QUANTIFYING URBAN RISK AND VULNERABILITY – A TOOLSUITE OF NEW METHODS FOR PLANNERS

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QUANTIFYING URBAN RISK AND VULNERABILITY – A TOOLSUITE OF NEW METHODS FOR PLANNERS

W. Riedel[1], Albert Nieuwenhuijs[2],K. Fischer[1], S. Crabbe[3], W. Hynes[4], I. Müllers[5], S. Trojaborg[6] and I. Häring[1]

[1] *riedel@emi.fraunhofer.de,* Fraunhofer EMI, Eckerstr. 4, 79106 Freiburg (D)
[2] *albert.nieuwenhuijs@tno.nl*, TNO, Waalsdorperweg 63, 2597 AK, Den Haag (NL)
[3] *stephen.crabbe@crabbe-consulting.com*, CCLD, Allerheiligenstr. 17, Erfurt (D)
[4] *william.hynes@futureanalytics.ie*, Future Analytics, 23 Fitzwilliam Squ., Dublin 2 (IE)
[5] *imuellers@schuessler-plan.de*, SP, St.-Franziskus-Str. 148, 40470 Düsseldorf (D)
[6] *sst@dw.dk*, Dissing+Weitling Architecture, Dronningensg. 68, 1420 København (DK)

Abstract

Increasing urbanisation drives the need for new solutions for security issues on all levels of urban planning. This paper describes a toolset of computer assisted tools that enables urban planners and associated parties, such as architects or engineers to make well-considered, systematic, qualitative and quantitative assessments of urban areas regarding security issues. In the long-term this will contribute to more robust and resilient cities with a quantitative balance between costs and benefits.

Keyword: Urban planning, security, risk, consequences, terrorism, crime, traffic, cost

1 INTRODUCTION

At this moment, more than half of the world population lives in urban environments. A rise to 80% by 2050 is predicted [1]. This concentration of population increases associated security issues. As traditional mitigation measures prove to have limitations, cities are looking for new solutions. The VITRUV toolsuite offers such a solution in enabling urban planners to design security into their plans to:

- Make well-considered systematic qualitative analyses with decision support at the *“concept level”* (see Section 2),
- Analyse the susceptibility of urban spaces (e.g. building types, squares, private and public transport and their functionalities) with respect to new threats at the *“plan level”* (see Section 3.1), and
- Perform vulnerability analyses by computing the likely damage to individuals, buildings, traffic infrastructure at the *“detail level”* (see Section 3.2).

All levels contribute to enabling the development of more robust and resilient structures with respect to urban (re)planning, (re)design or (re)engineering.

2 DECISION SUPPORT AT THE CONCEPT LEVEL

At the first stage of urban planning, there is a general formulation of the elements to be contained in a new or a re-development. Even in this early stage, the urban planner can obtain a clear understanding, which security issues require attention by using the SecuRbAn [2] risk assessment tool and Urban Securipedia knowledge base. These tools are used in conjoined fashion, as illustrated in Fig. 1.

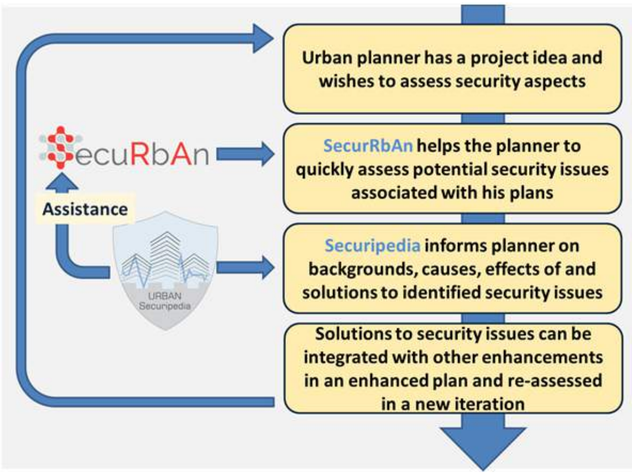

Fig. 1: Use of SecuRbAn and Urban Securipedia in the urban planner's process.

2.1 SecuRbAn Risk Assessment Tool

SecuRbAn [2] is essentially a self-assessment tool which performs a quick and efficient risk analysis on the intended or existing urban design based on the planner's answers to a set of questions. The assessment provides a clear overview of potential security issues. Performing a new assessment with the tool will take an experienced user about half an hour, re-assessments can be done quicker.

