Visualization of a Fire Risk Index Method with Combined Deferred Maintenance Cost Estimation within a BIM Environment

Kristian Schatz[1] and Uwe Rüppel[1]

[1]Institute for Numerical Methods and Informatics in Civil Engineering, Department of Civil and Environmental Engineering, Technische Universität Darmstadt, Germany; email: {schatz, rueppel}@iib.tu-darmstadt.de

ABSTRACT

The goal of fire protection activities are to prevent fires, rescuing people and ensuring the effectiveness of firefighting. To achieve these goals for complex buildings, holistic fire protection concepts are developed which should take into account the special characteristics of each building. To ensure fire safety during the building lifecycle a maintenance strategy is required. This includes recurring site inspections by experts, especially when a building needs to be refurbished or in the context of a technical due diligence during real estate transactions. If a malfunction of a fire safety element is detected in the context of these inspections, this is called a fire protection deficiency. These deficiencies decrease the fire safety rating of the building, increase the risk level and results in deferred maintenance costs. For the analysis of the fire risk level and for risk comparisons between buildings and fire protection concepts different techniques and approaches are available, that are summarized under the term risk methods. A problem during this process is, that findings and results from risk assessments are difficult to bring together with the real building. Information of the influence of individual fire safety deficiencies (technical, structural fire protection elements/components) on the risk level of the whole building and the associated repair and replacement costs are not directly related. This relationship must be associated in the experts mind based on different documents. To overcome these limitations and to support the planning of deferred maintenance tasks the goal of the presented approach is to visualize all required information within a BIM environment.

INTRODUCTION

In the fire safety engineering context, the term security defines the degree of certainty that damages to persons and property do not occur in excessive and unexpected dimensions. In general, it is the task of the fire safety engineer to take into account the principles of fire safety during the building design phase. The term fire safety summarizes all measures for fire prevention and fighting to minimize fire damage. Only through optimal interaction of the individual fire safety measures an adequate security level for a building can be ensured. The base for this is the fire safety concept.

A sufficient security level exists when, for example, the failure of a structure in case of fire within a limited time occurs with an acceptable small probability (residual risk). The residual risk is due to the false behavior of people, technical failures and uncontrollable natural conditions. The goal of fire protection measures is to reduce the residual risk to achieve the safety objectives. The basis for such fire safety concepts are the results of risk assessments. In this context in addition to the deterministic engineering methods, probabilistic methods are used.

The term risk is the occurrence of an event with a negative outcome, which is connected to disadvantages, loss or damage. In general, the risk is the product of probability of occurrence of an event and its consequence related to the target deviation and should be valued in the unit of the target size. In general following formula is used:

$$Risk = Measure\ of\ damages\ [e.g.\$, € \ldots] \times Incidence\ rate$$

The measure of damage describes the size of damage in terms of its extent, the degree of destruction and the associated consequences for humans and the environment. The incidence rate describes the frequency of occurrence of a loss event and the associated consequences of damage in a building specific use that has a direct impact on the reliability of the assessment results for design and proof of personal safety.

RISK MANAGEMENT & RISK ANALYSIS

For a systematic treatment of risks, the implementations of risk management methods are required. The application of risk management in the fire safety context combines the topics of risk analysis, prevention and safety concept. It is understood as a dynamic process, to assess and to identify risks as early as possible in addition to assess, manage and continuously monitor the appropriate measures (Hosser 2009). The overall process is to be included in the facility management over the building lifecycle.

Risk identification. Risk identification is a central task of risk management, which protects the objectives of fire safety as early as possible. It requires a structured and systematic approach, with the aim to enable a complete and ongoing recording of all existing, potential and theoretically conceivable hazards and their interrelationships.

Risk analysis. Following the risk identification, the risk analysis takes over the task of examining risks in order to assess and evaluate them in the given context. The risk analysis illuminates the totality of damage in terms of frequency of occurrence (incidence rate) and measure of damage. The evaluation of different kind of buildings is due to the large number of factors, in particular different design of the building a challenge for fire safety engineers. For fire safety assessment and for risk comparisons between various buildings, usage types or fire protection concepts, different techniques or procedures are available. In the following some of their advantages and disadvantages are briefly introduced.

Qualitative risk analysis. The qualitative risk analysis is based on expert's knowledge. It turns out to be one of the elementary forms of the presented methods. In the framework of fire protection concepts this method is a usual way for fire security risk detection. The risk is determined based on technical relationships between appropriate compensation measures against increased fire risk. This is then purely qualitatively discussed and finally determined whether the increased fire risk is sufficiently remedied by the appropriate action. The result is not verified by quantitative analysis.

