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ACQUISITION AND PROCESSING OF INPUT DATA FOR AN OBJECT - ORIENTED SAFETY RISK SIMULATION IN BUILDING CONSTRUCTION

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ABSTRACT

The construction industry records the highest rate of accidents amongst all industrial sectors. Accidents occur due to shortcomings in the identification of unsafe conditions before an activity is executed. Building Information Modeling (BIM) is a promising development in the construction industry, which can be applied to considerations relating to occupational health and safety issues. Only a few research activities have earlier focused on the use of BIM to identify safety hazards. The present work deals with the integration of the processes of risk assessment in a model-based environment. Based on algorithms that have been developed, a systematic identification and categorization of hazards - based on a building model - has been devised. The hazards are specifically identified with regard to object, process, and environment, and documented in the context of an object-oriented database. This paper will show the process of input data acquisition for generating the knowledge base.

1 INTRODUCTION

Construction is typically a one-of-a-kind business. Every building is built only once. Distinguishing features of unique processes in the construction industry, according to Franz (2010), are:

- Uniqueness of design and construction
- Different materials
- Availability of resources
- Many disturbances and parameters with stochastic properties
- Many different participants
- A variety of mandatory and useful dependencies in the processes

All these features are drivers of an unsafe working environment. In order to improve the safety standard at construction sites, both the determination of security procedures and the planning of safety equipment have to be included in the early phases of the project. Loss of information due to changing planners in the workflow can be avoided by using a continuous Building Information Model (BIM). In addition to planning the structural framework and structural-physical considerations, this model can be used to chalk out a work safety plan (Eastman et al. 2011).

The Federal Ministry of Transport and Digital Infrastructure defines BIM as follows: 'Building Information Modelling indicates a collaborative working method based on digital models of a building. The model consistently stores all relevant information and data for the building's lifecycle and provides information for a transparent communication between parties, or passes information over for further processing' (Bundesministerium für Verkehr und digitale Infrastruktur 2015) .

Integration of construction safety knowledge in the digital model of a building can enhance the quality and details of hazard assessment and safety planning in a project. The objective of this research is to formalize safety knowledge and the integration in the database. Therefore, all relevant data will be characterized according to a defined pattern and standardized workflows will be developed to establish a comprehensive framework for a project- specific safety risk assessment.

This paper provides an overview of the prior knowledge of technology and research. Next, the main issues connected with a hazard analysis will be presented. The paper, then, gives an insight into the possibility of adaptation of knowledge-based construction process planning to a hazard analysis. A framework for a knowledge-based hazard analysis on the basis of a BIM will be introduced.

2 BACKGROUND

2.1 BIM-based Construction Safety Management

A review of the latest aspects of hazard analysis and safety planning indicates that there is no integrated planning tool that would combine safety regulations and a particular project. The BIM provides a promising way to improve the safety standards at construction sites. The literature indicates that the use of a digital building information model offers several ways to improve construction safety. However, the integration of safety planning in a digital building model is still uncommon and relatively complicated. According to the object-orientated hazard analysis in building construction projects, there are some research approaches, which can be divided into three categories (Melzner, Bargstädt 2013a):

Manual tools for improving safety planning: The so-called “Design for Safety” (DFS) helps consider safety issues during the design phase to involve the cooperation of all participants with regard to the safety assessment (Gambatese et al. 1997, Cooke et al. 2008).

Possibilities of visualization and their potential for improving safety: The possibility that the safety equipment can be visualized has great benefits. 3D models, which include railings and similar objects, are easier to grasp and understand than traditional plans (Kiviniemi et al. 2011, Kim, Ahn 2011).

Automatic construction safety analysis. An example is the “automated safety rule checking” algorithm by Zhang et al. (2013). The goal is to identify hazards through a rule-based inspection process, and thus increase safety on the site. It will not only identify risk points, but also display appropriate safety measures. Based on this method, a case study showed that this application is flexible and customizable, and is applicable to different international conditions and health and safety regulations (Melzner et al. 2013c) (Figure 1).

