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Analysing Potentially Vulnerable Urban Areas with GIS and 3D City Models

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1 ABSTRACT

Metropolitan areas are exposed to a number of natural and man-made hazards. Within the group of man-made hazards metropolitan areas and mobility nodes can be considered as particularly vulnerable (Floeting 2007; Mitchell 2003). Due to their high concentration of technical, social and traffic infrastructure as well as their importance in politics, culture, economy and finance, metropolitan areas, in particular, can be considered as vulnerable environments (Swanstrom 2002; Coaffee 2003). Since not every part of an urban area is exposed to the same level of potential security threats, it can be assumed that this level differs regionally within 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. This analytical and geovisual potential of 3D city models can be instrumental for decision makers working in security agencies for both threat assessment and intuitive map-based communication of spatial phenomena related to urban security issues.

2 INTRODUCTION

Virtual representations of complex three-dimensional urban environments are constantly gaining popularity among both the scientific community and the wider public. Compared to the traditional medium for the communication of spatial related data – the two-dimensional map – virtual three-dimensional city models facilitate in-depth analysis and presentation of spatial data. Complex spatial situations like, e.g., planning scenarios, planning of mobile communication networks or noise and pollutant dispersal patterns are increasingly analysed and visualised by the use of 3D city models (Czerwinski et al. 2006, AWE 2000).

This paper presents an approach which couples GIS-based analysis with the 3D visualisation potential of virtual three-dimensional city models. This geoanalytical method is then applied to investigate selected issues in the field of civil security. As a prequisite this approach requires the integration of application-specific thematic information into existing city model databases. Taking the virtual 3D city model of the German capital Berlin as an example (Döllner et al. 2006a), this paper discusses selected geoanalysis methods targeted at data integration and vulnerability mapping of highly urbanised metropolitan regions.

Defining the terms “risk” and “vulnerability” is hampered by the fact that there are „as many different interpretations (…) as there are hazard researchers“ (Cutter 1993). Against this background vulnerability is defined here with Mitchell (2003) as a function of „exposure to risk, resistance to risk and resilience in the face of disaster“. The product of vulnerability and risk is termed a hazardous event. Relating urban environments to the above definitions, different urban regions can be characterised by different levels of exposure, resistance and resilience compared to possible security threats. The result is different levels and spatial distributions of vulnerability. A method to map and analyse regions which different degrees of exposure is presented in chapter 3. For this work data are processed in a commercial GIS (ArcGIS) and the 3D LandXplorer software system (Döllner et al. 2006b).

Of prominent importance in geoanalysis of urban environments are built-up areas, street and public transport network of a particular city. The database of the used Berlin city model 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: Topographic map K5 (scale 1:5,000), digital terrain model (resolution 25m), high resolution aerial photography (HRSC, resolution 20cm)

For further investigation, a study area has been selected that 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" (Kurfürstendamm boulevard) of the city as well as its "eastern centre" (Alexanderplatz Square).

3 SEMANTIC EXTENSION OF THE GEO-DATABASE FOR IMPACT ASSESSMENT ANALYSES

Detailed semantic information supplementing the existing built-up and street network datasets is crucial for any geovisual analysis. It has already been mentioned that three-dimensional city models are more and more available, with various cities possessing their own digital 3D representations. Typical datasets included in such databases contain, e.g., cadastral and topographic information, respectively, as well as information relating to buildings, such as use or function, dimensions, height, etc. What is widely lacking with these databases, however, is application-specific thematic content linked to the different topographic and 3D data layers. A workflow is described to enrich existing city model databases with thematic information required to conduct special-purpose geoanalysis in the field of civil security (cf. figure 1).