Quantitative risk analysis. In general quantitative risk analyses are methods in which the temporal sequence of events, for example from the fire origin to its expansion, is represented in a logical way. Every event is thereby assigned a probability based on long-term experience or statistical surveys, or can be calculated in individual cases by engineering methods. The graphical representation of this decision sequence is called event tree. Advantage of the quantitative risk analysis is that it is based mainly on mathematical foundations and is easily understood by the possibility of graphical representation. The disadvantages are that for complex buildings a lot of boundary conditions and relationships between individual measures must be taken into account which results in very complex event trees that makes it in some cases difficult to obtain the required input data.

Semi-quantitative risk methods (index method). The goal of an index method is the simplified schematic risk assessment of buildings. Semi-quantitative risk analysis or index methods allow a ranking for different buildings according to their fire risk level. However, they are not capable to assess the fire risk quantitatively. The result is indeed delivered in the form of a number. This number only provides information about the fire risk in comparison to other, similar buildings or the same building before or after refurbishments.

Semi-quantitative risk analyses have been developed to simplify the risk assessment. It should be noted that the application of this method must be customized according to the type of building. With a deviating application the method must be fashioned to the effect that only the relevant events to the risk situation has be taken into account.

Risk management. Identifying and assessing the fire risk raises the question how to deal with this risk. Risk management aims to influence risks actively and purposefully. Risks were evaluated in the risk assessment with a specific monetary loss. The output of the risk assessment is a calculated residual risk. Depending on the vulnerable target protection, risks are to be compensated by different protection measures. The requirement is only met if the residual risk is in an acceptable range. In the selection of measures mainly two strategies are pursued:

- **Avoid:** Here the risk is excluded from the outset. To this end, preventive measures can be used.
- **Reduce:** The effects that arise when entering a fire event are reduced. In addition, both preventive and mitigating measures come into question.

Summary. In this section, risk analysis techniques were presented, which varies according to the complexity and the desired accuracy of the values. Of course, the results of the analysis strongly depend on the chosen type of analysis tools. Therefore quantitative statements by a qualitative method cannot be expected. The semi-quantitative risk analysis obviously represents a very good compromise between a practical and rapid development and is consistently based on mathematical and stochastic models for risk analysis. The influence of the user on the quality of results can be minimized at a reasonable cost. Furthermore satisfies the semi-quantitative method, other requirements of the risk management process. So the request is to identify potential risks through the application of the Delphi method, which ensures the availability of the output data for the index method or other semi-quantitative techniques. A practical and efficient semi-quantitative method for the evaluation of the fire risk of multi-storey buildings, is the Fire Risk Index Method (FRIM).

FIRE RISK INDEX METHOD (FRIM)

The FRIM was developed by a group of experts and evaluated and confirmed by using a Delphi survey. The expert group was composed of one expert of the four participating countries Denmark, Finland, Norway and Sweden. The group for the Delphi survey consisted of a total of 20 participants, who came from the areas of consulting engineers, fire service, material testing, research and insurance. The evaluation of the individual weights was based on the expert's knowledge and experience. (Guðnadóttir 2011, Karlsson and Larsson 2000).

Structure of FRIM. The hierarchical structure of the FRIM is shown in Figure 1. The top level is the *policy*. The *policy* is divided into different protection goals for the safety of users, for the protection of the building and the environment. These goals are called *objectives*. The third level contains the various *strategies* by which the safety objectives should be achieved. These strategies are measures for the prevention of a fire, for the subdivision of the building into fire compartments and usage areas, for early fire detection and firefighting etc. The lowest level is called *parameters* and includes a plurality of (fire protection) measures contributing to the implementation of the *strategies* such as fire alarm systems, sprinkler systems or fire-doors. Since the *parameters* must be measurable or assessable in an appropriate manner, they are partly divided in *sub-parameter* and *survey-items*.

Limitations. The FRIM can be used for fire safety risk assessment of multi-storey residential buildings. Only a comparative assessment of one specific building in comparison with similar buildings is possible. In the assessed buildings, building inspection requirements shall be complied. The index method is not a substitute for the design of fire protection measures. It should be pointed out that the method also has been validated only for buildings whose fire protection concepts corresponded to the general standard requirements.

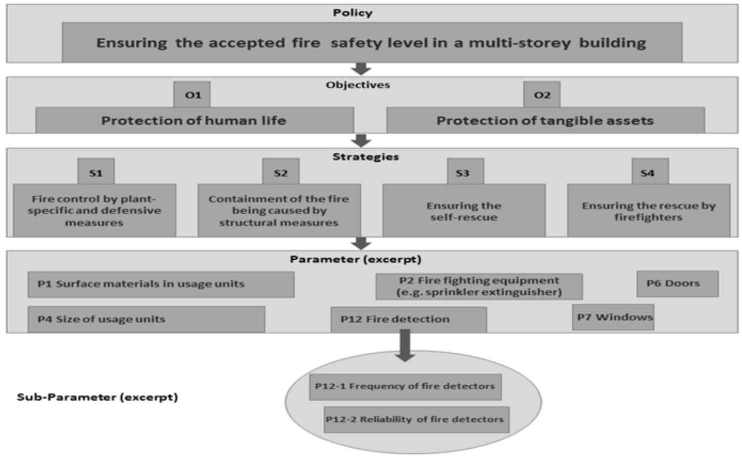

Figure 1. FRIM hierarchy

CONCEPT

The goal of the presented approach is to combine the FRIM with a maintenance cost-estimation of repair and replacement costs through visualization within a BIM environment. This section of the paper will deal with the concepts of the data model, the algorithms and the visualization of results.