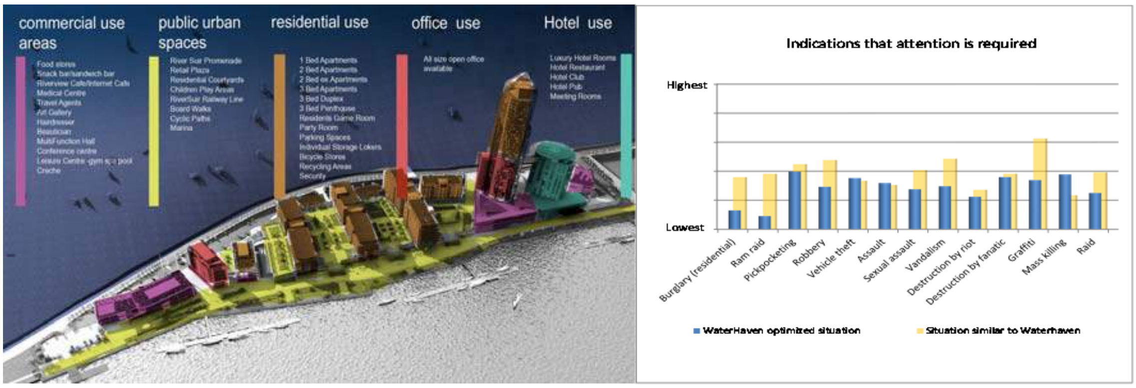

Fig. 2, Left: Application case Water Haven of Waterford City (courtesy of Bolster Group); Right: SecuRbAn assessment comparing an optimized layout (blue) to a district elsewhere (yellow).

The tool supports the comparison of two different designs, e.g. of the same plan, and can thereby quickly identify disparities in security levels (see Fig. 2). It also presents in a transparent fashion which answers resulted in the varying security scores – a feature which is very helpful for finding solutions – and it directs the user to relevant information on the security issues in the online knowledge base Urban Securipedia [3]. The assessment score is based on a weighted evaluation of the occurrence of indicators for increased or decreased security with regards to 13 relevant crime types. The indicators and the scientific studies underlying them are described in [3].

2.2 Urban Securipedia online Knowledge-Base

Urban Securipedia [3] is a comprehensive online knowledge base containing:

- Information on a wide range of 13 different crime types in urban environments, ranging from pickpocketing to mass killing; included are factors identified as causes of the problems, associated economic, social, mobility and safety issues and mitigation measures that could be effective for each specific crime type;

- Information on the application of measures, including their effectiveness and their social, economic, safety and legal drawbacks;
- Generic information on security and how to deal with it from the point of view of the urban planner;
- A wide range of references to more extensive scientific and practical information sources.

The knowledge base is built on the familiar Mediawiki platform known from Wikipedia and it offers ample opportunities to find and access the contained knowledge. Its contents are written to provide easy access to concepts which might be unfamiliar to urban planners, such as specialised security terminology. The knowledge base is freely accessible on-line [3]. A screenshot of the opening page is presented in Fig. 3.