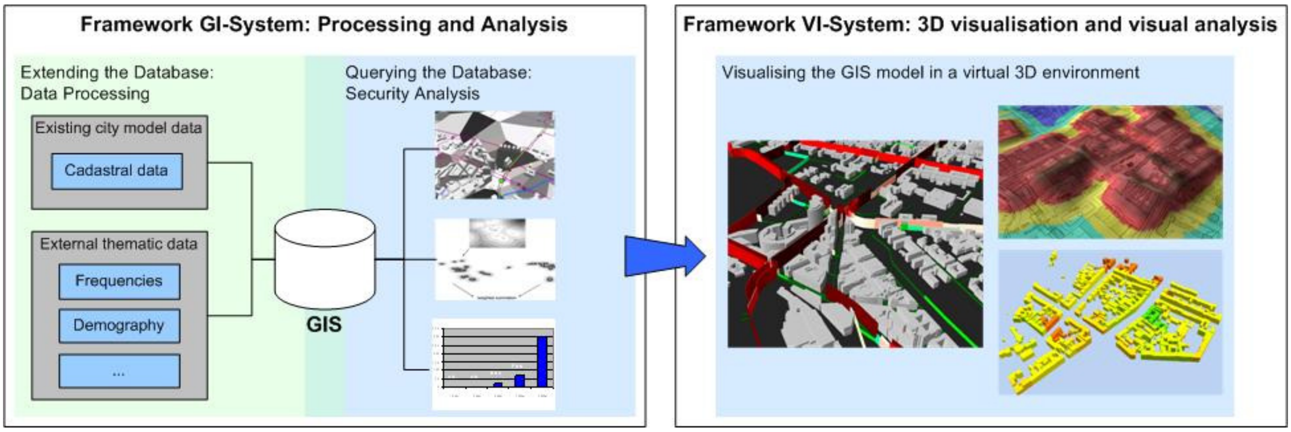

Fig. 1: Workflow for augmenting typical city model databases with application-specific thematic information. In GIS, thematic information is added to existing databases, which allows for analysing pedestrian flows and demographic parameters (left). In addition, this information is pipelined into a visualisation system which facilitates visual analysis through 3D visualisations (right).

3.1 Populating the building dataset: Adding frequencies and demographics

An important factor in security related analysis of mobility nodes and metropolitan areas is detailed information on the activity flows within 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 not yet 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 transport frequencies. Frequencies are calculated as average values per hour on a working day basis for the years 1999 to 2005 (Data description FAW-frequency-Atlas 2006). Technically speaking, one FAW point exists with the corresponding frequency values for each road segment. 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: Number of pedestrians, cars and public transport carrier that frequent any given street segment per hour of an average working day (cf. figure 2).

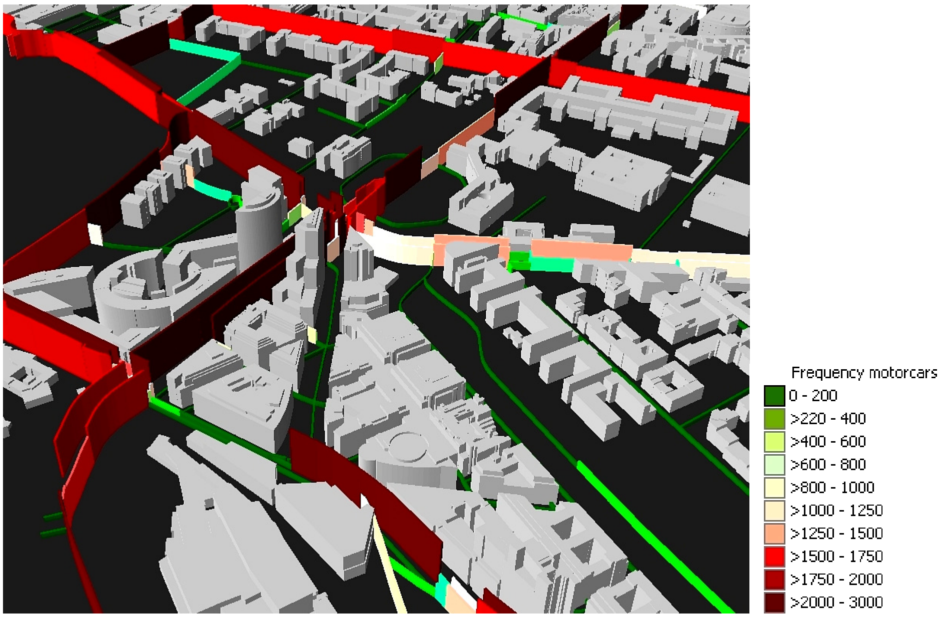

Fig. 2: 3D visualisation of street segments according to their frequency information for cars (green to red colored walls). Segment height and colour indicate the respective frequency values. Area shows Potsdam and Leipzig Squares (centre) in central Berlin. Frequency data provided by FAW.