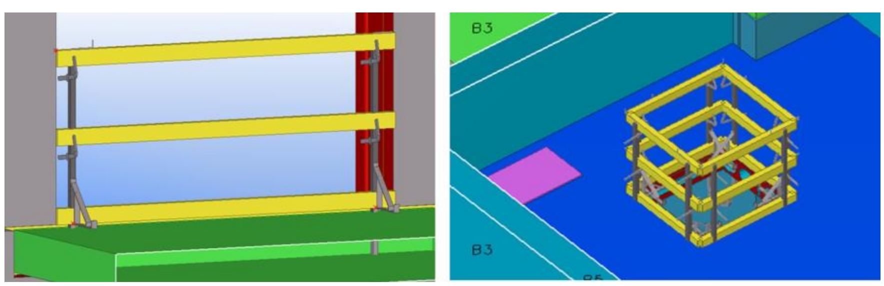

Figure 1: Visualization of protective safety equipment generated by the automated safety rule checking system (source: Melzner et al. 2013b)

2.2 Knowledge Management

Knowledge-based systems support people in solving complex problems by deriving recommendations for action from a knowledge base. So-called if-then relationships can reflect human knowledge and make it machine-readable. Knowledge-based systems are part of the field of artificial intelligence. The methods and procedures of knowledge processing make this knowledge explicit and link it to formal knowledge holders. Thus, access to experience allows for the use and re-use of knowledge in a project (Gehle 2006).

The embedding of knowledge in a formal model assumes the process of knowledge acquisition. In these processes the implied expert knowledge is acquired, structured and formalized for further processing. Knowledge-based systems consist of a knowledge base in connection with methods that represent the knowledge processing. Knowledge-based systems allow an intelligent data handling by collecting and analyzing data in a formalized workflow. The basic requirements are the processing and management of knowledge in order to use this selectively for certain subject specific tasks.

The methods of knowledge based systems are also used in the construction industry to apply expert knowledge for future problems (Mikuláková 2010). Knowledge-based systems use different methods to draw possible conclusions. Mikulakova presents a case-based reasoning (CBR) method to determine possible execution sequences of construction processes. She proposed a knowledge-based system to formalize execution problems in case problems and compares these with previously stored projects (Mikuláková et al. 2010).

A further method of knowledge-representation is the constraint satisfaction paradigm. Beißert proposed a constraint-based approach for creating possible execution alternatives of outfitting processes in construction. (Beißert 2010). She used a constraint-based approach to describe restrictions of outfitting processes. Her approach contains the description of so called hard and soft constraints. Hard constraints take technological dependencies into consideration. By using soft constraints, it is possible to regard conditions that do not have to be completely fulfilled.

Wang and Boukamp (2011) presented a framework to improve access to construction company´s safe assessment knowledge by using ontologies for formalizing knowledge about activities, job steps, and hazards. Based on these general definitions, Zhang et al. (2012) proposed a framework for automated and ontology-based job hazard analysis in BIM.

2.3 Construction Job Hazard Analysis

The practice of health and safety in construction is characterized by the manual observation of 2D drawings. Safety analysis is mostly based on the finished product represented in the drawing. The problem in the practiced work flow is that hazards arising in or from temporary construction stages, such as fall hazards that are caused by unfinished exterior walls, will or cannot be addressed with appropriate and safe measures. In fact, safety planning in the world wide construction industry has to be improved (Melzner et al. 2012b). It is in the nature of the construction business that quality planning and work preparation is directly linked to the knowledge of the executing person. Therefore, knowledge-based decision support tools can help humans to improve the planning standard by, for example, assisting the safety planning engineer in making better and safer decisions.

The German Occupational Safety Act (ArbSchG § 1 Abs. 1) states that: "[…] safety and health of employees at work need to be secured and improved by the means of protective measures". Therefore, a job hazard analysis (JHA) is useful for detecting hazards and risks present in the daily work at a construction site. The three main parts of job hazard analysis is visualized in Figure 2. First, the potential hazard has to be identified by observing.