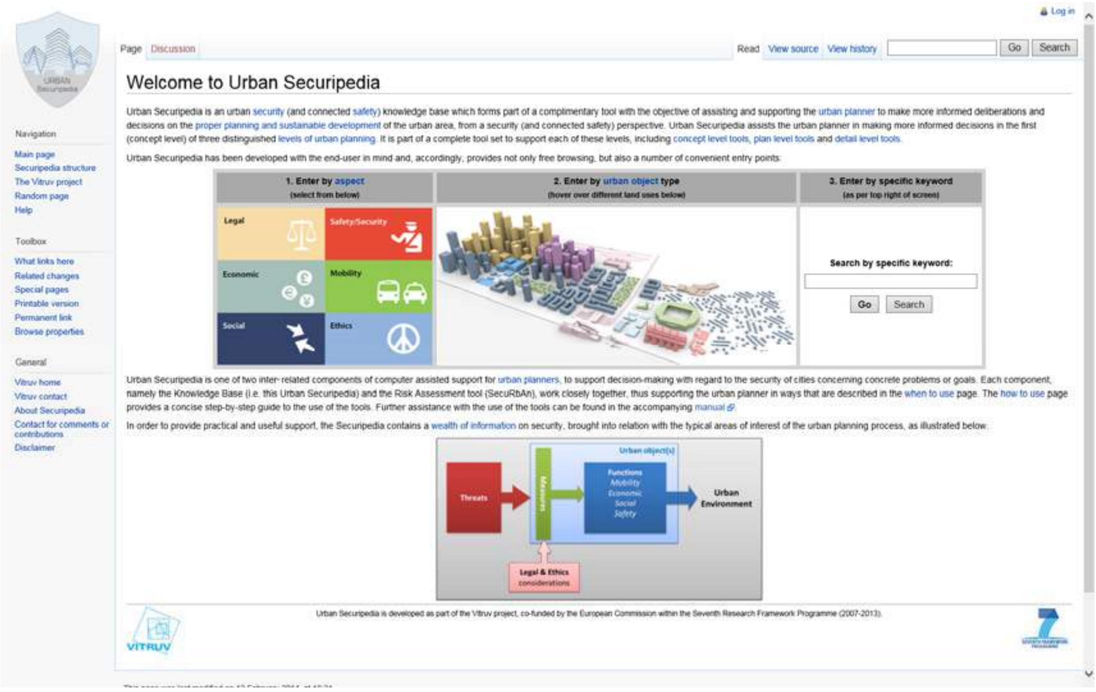

Fig. 3: Urban Securipedia screenshot: The opening page.

The two tools together permit the urban planner to include security into his/her plans from the very early conceptual stages of urban planning. As the plans at this level are generic and of limited detail, so is the advice. Further planning details and quantitative measures against a subset of threat types are supported by the 3D planning tools described in the following section.

3 DECISION SUPPORT AT THE PLAN AND DETAIL LEVEL

3.1 Plan Level Assessment using Empirical Data of Past Events

3D digital representations of an urban area are used for more detailed and quantitative assessments, with focus on explosion effects, propagation of poisonous gases and criminal behaviour. The planner can choose pre-defined, physically fully detailed buildings from a catalogue with a wide range of urban infrastructure types and uses (e.g. Fig. 4, Fig. 6, [4]). This fast approximation of the actual urban buildings allows a judgement based on physical background without demanding very deep engineering knowledge of the planner.

On the *"plan level"* Eq. (1) – (3) are essentially used to derive the empirical risk. For a given threat type T_i^{threat} a single urban object $\vec{b}_k$ has a number of hazardous events

$N(T_i^{threat}, \vec{b}_k)$ occurring in a time interval t_{threat}. Eq. (1a) describes the empirical frequency P_{event} in dependency of the building category and the threat. It can be enriched by normalized empirical scaling factors s_{ij} of safe or critical neighbourhoods, increased surveillance etc. to obtain the frequency F_{event} (1b). The frequency is related to the number of buildings for a special category $N_{\vec{b}_k}$. The data is based on the German "Terror Event Database TED" [4] and UK Home Office reports on crime [5], [6]. The latter is implemented as a research version with crime data for West Yorkshire, UK provided by the region's police force as a project partner.

$$P_{event}(T_i^{threat}, \vec{b}_k) = \frac{N(T_i^{threat}, \vec{b}_k)}{N_{\vec{b}_k} \cdot t_{threat}} \quad \left[\frac{events}{year}\right]$$

$$F_{event}(T_i^{threat}, \vec{b}_k) = P_{event}(T_i^{threat}, \vec{b}_k) \cdot \prod_{j=1}^{4} s_{ij} \quad \left[\frac{events}{year}\right] \qquad (1a,b)$$

$$C_{event}(T_i^{threat}, \vec{b}_k) = \frac{D(T_i^{threat}, \vec{b}_k)}{N(T_i^{threat}, \vec{b}_k)} \quad \left[\frac{consequences}{event}\right] \qquad (2)$$

$$R(T_i^{threat}, \vec{b}_k) = F_{event}(T_i^{threat}, \vec{b}_k) \cdot C_{event}(T_i^{threat}, \vec{b}_k) \quad \left[\frac{consequences}{year}\right] \qquad (3)$$

The empirical consequences C_{event} (2) are derived from the same databases to provide magnitudes of empirical damage $D(T_i^{threat}, \vec{b}_k)$ (e.g. number of injured people, financial damage of burglary) related to the number of events $N(T_i^{threat}, \vec{b}_k)$. They depend also on the threat type T_i^{threat} and the considered urban object $\vec{b}_k$. Finally, the empirical risk *R* (3) is defined as the product of the frequency *F* and the consequence *C*. Fig. 4 shows consequence measures for terror events (left) and monetary risk of crime (right) on the example of the Water Haven project at Waterford City, Ireland.

