

            For i = 0 To pFieldsZonal.FieldCount - 1
                pFieldZonal = pFieldsZonal.Field(i)
                If (pFieldZonal.Type =
                 ESRI.ArcGIS.Geodatabase.esriFieldType.esriFieldTypeInteger) Or (pFieldZonal.Type
                 = ESRI.ArcGIS.Geodatabase.esriFieldType.esriFieldTypeString) Then
                    ComboBox_ZonalField.Items.Add(pFieldZonal.Name)
                End If
            Next
        End If
End Sub

Private Sub Button_DissLoadRaster_Click(ByVal sender As System.Object, ByVal e As
     System.EventArgs) Handles Button_DissLoadRaster.Click

    'Auswählen eines Grids
    Dim pGxDialogGrid As ESRI.ArcGIS.CatalogUI.IGxDialog
    pGxDialogGrid = New ESRI.ArcGIS.CatalogUI.GxDialog

    Dim pGxFilterGrid As ESRI.ArcGIS.Catalog.IGxObjectFilter
    'filter auf Raster
    pGxFilterGrid = New ESRI.ArcGIS.Catalog.RasterFormatGridFilter

    'Dialog vorbereiten, Eigenschaften setzen
    With pGxDialogGrid
        .Name = "Select Distance Grid"
        .AllowMultiSelect = False
        .ObjectFilter = pGxFilterGrid
        .ButtonCaption = "Select"
        .StartingLocation = TextBox_DistOut.Text.ToString
    End With

    'Objektrückgabe durch Dialog vorbereiten, zurückgegebenes Shapefile verarbeiten
    Dim pGxObjectsGrids As ESRI.ArcGIS.Catalog.IEnumGxObject
    Dim pGxDatasetGrid As ESRI.ArcGIS.Catalog.GxDataset

    pZonalRaster = New ESRI.ArcGIS.Carto.RasterLayer

    'AuswahlDialog anzeigen
    pGxDialogGrid.DoModalOpen(0, pGxObjectsGrids)
```

```vb
        'Die zurückgegebenen Objekte (Shapefile(s)) durchgehen
        pGxDatasetGrid = pGxObjectsGrids.Next
        'Wenn kein Shapefile ausgewählt wurde, ist pGxDataset LEER!
        If Not pGxDatasetGrid Is Nothing Then

            pZonalRaster.CreateFromDataset(pGxDatasetGrid.Dataset)

            TextBox_ZonalRaster.Text = pZonalRaster.Name.ToString

        End If

        'Wichtig für die ZonalOp: Die Cellsize des ZoneFeatures(des Stadtmodells) darf nicht
        kleiner sein als die des Input Rasters
        'die Cellsize für die Rasterisierung auf die ceelsize des geladenen Rasters setzen
        'Cellsize berechnen
        Dim pRasterProps As ESRI.ArcGIS.DataSourcesRaster.IRasterProps
        pRasterProps = pZonalRaster.Raster
        Dim pCell As ESRI.ArcGIS.Geometry.IPoint

        pCell = New ESRI.ArcGIS.Geometry.Point
        pCell.X = pRasterProps.MeanCellSize.X
        pCell.Y = pRasterProps.MeanCellSize.Y

        'Cellsize setzten für die interne Rasterung
        TextBox_ZonalCellsize.Text = pCell.X.ToString

        'Button freischalten für ZonaleStatistik, da nun erst die Cellsize determiniert wurde
        Button_ZonalStats.Enabled = True
    End Sub

    Private Sub Button_ZonalStats_Click(ByVal sender As System.Object, ByVal e As
        System.EventArgs) Handles Button_ZonalStats.Click

        'WaitCursor
        Dim pMouseCursor As ESRI.ArcGIS.Framework.IMouseCursor
        pMouseCursor = New ESRI.ArcGIS.Framework.MouseCursor
        pMouseCursor.SetCursor(2) 'HourGlass


        'RasterZonalOp operator
        Dim pZonalOp As ESRI.ArcGIS.SpatialAnalyst.IZonalOp
        pZonalOp = New ESRI.ArcGIS.SpatialAnalyst.RasterZonalOp

        'Zur Weiterverarbeitung ein IGeodataset anlegen. Dies benötigt ZonalOp als Input - vor
        allem bei Shapefile!
        Dim pGeoDS As ESRI.ArcGIS.Geodatabase.IGeoDataset
        pGeoDS = pFeatLayerCity.FeatureClass     'Übernahme des ausgewählten Stadtmodells