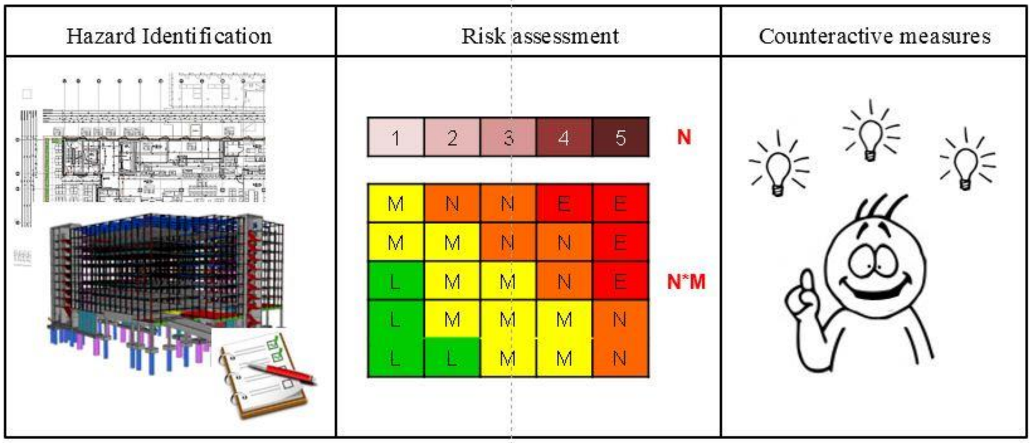

Figure 2: The process of job hazard analysis.

Rozenfeld et al. (2010) proposed a method called 'Construction Job Safety Analysis' (CJSA). The CJSA method is based on the traditional JSA procedure to safety planning in manufacturing. The CJSA generates a knowledge-base describing all possible loss-of-control events and assessment of the probability of occurrence for each event identified in construction. Fragments of the discussed former researches will be adopted and expanded in this paper.

3 FRAMEWORK

3.1 Overview

This research contributes to improvement of safety measures at construction sites by applying a knowledge-based system to the digital building model. By formalizing expert knowledge in a database, future risk assessments can be executed faster and in more detail than ever before. The system architecture of the framework of object-oriented risk analysis, which is based on a knowledge-based system, is shown in Figure 3.

The four main parts of the overall system are the database, the formalized expert knowledge, the risk assessment procedure, and the communication system. This paper uses the method of modelling to convert real-world problems into an abstract simplified model problem. The formalized and structured information from the building model and the hazards represent the expert knowledge.

This paper focuses on the process of acquisition and processing of input data, which is represented in the first two steps of the framework.

3.2 Data Acquisition

Knowledge in the field of occupational health is fragmented, partially redundant, and distributed among different knowledge-holders. This can be attributed to many project participants and stakeholders. In this research a method will be presented to show how Occupational safety and health (OSH)-related knowledge can formally and universally be collected, stored, and processed for reuse. Data collection is represented by three models, namely the product model, the process model, and the labor security model (Figure 4).