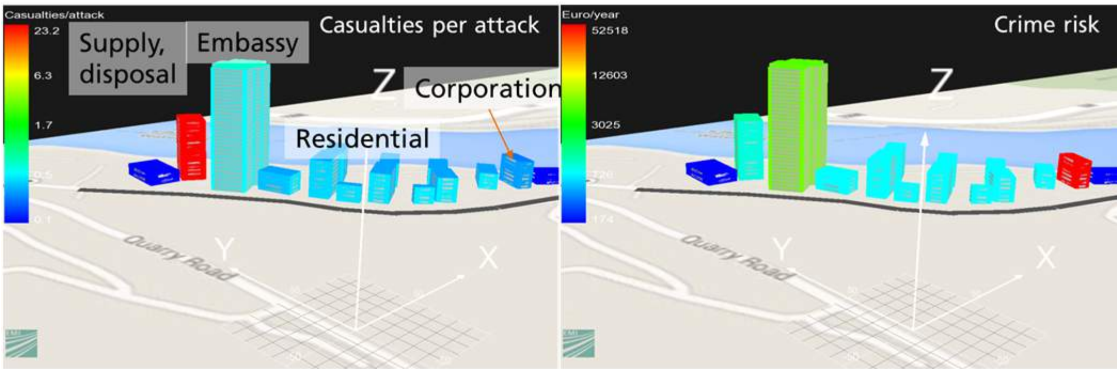

Fig. 4, Left: 3D Model of Water Haven with types of buildings and empirical consequences in terms of injuries + fatalities per attack; Right: Empirical monetary risk analyses for crime.

Recent detailed mathematical investigation of the statistical accuracy of the results derived by the empirical data revealed that the prediction of the frequency of terror events is well based, while the confidence interval for the values of the consequence measures is often very large [7]. Based on Eq. (3) the resulting, purely empirical based risk can only give a first indication of important urban configurations to look at.

3.2 Detail Level Analysis introducing Physical Consequence Models

To be able to accurately assess the likelihood and consequences of hazardous events involving explosives, chemical or biological substances, a more detailed and accurate representation of the area is required. The instantaneous but less accurate *"plan level"* calculations can therefore be supplemented at the *"detail level"* by more accurate physically based consequence models running in minutes to hours. They lead consequently through Eq. (3) also to better risk predictions. Furthermore they allow to consider neighbourhood and physical protection measures (see 3.2.4). The approach is suitable for a wide range of consequence models, current implementations of functionalities into the VITRUV software are briefly described below and in Fig. 5.