        'ZoneFiled ermitteln: Ausgewählter Eintrag aus der ComboBox: Text in Box!
        Dim ZoneField As String
        ZoneField = ComboBox_ZonalField.Text

        'Einen **Featureclassdescriptor** verwenden
        'dieser ermöglioht es, ein Grid auf Basis einer Spalte eines Featurclass zu erstellen!
        (Für ZonalStat-Analysen)
        'Damit ist ein späterer Link der Zonal(Raster-)Ergebnisse an das Ausgangsshape möglich!
        'Dieser FcD soll auf basis des ausgewählten Feldes (ZoneField) erstellt werden
        Dim pFeatClassDescrZone As ESRI.ArcGIS.GeoAnalyst.IFeatureClassDescriptor
        pFeatClassDescrZone = New ESRI.ArcGIS.GeoAnalyst.FeatureClassDescriptor

        pFeatClassDescrZone.Create(pGeoDS, Nothing, ZoneField)

        'SETZEN DES Geodatasets
        pGeoDS = pFeatClassDescrZone

        'auch den Rasterlayer als Geodataset übernehmen
        Dim pGeoDSRaster As ESRI.ArcGIS.Geodatabase.IGeoDataset
        pGeoDSRaster = pZonalRaster.Raster

        'Create zonal statistics table
        Dim pTable As ESRI.ArcGIS.Geodatabase.ITable

        'RasterEnvironments
        'CellSize für die **interne Ratsrisierung des Stadtmodelles**
        Dim pEnvZonal As ESRI.ArcGIS.GeoAnalyst.IRasterAnalysisEnvironment
        pEnvZonal = pZonalOp

        pEnvZonal.SetCellSize(ESRI.ArcGIS.GeoAnalyst.esriRasterEnvSettingEnum.esriRasterEnvValue,
        CSng(TextBox_ZonalCellsize.Text.ToString))
```

```vb
    'Workspace Facrory erstellen
    Dim pWF As ESRI.ArcGIS.Geodatabase.IWorkspaceFactory
    Dim pRWzonal As ESRI.ArcGIS.DataSourcesRaster.RasterWorkspace

    'Ausgabepfad
    Dim workspace As String
    workspace = TextBox_ZonalTableOut.Text  'TextBox_raster.Text 'Aus dem Distances Menu
     **besser hier direkt verfügbar machen** C:\Temp

    pWF = New ESRI.ArcGIS.DataSourcesRaster.RasterWorkspaceFactory
    pRWzonal = pWF.OpenFromFile(workspace, 0)

    pEnvZonal.OutWorkspace = pRWzonal

    'Operation ausführen
    MsgBox("ZonalStatistics with Raster " & pZonalRaster.Name.ToString & " and Shape: " &
     pFeatLayerCity.Name.ToString & " Field: " & ZoneField)
    pTable = pZonalOp.ZonalStatisticsAsTable(pGeoDS, pGeoDSRaster, True) 'mit GeoDataset und
     mit IGNORE NO DATA

    'Funktion aufrufen, um erzeugte INFO-Table zu ArcMap hinzuzufügen
    'Diese Funktion liefert zudem eine StandALoneTable zurück!
    'diese zurückgegebene Tabellenobjekt kann für den Join weiterverwendet werden
    Dim pStTab As ESRI.ArcGIS.Carto.IStandaloneTable
    pStTab = New ESRI.ArcGIS.Carto.StandaloneTable
    'Hier wird die StandaloneTable auf pTable gesetzt! --> Damit liegt eine StandaloneTable
     vor --> diese zurückgeben um weiter zu verarbeiten (z.b. Join)
    'Hinzufügen der Tablelle und gleichzeitiges Setzten der StandaloneTable
    'Diese pStTab für den Join nutzen
    pStTab.Table = AddInfoTableToTOC(pTable)


    'Ausgabepfad der INFO-Tabelle anzeigen
    Dim pDataSet As ESRI.ArcGIS.Geodatabase.IDataset
    pDataSet = pTable

    Dim FeldAttributTabelle As String
    Dim FeldStandAloneTable As String

    FeldAttributTabelle = ZoneField
    FeldStandAloneTable = "VALUE"   'hard codiert: Feld wird bei der Erzeugung der pTable
     automatisch angelegt