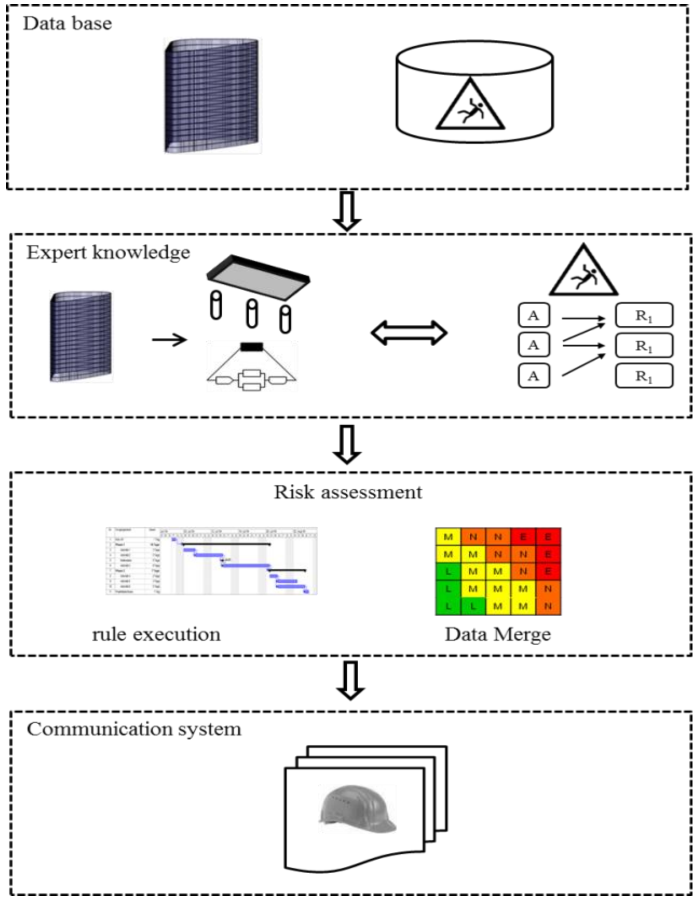

Figure 3: System Architecture

The product model represents the future construction site as a virtual building model. The process model comprises processes associated with construction methods, which are necessary to produce the building objects. Both the elements in the product model and the process model are associated with hazards represented in the occupational safety model along with the injuries and preventive measures.
The BIM, also known as the product model, includes the object-related data of all individual elements. Through this model the objects are identified with a unique identification number, the object types (e.g., wall, column, ceiling, the global position of the object), and other additional information.

The process model is a model with three hierarchical levels. It describes individual steps that are necessary to build the objects contained in the BIM. Every activity in the Gantt chart is linked to building objects in the product model. To produce or assemble a building object, a construction method is required which consists of one or several processes. This breakdown of the process model is necessary to consider the process-related safety hazards. The safety model includes specific knowledge of occupational safety. It comprises the database, which establishes the relationship between hazards, injuries, statistical indicators, and related preventive measures.

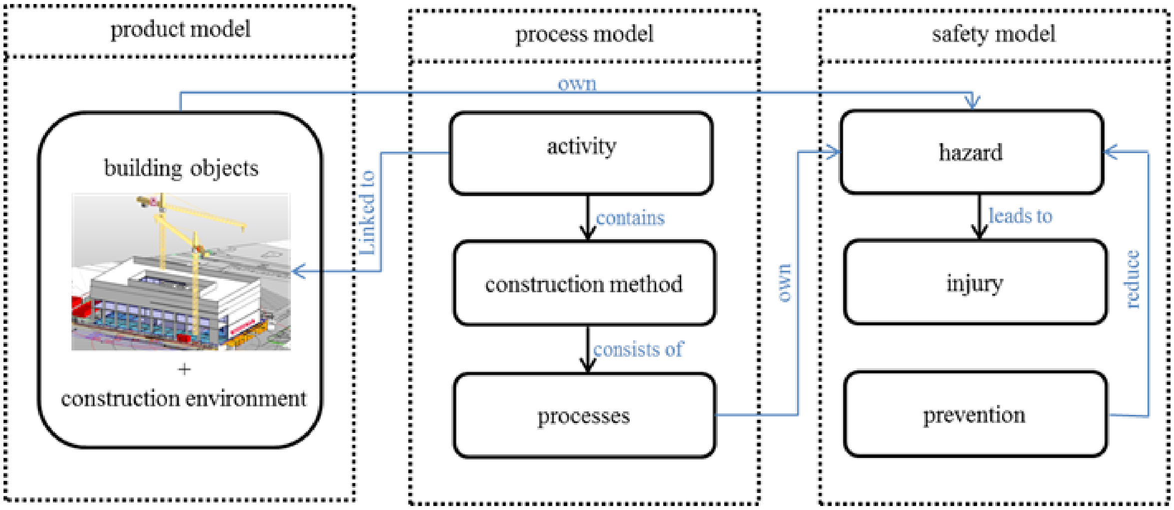

Figure 4. Framework of Sub-models' products, processes, and safety

4 KNOWLEDGE MODELING IN AN OBJECT-ORIENTED CONTEXT

The first step of knowledge acquisition is knowledge collection. Data is collected with the corresponding meaning in a database and assigned to the associated module (Figure 5). Next, the contents of the models will be described for generation of the knowledge base.