Requirements.

Building Information Model. The data source for the material and structural conditions of the building. For this, the data of all building elements especially for the fire safety equipment must be complete and up to date. This represents an essential prerequisite for a reliable and error-free result of the analysis.

Storing the schematic risk classification for certain types of buildings. Another significant prerequisite for the implementation of the FRIM is the presence of a schematic data schema. Due to the hierarchical structure of the FRIM and the need of flexible access to the data, a relational approach was chosen.

User interface and 3D data-visualization. After successful completion of the analysis the results should be presented through a user interface in a structured form. In addition to the cumulative presentation of the results in the user interface a report should be generated and the data should be visualized in the 3D building model.

Database model. The corresponding data model is based on the five-level hierarchical structure of the FRIM. To realize the relationship between the levels *parameter* and *survey items* an additional level *sub-parameter* had to be defined (see figure 2). The following entities were considered relevant:

- **Building**: The top element, it refers to the object to be examined.
- **Policy:** Describes the top-level objectives of the safety concept.
- **Objectives**: Describes various protection goals, explained in the safety concept.
- **Strategies**: Represents the strategies needed to achieve the objectives.

- **Parameters**: All measures, which are needed for implementing the strategies.
- **Sub-parameter**: Serves as a link for a better understanding of the relationships between the measures and the evaluation criteria.
- **Survey Items**: Defines the assessment criteria of the parameters or sub-parameters. These criteria are decisive for the analysis.
- **Survey Items Property**: Represents the characteristics of the evaluation criteria. The properties affect the value of the corresponding sub-parameter or parameter.
- **Sub-parameter scenarios**: Describes the interaction of the properties of all existing evaluation criteria of a sub- parameter and their weights.
- **Parameter scenarios**: Shows the interplay of the values of all existing sub-parameter of a parameter and its significances.

Determination of risk index and maintenance costs.

The algorithm for the determination of risk index and maintenance costs (compare figure 3) starts with a query to retrieve for the analysis relevant *parameters*, their *sub-parameters* and the associated *survey items*. An essential prerequisite for carrying out the assessment are the criteria and properties of the *survey items* which are directly linked with building elements of the BIM database. This element type has a direct impact on the effectiveness of the fire safety equipment and accordingly they are measured differently. During the analysis, the properties of each relevant building element are checked against the criteria of the linked *survey item* which defines the rules for the calculation of the results for one *survey item*. The sum of the weighted results after evaluation of all parameters results in the Risk Index.

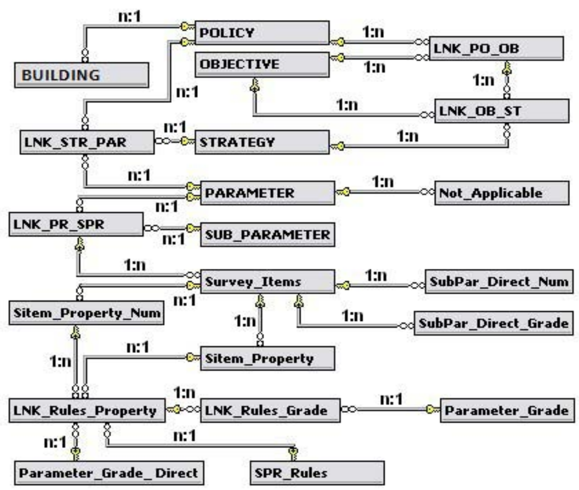

Figure 2. Database model.

The process for the identification of defective equipment and its maintenance cost is associated with the calculation of risk index. The determination of maintenance costs is included in the iteration over each *parameter*, *sub-parameter* and *survey item* as described above. The end result is the sum of all existing maintenance costs of the assessed building.

3D data-visualization. The visualization concept of the results follows the idea of a 3D bubble chart. The bubbles are to be displayed directly on the elements that caused the costs and risks. The influence on the risk index is connected with the radius, the portion of costs compared to the most expensive measure with color of the bubble (see Figure 4).