    JoinTableToLayerOneToOne(FeldAttributTabelle, FeldStandAloneTable, pTable,
     pFeatLayerCity.FeatureClass, pFeatLayerCity)

End Sub

Public Function AddInfoTableToTOC(ByVal pTable As ESRI.ArcGIS.Geodatabase.ITable) As
    ESRI.ArcGIS.Carto.StandaloneTable

    Dim pImxDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
    pImxDoc = GetMxDocument(XploreData.m_application)
    Dim pMap As ESRI.ArcGIS.Carto.IMap
    pMap = pImxDoc.FocusMap

    ' Create a new standalone table and add it
    ' to the collection of the focus map
    Dim pStTab As ESRI.ArcGIS.Carto.IStandaloneTable
    pStTab = New ESRI.ArcGIS.Carto.StandaloneTable
    'Hier wird die StandaloneTable auf pTable gesetzt --> Damit liegt eine StandaloneTable
     vor --> diese zurückgeben, damit kann man weiter arbeiten (z.b. Join)
    pStTab.Table = pTable
    Dim pStTabColl As ESRI.ArcGIS.Carto.IStandaloneTableCollection
    pStTabColl = pMap
    pStTabColl.AddStandaloneTable(pStTab)

    'Refresh TOC
    pImxDoc.UpdateContents()

    AddInfoTableToTOC = pStTab

End Function

Public Function JoinTableToLayerOneToOne(ByVal pJoinFieldFeature As String, ByVal
    pJoinFieldStandAlone As String, ByVal pJoinTable As ESRI.ArcGIS.Geodatabase.ITable, ByVal
    pToTable As ESRI.ArcGIS.Geodatabase.ITable, ByVal pFeatureLayer As
    ESRI.ArcGIS.Carto.IFeatureLayer) As Boolean
```

```vb
    'Layer, an dessen Attributtablee gejoined werde soll: pFeatureLayer
    'Tabelle, an die gejpined werden soll: pToTable      (ITable)
    'Welche Tabelle gejoined werden soll: pFromTable     (IStandAloneTable)
    'Feld, für Join: pJoinField

    Dim pMemRelClassFact As ESRI.ArcGIS.Geodatabase.IMemoryRelationshipClassFactory
    Dim pRelClass As ESRI.ArcGIS.Geodatabase.IRelationshipClass
    Dim pDispRelClass As ESRI.ArcGIS.Carto.IDisplayRelationshipClass

    'Memory RelationShip class erzeugen
    pMemRelClassFact = New ESRI.ArcGIS.Geodatabase.MemoryRelationshipClassFactory
    pRelClass = pMemRelClassFact.Open("Table to Layer", pJoinTable, pJoinFieldStandAlone, _
     pToTable, _
    pJoinFieldFeature, "dist", "build", _
     ESRI.ArcGIS.Geodatabase.esriRelCardinality.esriRelCardinalityOneToOne)

    'Join nun durchführen
    pDispRelClass = pFeatLayerCity
    pDispRelClass.DisplayRelationshipClass(pRelClass, _
     ESRI.ArcGIS.Geodatabase.esriJoinType.esriLeftOuterJoin)
    MsgBox("Join successfull! Please export the citymodel shapefile.")
    JoinTableToLayerOneToOne = True

End Function


Private Sub Button_LegLoadShape_Click(ByVal sender As System.Object, ByVal e As _
 System.EventArgs) Handles Button_LegLoadShape.Click

    'Auswählen eines City Models (Shapefieles, polygon)
    Dim pGxDialog As ESRI.ArcGIS.CatalogUI.IGxDialog
    pGxDialog = New ESRI.ArcGIS.CatalogUI.GxDialog            'Reference Catalog
     muss hinzugefügt werden!

    Dim pGxFilter As ESRI.ArcGIS.Catalog.IGxObjectFilter
    'Filter auf Shapefiles setzen
    pGxFilter = New ESRI.ArcGIS.Catalog.GxFilterShapefiles

    'Dialog vorbereiten, Eigenschaften setzen
    With pGxDialog
        .Name = "Select Shapefile"
        .AllowMultiSelect = False
        .ObjectFilter = pGxFilter
        .ButtonCaption = "Select"
        .StartingLocation = "C:\"
    End With

    'Objektrückgabe durch Dialog vorbereiten, zurückgegebenes Shapefile verarbeiten
    Dim pGxObjects As ESRI.ArcGIS.Catalog.IEnumGxObject
    'ein Dataset, welches GxObjects nacheinander aufnimmt und einem Featurelayer über die
     FeatureClass Eigenschaft zugewiesen werden kann!
    Dim pGxDataset As ESRI.ArcGIS.Catalog.GxDataset

    'Dieses Shape muss funktionsübergreifend zur Ferfügung stehen, sonst nicht referenzierbar
     aus ZonalStat-Funktion
    pFeatLayerLegendShape = New ESRI.ArcGIS.Carto.FeatureLayer      'new Layer!