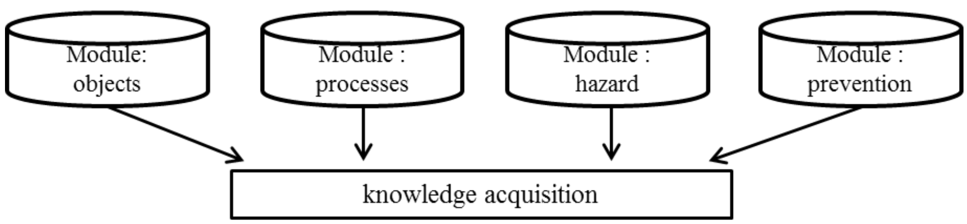

Figure 5: Overview of Modules of Knowledge Acquisition

The module 'objects' is the basis for object-oriented risk assessment. The developed analytical method decomposes the building model for a specified algorithm. The geometric analysis process involves several steps. The components are represented according to an object-oriented approach in this work. Thus, objects with the same characteristics belong to a class, and will be sufficiently and precisely described with these attributes. Building information models contain, in addition to geometrical data already available in the CAD application, information about the material, position, weight, and other attributes. The data structure of the Industry Foundation Classes (IFC) is used to analyze the BIM. The components are assigned to both floors and rooms. Similarly, there is a relationship between the building (IfcBuilding) and the construction field (IfcSite). The IFC entity 'IfcBuildingElements' describes 20 classes for the definition of components. All component types, such as 'IfcColumn', 'IfcWall', or 'IfcSlab', are derived from these entities. Other features of components are also mapped within the hierarchical structure - for example, the entities 'IfcMaterial' or 'IfcMaterialList' are available to define the material.

The module 'processes' contains a database with process templates for all possible construction methods. It seems useful to introduce process templates to reduce the specification effort in modeling construction processes (Huhnt and Enge 2006; Melzner u. a. 2012). Process templates help to systematize project-independent standard procedures, and individual processes could be structured with interrelationships to represent the entire system. A process template defines a specific sequence of tasks and subtasks for producing an object. Construction methods are either assigned to the objects of the BIM in a manually interactive manner or by the default setting. Various construction methods can be available for selection, depending on the selected object. With the presented approach, different construction methods can be assets in terms of their risks for construction workers. An example of the process diagram in the module processes for producing a reinforced concrete wall is shown in Figure 6. For this isolated part, the process diagram illustrates how differently the object-oriented risk assessment is carried out in the approach - for example, hazards relating to the process 'pour concrete' is linked to the corresponding resource 'concrete bucket'.

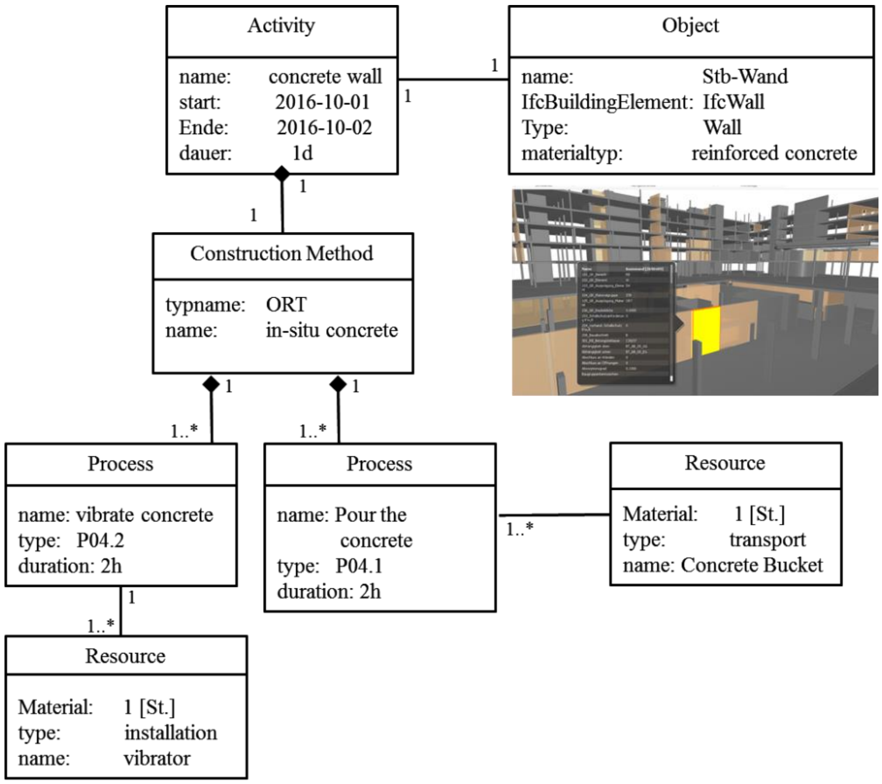

Figure 6: Example of a Process Diagram for Producing a Reinforced Concrete Wall

The aim of the module 'prevention' is to systematically assign prevention measures to the identified hazards. Elimination of safety hazards must always be the first consideration in the prevention process. Technical prevention measures must always be preferred to organizational measures and personal measures (e.g., personal safety equipment).