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 3). First, centroids of each building are calculated (upper left). Second, new points are created along the road segments for every 30 meters (upper right). Third, the four nearest segment points, based on each centroid, are identified (lower left). Finally, an average value is calculated from their frequency values which is assigned to the whole building (lower right). As a result, such "smart" buildings can be queried for their frequency data.

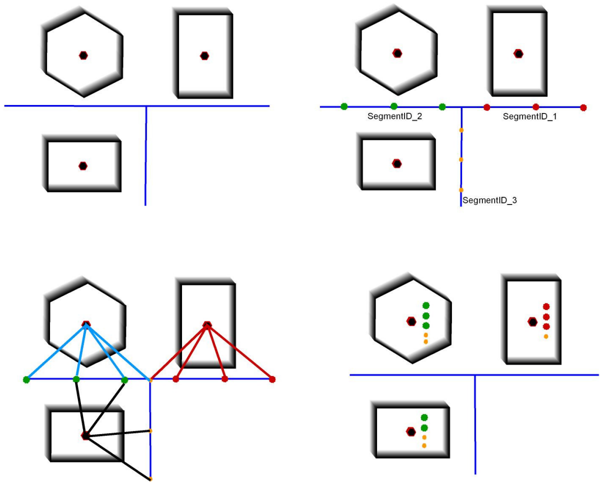

Fig. 3: Schematic representation of algorithm application to transfer frequency values from road segments to adjacent buildings.

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 within 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.

Similar to the 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. Data are, however, not available for single buildings for data privacy reasons 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 4 is a 3D visualisation showing purchasing power related to each building block.

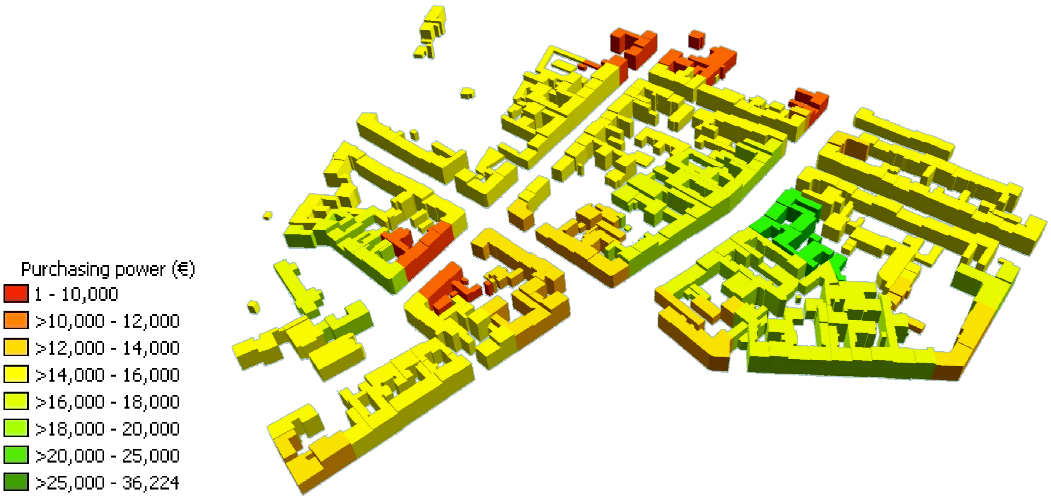

Fig. 4: 3D visualisation of purchasing power by building block. Data provided by GfK.