    'AuswahlDialog anzeigen
    pGxDialog.DoModalOpen(0, pGxObjects)

    'Nun die zurückgegebenen Objekte (Shapefile(s)) durchgehen
    pGxDataset = pGxObjects.Next
    'Wenn kein Shapefile ausgewählt wurde, ist pGxDataset LEER!
    If Not pGxDataset Is Nothing Then

        pFeatLayerLegendShape.FeatureClass = pGxDataset.Dataset
        'Fields und Field nötig
        Dim pFieldsLegends As ESRI.ArcGIS.Geodatabase.Fields
        Dim pFieldLegend As ESRI.ArcGIS.Geodatabase.Field
        Dim i As Integer

        pFieldsLegends = pFeatLayerLegendShape.FeatureClass.Fields

        For i = 0 To pFieldsLegends.FieldCount - 1
            pFieldLegend = pFieldsLegends.Field(i)

            'Ein zonalField kann nur eins vom Typ Integer oder Char sein
            ComboBox_LegSourceField.Items.Add(pFieldLegend.Name)
        Next
    End If
```

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End Sub

Private Sub Button_LegGOLabelField_Click(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles Button_LegGOLabelField.Click

    'Das zuvor geladene Shapefile wird um eine neue Spalte erweitert
    'Diese Spalte fasst features gemäß einer Auswahl zusammen
    'Dieses Feld lässt sich dann für weitere Aggegierte Symbolisierungen - vor allem in
    LandXplorer - nutzen

    '1
    'Neues Feld anlegen für ClassifizierungsSpalte
    'Feldvariablen werden wieder erzeugt, sterben nach Funktionsende
    Dim pTable As ESRI.ArcGIS.Geodatabase.ITable
    Dim pField As ESRI.ArcGIS.Geodatabase.IField
    Dim pFieldEdit As ESRI.ArcGIS.Geodatabase.IFieldEdit

    Dim name As String
    Dim stellen As Integer

    'Feldname aus Textfeld
    name = TextBox_LegTargetField.Text
    stellen = 40

    pField = New ESRI.ArcGIS.Geodatabase.Field
    pFieldEdit = pField

    pTable = pFeatLayerLegendShape

    If CreateFieldString(pField, pFieldEdit, pTable, name, stellen) = False
        MsgBox("Field " & name & " could not be created")
    End If

    '2
    'Elemente auswählen gemäß TextBox mit Schwellenwerten
    'Where Clause definieren, basiert auf Elementen in Listbox
    Dim WhereClauses() As String 'Array nimmt alle AbfrageStrings auf
    'WhereClauses = New String() {}

    Dim lower As String
    Dim upper As String
    Dim temp As String

    Dim size As Integer
    Dim i As Integer

    Dim SearchField As String
    SearchField = ComboBox_LegSourceField.Text.ToUpper

    size = ListBox_LegTreshValues.Items.Count
    ReDim WhereClauses(size)

    'WaitCursor
    Dim pMouseCursor As ESRI.ArcGIS.Framework.IMouseCursor
    pMouseCursor = New ESRI.ArcGIS.Framework.MouseCursor
    pMouseCursor.SetCursor(2) 'HourGlass

    'Schleife um Schwellenwerte auszulesen und zu setzen
    For i = 1 To size 'Step 2

        lower = ListBox_LegTreshValues.Items.Item(i - 1)
        upper = ListBox_LegTreshValues.Items.Item(i)

        temp = Chr(34) & SearchField & Chr(34) & " > " & lower & " AND " & Chr(34) &
            SearchField & Chr(34) & " <= " & upper.ToString
        ListBox_LegWhereClause.Items.Add(temp)

        'In Array aufnehmen für Abfrage
        WhereClauses(i) = temp
        Debug.Print(WhereClauses(i))


        If i + 2 > size Then
            Exit For
        End If

        'Feld für Feldnamen sperren
        TextBox_LegTargetField.Enabled = False
        'Calclulate Fields freigeben
        Button_LegCalcFields.Enabled = True
    Next
```

```vb
    End Sub

    Private Sub Button_LegCalcFields_Click(ByVal sender As System.Object, ByVal e As
        System.EventArgs) Handles Button_LegCalcFields.Click