The module 'hazard' includes a set of algorithms to detect safety hazards in a building information model. Such hazards will be structured according to their types of sources because of the complexity of constructions projects.

The identification of hazards and risks associated with the construction of a building can be divided into three categories (sources): hazards caused by the building geometry, risks caused by the construction method, and hazards caused by the building and construction environment.

Hazards and risks of these categories are identified with individual methods. In fact, hazards caused by the building geometry are geometrical structures (lines, areas, rooms) of the building and their construction components (Figure. 6). Geometrically-related hazards could be derived from the shape, location, or size of an object - for example, the likelihood of falling from the edge of a slab is higher if the workplace is near the edge. Hazards can be deducted based on the attributes of the objects in the 3D-building model.

Examples of geometrically-related hazards are:

- Distance to the building edge
- Distance to the lower level,
- Angle of slope of an object
- Dimensions of a room

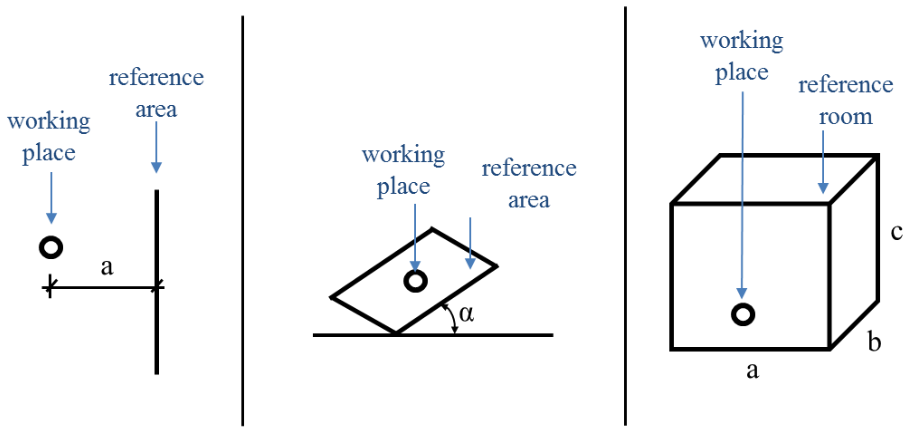

Figure 6: Definition of Line-, Area-, Spatial-related Hazards

Each construction method consists of different processes, which result in different risks and hazards. The result is a clear structure, which is necessary to understand the hazards and risks so that they can be implemented in a database. All construction methods of the module ‘processes’ will be analysed concerning their process-related hazards. The identified hazards will be assessed with respect to their probability of occurrence and severity, and then stored in the database.

Hazards caused by the building and construction environment are identified on the basis of the particular area in the work. The category of environmental hazards includes, for example, the analysis of weather conditions that may affect the safety and health of construction workers. Climatic hazards, including the weather, ozone, and ultraviolet (UV) radiation, are linked with the activities of the process model. This activity-based approach is used because of the temporal characteristic of climatic hazards. In addition, load duration and load level are factors that must be assessed, depending on the scheduled activities.

Another category classifies hazards concerning power supply cables and pipes in the field of construction environment. These can be seen in power supply lines at construction sites in urban areas. These include sewer pipes, water pipes, gas pipes, electric lines, and district heating pipes (Figure 8, left). Because of insufficient preparation and improper execution of works, power supply lines may get damaged, which can lead to hazardous situations for construction workers. There are about 100,000 reported cases of damage to supply and waste pipes each year in Germany (Berufsgenossenschaft der Bauwirtschaft 2010). This number shows the need of an adequate hazard assessment in this category.

The third category in the field of construction environment is concerned with hazards resulting from the direct job site environment. The periphery to the site involves different hazards regardless of the executed activity or current climatic conditions. It is important to distinguish between hazards caused by emissions from the environment, such as traffic noise, and by the presence of a dangerous situation in the environment. These include, for example, water surfaces or traffic areas near the construction site (Fig. 8, right).