4 USING THE AUGMENTED 3D DATABASE FOR URBAN RISK ANALYSIS

The augmented 3D city model database is a prerequisite for further and in-depth geoanalysis of urban risk and vulnerability. The broad range of thematic data integrated into the database allow, e.g., for further spatial analysis in the context of an urban impact assessment. Such analysis will, however, not produce any precise results which building (the element-at-risk, EAR), e.g., is exposed to an increased threat of what nature. For such evaluation of factual threat levels, a substantial amount of additional data would be required, many of which are not available publicly. In this context Koonce et al. (2006) 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 security threats.

4.1 An urban impact assessment for a certain element at risk

Dealing with the nature and location of potentially hazardous events in urban environments, 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 decisive to differentiate whether the structure is surrounded by open space or by dense urban housing. To perform such 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 second step the intersections of impact zones and buildings allow for statistical analysis based on the built-up-area database. This analysis shows that buildings within zones one to three (up to 500 m from the EAR) are passed by an average of 200 pedestrians. This value is decreasing 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 (figure 5). As a consequence the number of potentially affected pedestrians is decreasing while the number of residents is increasing.

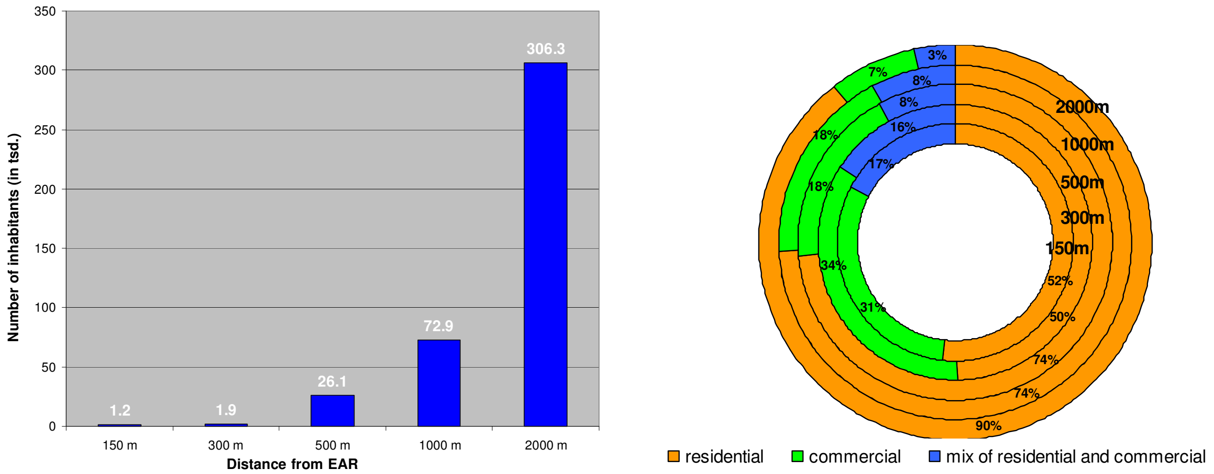

Fig. 5: Distribution of population figures (left) and building occupancy (right) per impact zone.

4.2 Analysing different levels of threat exposure in city environments

In the following an approach 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 within 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 1).

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

Table 1: Reclassification of distance based values.

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 6).