        'Vield Values berechnen
        '3
        Dim pQueryFilter As ESRI.ArcGIS.Geodatabase.IQueryFilter
        pQueryFilter = New ESRI.ArcGIS.Geodatabase.QueryFilter

        Dim pUpdateFeatures As ESRI.ArcGIS.Geodatabase.IFeatureCursor
        Dim pFeatureClass As ESRI.ArcGIS.Geodatabase.IFeatureClass

        Dim temp As String
        Dim WhereClauses() As String
        Dim count As Integer
        Dim i As Integer
        Dim a As Integer
        Dim len As Integer
        Dim pos As Integer
        Dim cut As Integer
        Dim upTo As String

        'Das label für die Klassifizierung: Standard engl. "up to"
        upTo = TextBox_LegendLabel.Text

        count = ListBox_LegWhereClause.Items.Count
        ReDim WhereClauses(count)

        'WhereClauses einlesen
        For i = 0 To count - 1
            WhereClauses(i) = ListBox_LegWhereClause.Items.Item(i)
        Next

        ' Für jede WhereClause eine Abfrage bauen
        For i = 0 To count - 1

            pQueryFilter.WhereClause = WhereClauses(i)

            pFeatureClass = pFeatLayerLegendShape.FeatureClass
            pUpdateFeatures = pFeatureClass.Update(pQueryFilter, False)

            'Werte berechnen
            Dim indexClass As Integer
            Dim pFeature As ESRI.ArcGIS.Geodatabase.IFeature

            temp = TextBox_LegTargetField.Text.ToString
            indexClass = pUpdateFeatures.FindField(temp)
            pFeature = pUpdateFeatures.NextFeature

            Do Until pFeature Is Nothing

                'Aktuelle Wheere Clause auslesen:
                'Leerzeichen raus TRIM
                'String abschneiden bis inklusive "=" Zeichen FIND ", LEFT length – FIND
                'übrig bleibt letzter Schwellenwert --> up to
                temp = pQueryFilter.WhereClause
                len = temp.Length
                pos = temp.LastIndexOf("=")
                cut = (len - pos) - 2
                temp = Microsoft.VisualBasic.Right(temp, cut)

                pFeature.Value(indexClass) = upTo & temp '"up to " & temp
                pUpdateFeatures.UpdateFeature(pFeature)

                pFeature = pUpdateFeatures.NextFeature
            Loop
        Next

        'Button sperren (bis neue WhereClause generiert wurde)
        Button_LegCalcFields.Enabled = False

    End Sub

    Private Sub Button_LegTakeValues_Click(ByVal sender As System.Object, ByVal e As
        System.EventArgs) Handles Button_LegTakeValues.Click

        'Durch Semikolon getrennte Einträge aus Textfeld in ListBox eintragen
        'String splitten
        Dim stringArray() As String
```

```vb
    Dim count As Integer
    stringArray = Split(TextBox_LegThresholds.Text, ",")

    'Wie viele KOMMA?
    count = stringArray.GetUpperBound(0)

    Dim i As Integer
    For i = 0 To count
        ListBox_LegTreshValues.Items.Add(stringArray(i))
    Next

End Sub

Private Sub Button_LegendListClear_Click(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles Button_LegendListClear.Click

    ListBox_LegWhereClause.Items.Clear()
    ListBox_LegTreshValues.Items.Clear()

    'Calclulate Fields sperren
    Button_LegCalcFields.Enabled = False

End Sub

Private Sub TextBox_LegTargetField_TextChanged(ByVal sender As System.Object, ByVal e As
    System.EventArgs) Handles TextBox_LegTargetField.TextChanged
    'Nicht mehr als 10 Zeichen
    Dim name As String
    Dim len As Integer
    name = TextBox_LegTargetField.Text
    len = name.Length

    If len > 10 Then
        MsgBox("Fieldname limited to 10 characters")
        TextBox_LegTargetField.Clear()