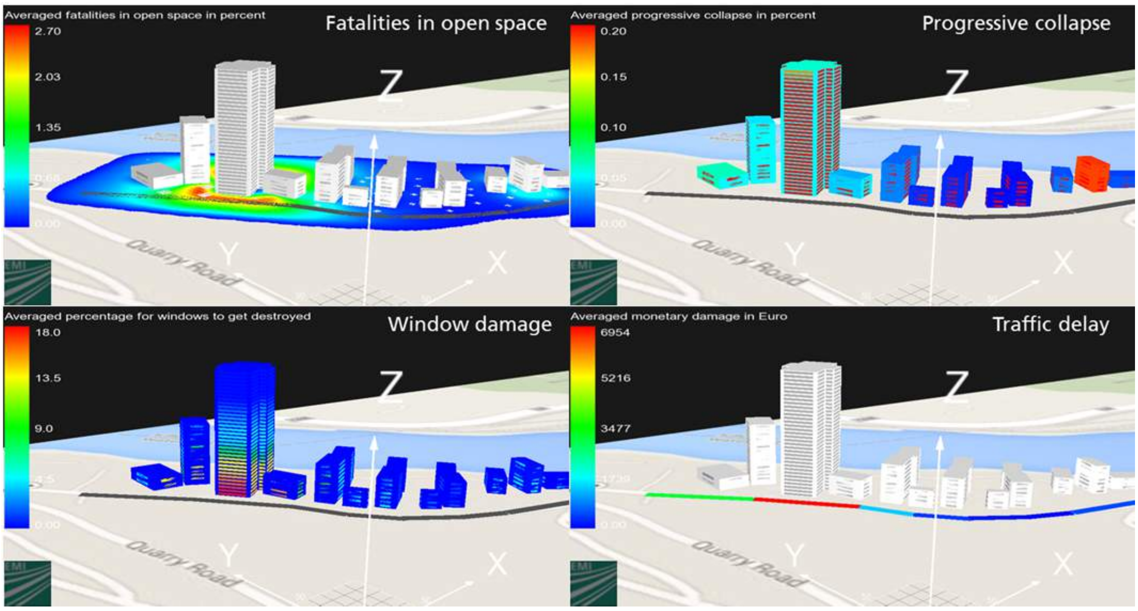

Fig. 5: Consequence calculations for quantitative risk analyses. Upper left: Fatalities in open space. Upper right: Progressive collapse of buildings. Lower Left: Window damage. Lower right: Monetary damage caused by traffic delay.

3.2.1 Explosion Effects on Buildings and Persons

The risk posed by a wide range of intentional or accidental explosion sources can be accurately assessed in the VITRUV toolset, using pressure-time-loading functions with empirical equations e.g. by Kingery and Bulmash [8] for mass-distance relationships.

The damage for persons and for buildings can be determined using probit-functions or simplified mechanical models, such as single-degree-of-freedom (SDOF) approaches [9]. Typical person densities and reconstruction values have been defined by experienced civil/structural engineers for each building type and use, which allow quantitative damage predictions to persons and buildings in the software (see Fig. 5).

Name	Persons []	Casualties []	Monetary damage [€]
Residential1	32	0.0306	1,173 €
Residential4	7	0.00336	50 €
Residential7	5	0.000789	9 €
Residential8	24	0.00808	434 €
Shopping mall1	155	0.0406	1,120 €
Commercial	145	0.0938	6,316 €
Residential2	63	0.0315	1,377 €
Residential3	56	0.0275	1,208 €
Residential5	42	0.0097	264 €
Residential6	49	0.0112	315 €
Shopping mall2	46	0.00454	35 €
Sports_Hall-Conference_Facility	554	0.338	7,630 €
Multinational-corporation	33	0.0137	15,858 €
Hotel_w_mixed_uses	1,120	0.503	171,159 €
Total:	**2,331**	**1.127**	**206,947 €**

→

Name	Persons []	Casualties []	Monetary damage [€]
Residential1	32	0.000425	8 €
Residential4	7	0.00038	5 €
Residential7	5	0.000528	8 €
Residential8	24	0.000577	12 €
Shopping mall1	155	0.00257	139 €
Commercial	145	0.00102	61 €
Residential2	63	0.0013	26 €
Residential3	56	0.000508	11 €
Residential5	42	0.000706	15 €
Residential6	49	0.00228	48 €
Shopping mall2	46	0.000785	15 €
Sports_Hall-Conference_Facility	554	0.00242	55 €
Multinational-corporation	33	0.0166	1,311 €
Hotel_w_mixed_uses	1,120	0.52	39,969 €
Total:	**2,331**	**0.55**	**41,683 €**

Fig. 6: Damage to persons and buildings in the original (left) and the improved configuration of Fig. 5, allowing cost-benefit analysis for re-configuration and protection measures.

3.2.2 Travel Times and Cost on Disturbed Traffic Networks

As mobility is an important aspect of urban planning and resilience, the consequences of interuptions on transport networks can be assessed. The empirical code CONWEB has been used to derive crater depth for various types of traffic borne explosion sources. Together with reconstruction costs per length of traffic element (street, rail traffic) defined by civil engineers, repair cost estimates are provided directly.

The traffic simulation software Visum 12.01 from PTV Planung Transport Verkehr AG which is based on engineering equations on generation and allocation of numerous individual trips has been used on a number of traffic disruption scenarios (see Fig. 7, left). The calculations considered different level of streets (local highway, trunk, shopping, collecting, residential and commercial roads) and public transport (bus and light rail). By introducing disturbances (red dot in Fig. 7, left), typical consequences in terms of increased travel times and costs for deviations and reconstruction were assessed, tabulated and implemented into the VITRUV detail level tool.