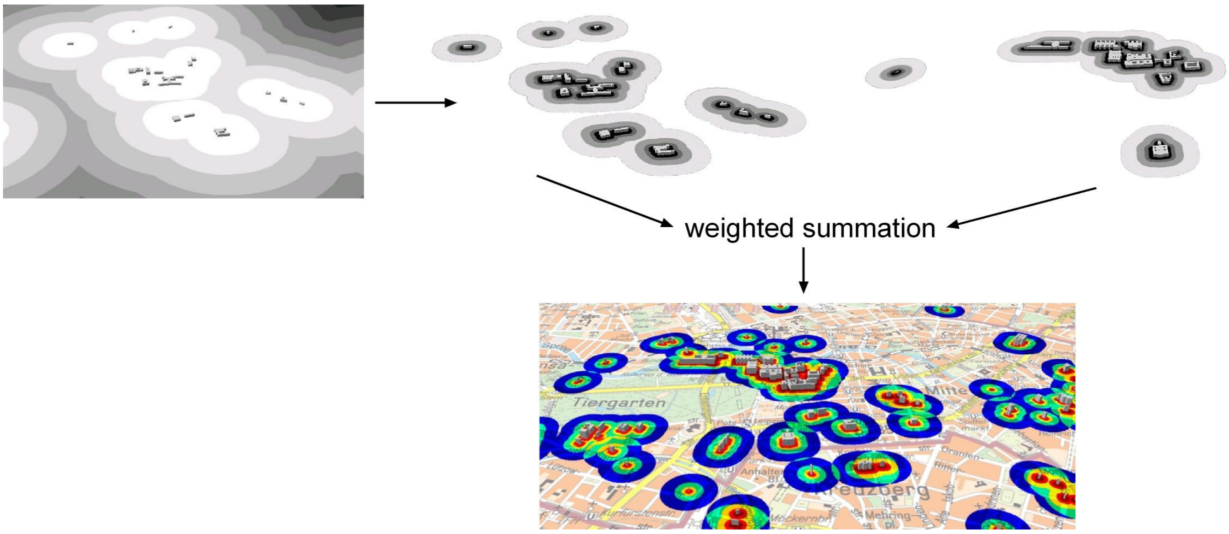

Fig. 6: Workflow to identify different levels of threat exposure. Based on grids of proximity values to the closest exposed building (upper left), a set of new grids with different regional levels of exposure is calculated by reclassification for each basis building class (upper right). Combination of 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 has been automated by developing a GIS tool using ESRIs ArcObjects based software development framework. Our ArcObjects tool facilitates an automated and fast processing of the single grids. 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 1.

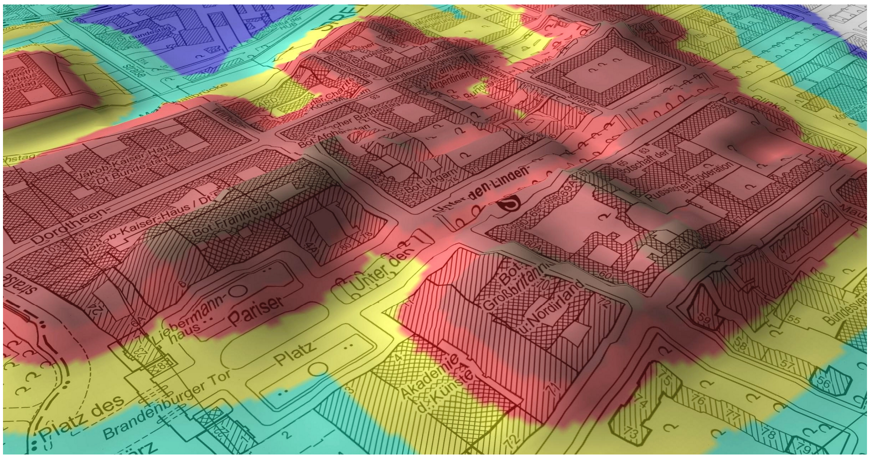

Fig. 7: 3D visualisation of areas with increased exposure level based on the location of vulnerable buildings, area Brandenburg Gate.

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 7). 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 includes an overlay of the exposure grid of embassy offices and is a graphic, easy-to-read visualisation of the spatial distribution of threats in urban environments.

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 within 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 those regions characterised by a number of inhabitants above average, significant purchasing power and high financial status (derived from net income per household).

4.3 Visibility analysis for specific buildings

Regarding the analyses of security related problems it is frequently important how well a building or area can be seen from specific positions. In contrast to GIS maps (2D/3D) virtual three-dimensional city models provide an excellent medium for 3D visibility analysis. To conduct this analysis a software tool called “visibility calculator” of the LandXplorer visualisation system is used. Based on user defined positions, this plug-in allows for calculation of visibility for a defined object within the 3D city model.

As an example the British embassy near Brandenburg Gate has been chosen as a target object. The viewing position is located on the roof of a high-rise building approximately 1.3 Kilometres away (figure 8). From this observation point, the tool calculates the parts of the embassy building visible from this perspective. As figure 8 shows, only a small strip of the upper front façade can be seen from the building.