    End If

End Sub

Public Function CreateFieldString(ByVal pField As ESRI.ArcGIS.Geodatabase.IField, ByVal
    pFieldEdit As ESRI.ArcGIS.Geodatabase.IFieldEdit, ByVal pTable As
    ESRI.ArcGIS.Geodatabase.ITable, ByVal name As String, ByVal laenge As Integer) As Boolean

    'Feldname zum Testen, ob Feld schon existiert
    Dim feld As String

    With pFieldEdit
        .Name_2 = name
        .Type_2 = ESRI.ArcGIS.Geodatabase.esriFieldType.esriFieldTypeString
        .Length_2 = laenge
    End With

    'Testen, ob Feld schon existiert
    feld = pField.Name

    If FieldExists(pTable, feld) = False Then

        pTable.AddField(pField)
        CreateFieldString = True

    Else
        CreateFieldString = False
    End If
End Function
Public Function FieldExists(ByVal pTable As ESRI.ArcGIS.Geodatabase.ITable, ByVal name As
    String) As Boolean

    If pTable.FindField(name) > -1 Then
        FieldExists = True
    Else
        'Feld ist noch nicht vorhanden, kann angelegt werden
        FieldExists = False
    End If

End Function

Private Sub ButtonHS_many_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
    Handles ButtonHS_many.Click

    'globales Flag setzten, dass Button many ausgewählt wurde
    FlagManyKDEFiles = True
```

```vb
        'Auswählen eines City Models (Shapefieles, polygon)
        Dim pGxDialog As ESRI.ArcGIS.CatalogUI.IGxDialog
        pGxDialog = New ESRI.ArcGIS.CatalogUI.GxDialog          'Reference Catalog muss
         auch hinzugefügt werden!

        Dim pGxFilter As ESRI.ArcGIS.Catalog.IGxObjectFilter
        'filter auf Shapefile
        pGxFilter = New ESRI.ArcGIS.Catalog.GxFilterShapefiles

        'Dialog vorbereiten, Eigenschaften setzen
        With pGxDialog
            .Name = "Select Shapefile"
            .AllowMultiSelect = True
            .ObjectFilter = pGxFilter
            .ButtonCaption = "Select"
            .StartingLocation = "C:\"
        End With

        'Objektrückgabe durch Dialog vorbereiten, zurückgegebenes Shapefile verarbeiten
        Dim pGxObjects As ESRI.ArcGIS.Catalog.IEnumGxObject
        Dim pGxDataset As ESRI.ArcGIS.Catalog.GxDataset


        'Ein Container, der alle ausgewählten Shapefiles speichert
        'ein Array von Typ FeatureLayer
        'Dieser Array muss funktionsübergreifend zur Ferfügung stehen
        pFlArray = New ESRI.ArcGIS.esriSystem.Array

        'Ein FeatureLayer
        Dim pFeatureLayer As ESRI.ArcGIS.Carto.IFeatureLayer
        pFeatureLayer = New ESRI.ArcGIS.Carto.FeatureLayer

        Dim pFeatureClass As ESRI.ArcGIS.Geodatabase.IFeatureClass

        'AuswahlDialog anzeigen
        pGxDialog.DoModalOpen(0, pGxObjects)

        'Nun zurückgegebene Objekte (Shapefile(s)) durchgehen
        pGxDataset = pGxObjects.Next
        'Wenn kein Shapefile ausgewählt wurde, ist pGxDataset LEER!
        Do Until pGxDataset Is Nothing


            ' Nun die Zuordnung des ausgewählten Objectes an den featureLayer über Featureclass
            pFlArray.Add(MakeFLayer(pGxDataset.Dataset))

            pGxDataset = pGxObjects.Next
        Loop

        'Array ausgeben
        Dim tempStr As String

        pFeatureLayer = pFlArray.Element(0)
        tempStr = pFeatureLayer.Name
        MsgBox(tempStr)

    End Sub

    Public Function MakeFLayer(ByVal pFc As ESRI.ArcGIS.Geodatabase.IFeatureClass) As
         ESRI.ArcGIS.Carto.IFeatureLayer
        MakeFLayer = New ESRI.ArcGIS.Carto.FeatureLayer
        MakeFLayer.FeatureClass = pFc
        MakeFLayer.Name = pFc.AliasName
    End Function
End Class
```