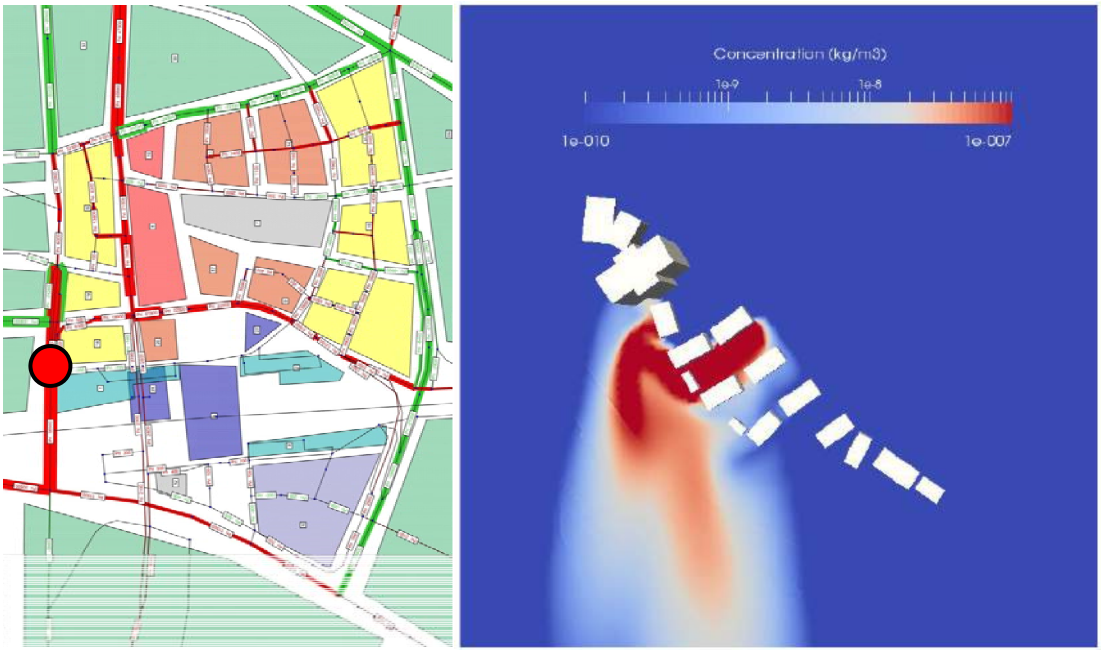

Fig. 7: Left: City and traffic model to derive engineering equations for disruption of different traffic elements, such as streets of different hierarchy, bus and train lines. Right: Concentration for biological dispersion on the Water Haven example.

3.2.3 Biological or Chemical Dispersion with Critical Concentration Thresholds

The computational fluid dynamics Code-Saturne (CFD) has been coupled by Thales Communications and Security SAS to the 3D urban representation. It computes automatically the dispersion of biological and chemical substances. One example calculation on the Water Haven test case is shown in Fig. 7, right. The results are coupled in turn with the typical - pre-defined but changeable - person densities of affected open spaces. A following evaluation against concentration levels with AEGL level 1 – 3 and above allows the prediction of injuries and fatalities (no injury, 40%, 90% injury, injuries and fatalities).

3.2.4 Vulnerability Modelling Approach and Resilience Enhancement Measures

Calculations of single incidents, as shown in Fig. 7, right, have a potential for misuse when made available to a broader range of software users. The interest of an urban planner is also not to calculate or harden against single scenarios, since this will lead to over-design compared to other intentions of urban planning.

Therefore, a vulnerability approach has been implemented into the VITRUV detail level tool. The software automatically determines and calculates numerous possible threat locations (see Fig. 8). The analysis is run for all threat positions and given as a summed mean but quantitative risk for all attacks. This approach allows the identification of the weakest spot in an urban configuration without any linkage to the best attack position and tactics. The urban planner can then increase the resilience by reducing the quantitative risk where the effect is most pronounced while balancing with inconveniences and increased costs as predicted by the tool.