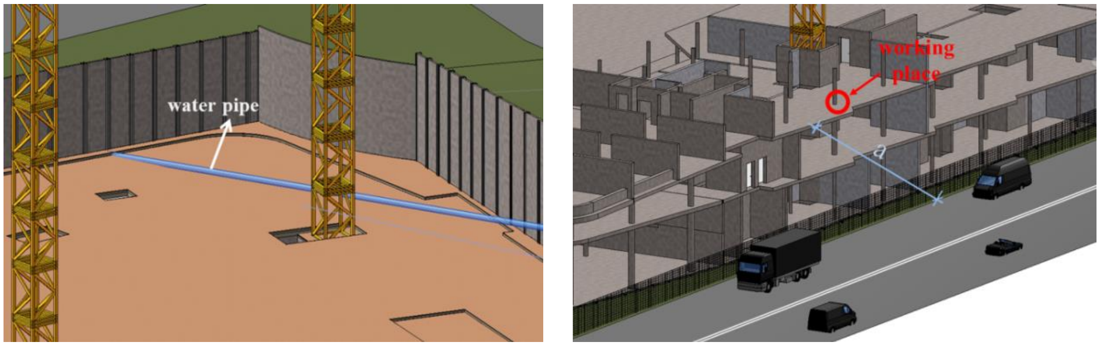

Figure 8: Examples of Hazards Resulting from Water Pipes (left) and Proximity to Traffic (right).

Data collection will be executed for the classes object-, environment-, process hazards. Figure 9 illustrates that hazards are generated from building models, from the construction processes, and also from the building environment. The exemplary attributes stand for a wealth of attributes that are assigned to the classes.

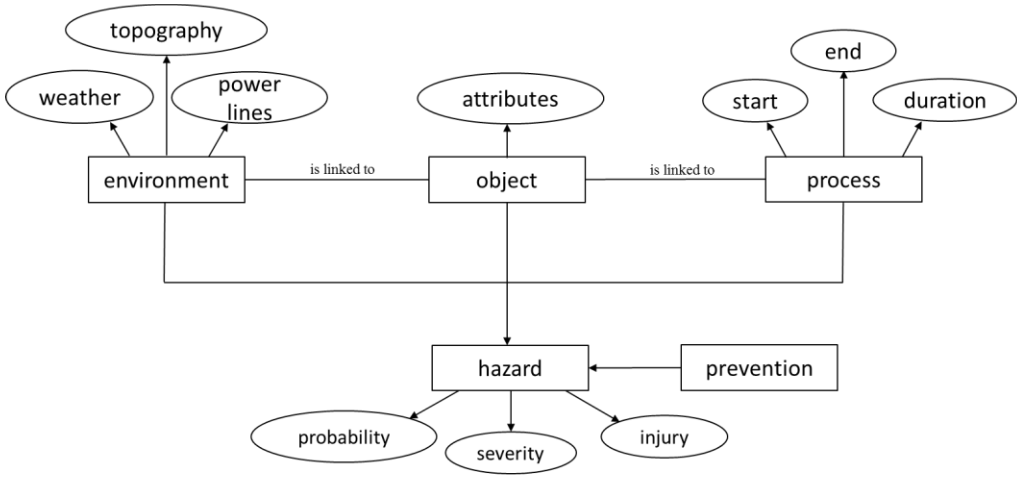

Figure 9: Data Structure Diagram

The knowledge acquisition processes were verified by analyzing traditional construction job hazard assessments and interviews with project engineers. The described process of acquisition and processing of input data for construction job hazards is a subpart of the research project on an overall risk assessment framework for building construction projects.

5 CONCLUSION

The record of accidents in the construction industry shows that the used methods in occupational health and safety often do not achieve satisfactory results. Modern methods in the form of digital building models represent a real construction site as a 3D model, and provide opportunities to identify and evaluate the hazards virtually before a construction project actually starts.

This research outlines the processes of knowledge acquisition that are necessary for an object-oriented safety risk assessment in building construction projects. The four modules ‘objects’, ‘processes’, ‘hazards’, and ‘prevention’ -all necessary for knowledge acquisition - will be introduced. This paper displays the categorization of construction job hazards. These hazards are caused by the building geometry, risks caused by the construction method, and hazards caused by the building and construction environment.

This research demonstrates the application of a model-based job safety analysis. The framework supplies the project team with important information about the connection between building objects, construction methods, and related risks. Future research on this topic may include its expansion to different trades and the evaluation of a real construction safety process.

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