Another example of 3D-visibility analysis is shown in figure 9. For a given linesegment the visibility of the side front is calculated. Passing the corner, the side front only can be seen from a small section of the line (from a road segment, e.g.).

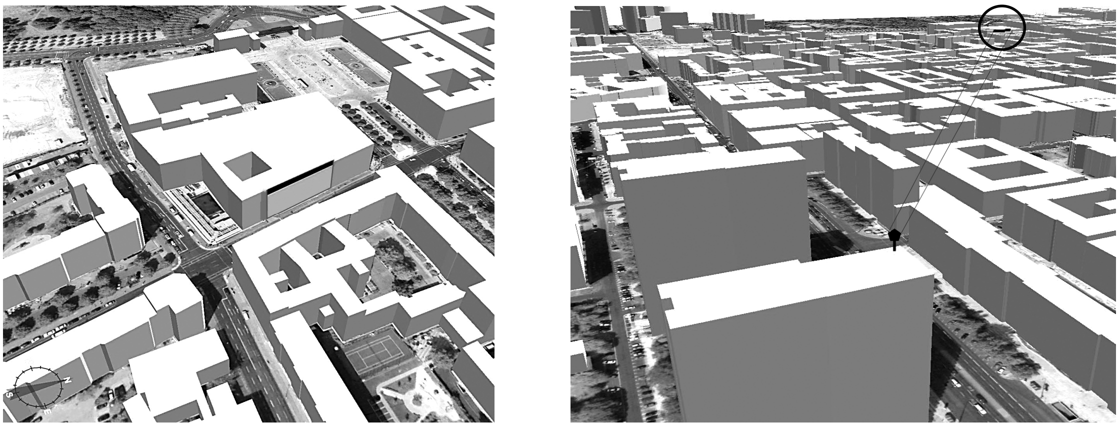

Fig. 8: 3D visibility analysis within the virtual city model using the example of the British embassy (left, building within the circle). An observer placed on a multi storey building aprox. 1.3 km away can just see a small strip on the upper front façade (right, black pigmented rectangle).

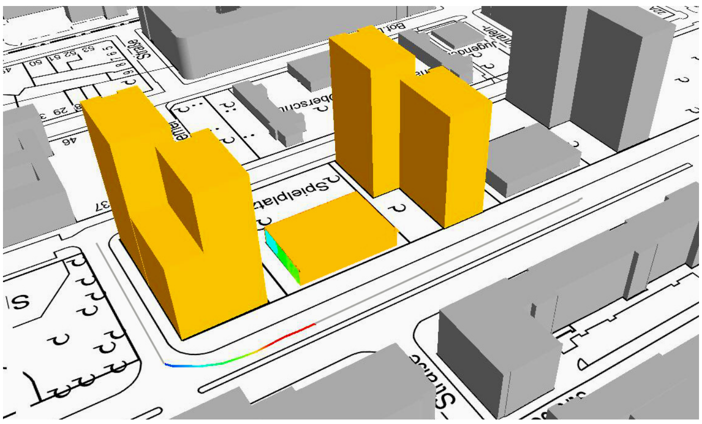

Fig. 9: 3D visibility analysis based on a line. Passing the corner, the side front can only be seen along the first line segment.

5 SUMMARY

This paper presents an approach 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 can be identified. By combining function-specific grids with threat exposure levels the spatial distribution of threat levels can be mapped. The resulting geographic distribution can subsequently be combined with additional socio-demographic or infrastructure data for further geovisual analysis.

6 ACKNOWLEDGEMENTS

Funding of this study by the German Federal Ministry of Education and Research (BMBF) within the framework of the InnoProfile research group '3D Geoinformation' (www.3dgi.de) is gratefully acknowledged. The authors also like to thank the German Association for Outdoor Advertising (FAW) for providing frequency atlas data, the German Society for consumer research (GfK) for providing social-demographical data and Berlin Partner GmbH for use of the official Berlin 3D city model.

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