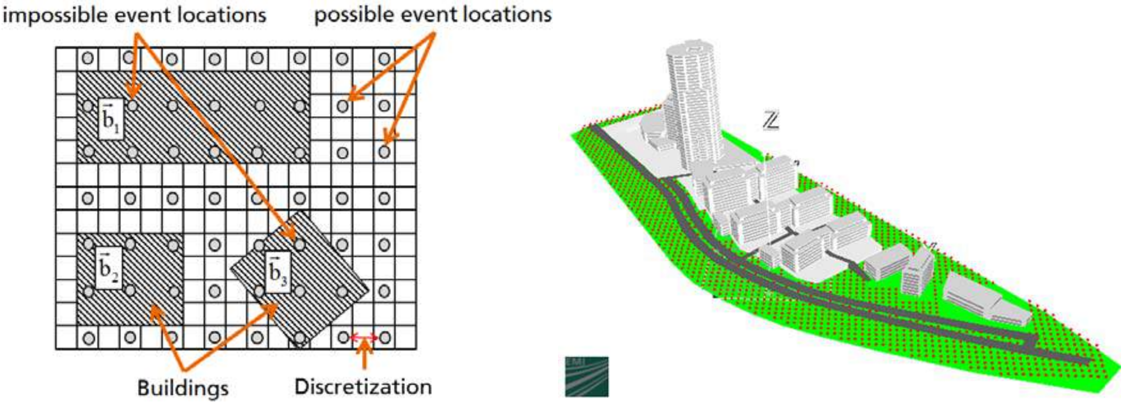

Fig. 8: Event location grid for an urban area (left) and the practical realization in the VITRUV software (right) on the Water Haven example test case.

The *"detail level"* tool provide the planner with a choice of possibilities to reduce the risk and thus increase the resilience of the urban area, including:

- Spatial re-configuration of the arrangements of critical building types and their accessibility through streets and open spaces;
- Physical countermeasures, such as bollards, security glazing or protection materials (e.g. [9]), further described in [3].

The effectiveness can be calculated as reduced damage and risk numbers (e.g. Fig. 5). The associated cost factors allow for a base-level quantitative cost-benefit analysis.

4 SUMMARY

A suite of computerized tools has been developed under the name *VITRUV* and is readily available for security considerations in urban planning. All the tools were intensively tested over a 12 month period in the project with representative users from urban areas in Bologna, Copenhagen, London and Waterford.

SecuRbAn [2] provides qualitative but well-structured decision support at the "*concept level*", before site maps are drawn. The tool assesses the potential relevance of security issues for (re)developed of urban areas based on a questionnaire. It allows the comparison with different configurations and similar situations. The support tool is linked with and supplemented by the online *Urban Securipedia* knowledge base [3] which provides a wider range of security relevant definitions, background and potential countermeasures to the user.

When maps are to be drawn, or partly exist for an area to be re-developed the *"plan and detail level tools"* allow quantitative risk analysis to be undertaken by none-specialist users. The 3D graphical analysis is based on a wide range of urban infrastructure types including their use and cost. First fast analysis on the "*VITRUV plan level"* is based on empirical data extracted from TED [4]. Transfer of the methods to crime data from UK sources [5], [6] has been initiated in the project and initially tested. The software allows the evaluation of the susceptibility (empirical probability of an event) of urban objects and their users and the vulnerability (empirical consequences per event). The quantitative empirical risk can be computed as the product of both quantities.

Statistical analysis [7] has shown that the quality of the empirical data is superior for the probabilities compared to the consequences – and thus also the risk. Empirical analysis extrapolates from past events, can furthermore not consider the neighbourhood of different susceptible urban objects and the effect of enhancement measures.

An additional refinement step allows on the "*VITRUV detail level*" a more accurate but more time-consuming prediction using physical consequence models. A wider range of model physics and algorithmic types is possible, so far the following functionalities have been implemented:

1) Explosive threats and effects, using empirical mass-distance relationships for the loading and SDOF mechanical models for the damage to infrastructure and persons, together with enhancement products and their associated costs;
2) Engineering tables to evaluate progressive collapse, derived from linear dynamic in combination with non-linear static finite element analyses of typical building structures;
3) An engineering model for traffic disruption, calculating delay times and reconstruction costs;
4) Poisonous gas clouds (biological or chemical) in CFD calculations combined with threshold concentrations for damage to humans.

The consequence models include quantitative damage, e.g. as human injury, structural damage and cost. Functionalities 1 to 3 are provided with enhancement measures including price estimates that allow cost-benefit analysis of re-configured urban areas with improved security.

ACKNOWLEDGEMENTS

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