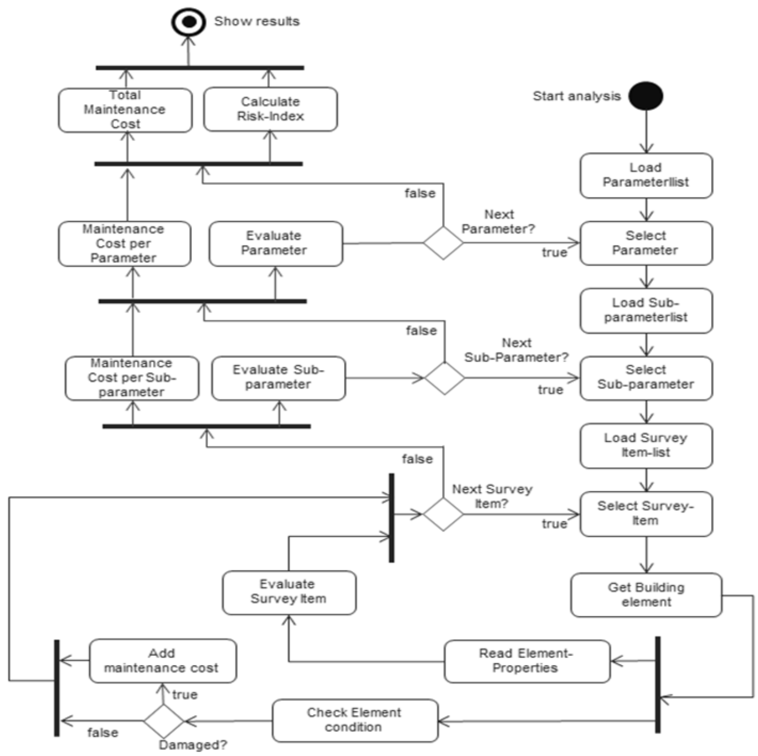

Figure 3. Algorithm for the calculation of risk index and maintenance costs.

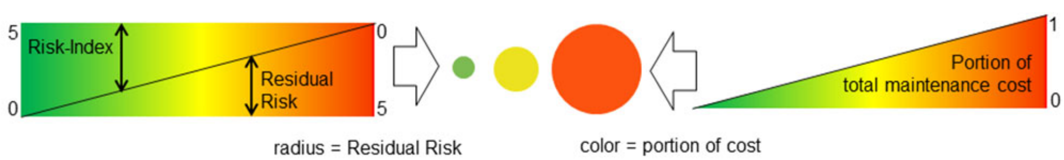

Figure 4. Visualization concept.

EXAMPLE USE CASE

After a prototypical implementation according to the concept, the functionalities of the developed solution are illustrated by an application example. The use case is discussed from the perspective of a facility manager and a fire safety engineer who are charged with the maintenance and optimization of fire safety level of an office building.

After an audit of the building, fire safety deficiencies are added directly to the corresponding building object of the digital building model over the Autodesk Revit GUI. After setting up the building model to the actual state of the building, the analysis is performed with the developed FRIM-Add-on for Autodesk Revit. In the GUI, the calculated risk index and optionally possible maintenance costs shown sorted by the fire sections. At the same time a list of all identified building elements is represented hierarchically according to the criteria fire compartment, space, category and item label.

Figure 5. GUI and 3D building model.

In addition to the consolidated presentation of the results, the results are visualized in the 3D building model with the analysis visualization framework (AVF) of the Revit API. Another functionality of the developed solution is to create a detailed report with the calculation steps of the risk index and maintenance costs. The report can be displayed in Microsoft Excel.

CONCLUSION AND OUTLOOK

This article introduces an approach to combine information of the influence of individual fire safety deficiencies (technical, structural fire protection elements / components) on the security level of the whole building and the associated costs. On the basis of this combination the facility manager is able to make decisions with what fire safety measures the security level can be obtained and increases in the most economical way. This has the potential to support the risk management processes during the building lifecycle, to avoid clashes, to detect security risks and generally increases the operating efficiency and security of buildings.

REFERENCES

Guðnadóttir, Í. (2012). "Timber as Load Bearing Material in Multistorey Apartment Buildings: A Case Study Comparing the Fire Risk in a Building of Non-combustible Frame and a Timber-frame Building". http://skemman.is/en/item/view/1946/10160

Hosser, D. (2009). Leitfaden Ingenieurmethoden des Brandschutzes

Karlsson, B., and Larsson, D. (2000). "Using a Delphi Panel for Developing a Fire Risk Index Method Multistorey Apartment Buildings." <lup.lub.lu.se/record/605399/ file/1259310.pdf> (2000).

Zewa, S. (2013). "Visualisierung von Risikomethoden mit kombinierter Kosten-Schätzung innerhalb einer BIM-Umgebung am Beispiel der Brandschutztechnischen Sicherheitsbetrachtung" Diploma-Thesis, Institue for Numerical Methods in Civil Engineering, TU Darmstadt.