Questionnaire „3D tactical intelligence assessments"

FRAGEBOGEN „POTENZIALE GEOVIRTUELLER 3D-LAGEBILDER"

GIS-CONFERENCE, POLIZEIPRÄSIDIUM KÖLN, 24.11.2009

ALLGEMEINE KARTENKOMPETENZ

---

1. Haben Sie Erfahrung mit dem <u>Lesen</u> von Karten?

☐ Ja   ☐ Nein

2. Haben Sie Erfahrung mit dem <u>Erstellen</u> von Karten oder kartenähnlichen Darstellungen, gleichgültig welcher Thematik?

☐ Ja   ☐ Nein

CRIMEMAPPING

---

3. Beschäftigen Sie sich bei Ihrer Arbeit mit Methoden der <u>raumbezogenen Straftatenanalyse</u>?

☐ Ja   ☐ Nein (weiter mit Frage 9, Seite 2)

4. Wie beurteilen Sie Ihre <u>Kenntnisse</u> in der <u>raumbezogenen Straftatenanalyse</u> (CrimeMapping)?

☐ Sehr gute Kenntnisse   ☐ Gute Kenntnisse   ☐ Grundkenntnisse

5. Haben Sie die Ergebnisse Ihrer Straftatenanalysen schon einmal in Form von Karten <u>dargestellt</u>?

☐ Ja, regelmäßig   ☐ Ja, gelegentlich   ☐ Nein, nie

6. Wie viel Stunden pro Arbeitstag verbringen Sie in etwa mit der <u>Anwendung</u> von Methoden der digitalen Straftatenanalyse bzw. deren Darstellung?

☐ geschätzt _____ Stunden pro Arbeitstag

7. <u>Wie lange</u> beschäftigen Sie sich in Ihrer täglichen Arbeit schon mit der raumbezogenen Straftaten-analyse?

☐ Seit _____Jahr(en)

8. Sind Sie Mitglied eines <u>Teams</u> von Spezialisten bezüglich der raumbezogenen Straftatenanalyse?

☐ Ja, mein Team umfasst _____ Personen

☐ Nein, für diesen Bereich bin ich allein zuständig

BITTE WENDEN!

3D-LAGEBILDER

9. Haben Sie sich persönlich schon einmal praktisch mit der <u>dreidimensionalen Visualisierung</u> von Straftatenverteilungen befasst?

☐ Ja, intensiv   ☐ Ja, gelegentlich   ☐ Nein, noch nie

10. Für wie <u>sinnvoll</u> halten Sie die demonstrierten Möglichkeiten der interaktiven dreidimensionalen Visualisierung von Straftatenverteilungen generell?

☐ sehr sinnvoll   ☐ sinnvoll   ☐ weniger sinnvoll   ☐ nicht sinnvoll

<u>Kurze Begründung</u>:

☐ _____

  _____

  _____

11. Zur Vermittlung von Analyseergebnissen an Dritte und verglichen mit der traditionellen 2D-Karte, <u>wie</u> würden Sie persönlich die präsentierten <u>interaktiv</u> und <u>dreidimensional</u> aufbereiteten Darstellungen von Straftaten-Verteilungsmustern <u>einschätzen</u>?

☐ 3D-Visualisierung <u>besser</u> geeignet (als 2D-Karte mit gleicher Thematik)
☐ 3D-Visualisierung eine <u>sinnvolle Ergänzung</u> (zur 2D-Karte mit gleicher Thematik)
☐ 3D-Visualisierung in dieser Hinsicht <u>generell ungeeignet</u>
☐ sonstiges _____

12. Unabhängig von der technischen Umsetzung in der jeweiligen Dienststelle - wie schätzen Sie das Potenzial der präsentierten Methoden zur dreidimensionalen Visualisierung raumbezogener Straftatenverteilungen für die <u>praktische Polizeiarbeit</u> ein?

☐ sehr hohes Potenzial
☐ hohes Potenzial
☐ niedriges Potenzial
☐ nicht von Relevanz

ALLGEMEINE FRAGEN ZUR STATISTISCHEN AUSWERTUNG

12. Sind Sie

☐ Anwender (Polizist, Analyst, etc…)   ☐ Wissenschaftler

13. Alter: ☐<18   ☐ 19-25   ☐ 26-35 ☐ 36-45   ☐ 46-55   ☐ 56-65   ☐ >65

14. Berufsbezeichnung: ☐ _____

Vielen Dank für Ihre Mitarbeit!

Markus Wolff, Universität Potsdam, Institut für Geographie, Markus.Wolff@uni-potsdam.de

Papers and presentations

Papers

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