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Analysis of Safety Risks on the Construction Site

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Abstract. Construction industry is one of the most dangerous industries in many countries, resulting in the fact that safety in construction industry is being considered a very important issue. From the period 2000-2012, 19.5% of all deaths were from construction industry. Safety factors influencing construction and methods of construction safety risks assessment have to form an integral part of construction safety management and therefore part of the construction project management. Analysis, assessment and elimination of construction safety risks are dealt with in the plan of occupational safety and health, which presents one of the construction management documents in Slovakia. Proposal of the plan of occupational safety and health processing for business centre construction has been presented in this paper. Safety risk assessment and way of risk elimination presents the input information into one dimension of building information model, which should be an integral part of integrated building design.

1. Introduction

The need to improve working conditions is a collective concern, prompted by both humanitarian and economic considerations. Creating more and better quality jobs is one of the main objectives of the EU social policy. Safe and healthy working environment is an essential element of the work quality. Moreover, safe, healthy working environment is a crucial factor in the individual's quality of life [1]. The issue of safe working environment is significant also in construction industry. Construction industry has witnessed a rapid development all over the world during the past few decades – large-scale projects have become widespread and international, new project delivery methodologies have been adopted, design theory and tools have been constantly improved, creative and new approaches, methods and materials for construction have been introduced [2]. On the other hand, construction industry is regarded to be a dangerous industry. However, it plays an important role in satisfying human development needs [3]. Construction industry accident fatality rate is doubled compared to all other sector average – 19.5% of all deaths from the period considered were from the area of construction industry.

1.1. Construction safety management

Construction work is mainly done in exterior conditions on construction site. Construction site layout is an important activity that is done to make good use of site space. A good site layout boosts the effectiveness and efficiency of the subsequent construction work, contributes to reduction of costs and material travel distance [4] and increases the safety level of the construction site [5]. However, correct decisions must be made when choosing among different site layout scenarios via valid and systematic safety assessments, so improving construction site safety management must be considered in both the



preconstruction and construction stages in the construction management documentation. Construction management documentation presents result of planning the construction processes and is necessary for its management. Processing and constant updating of construction management documentation are essential for management of changes which are common issues in construction projects. Whatever additions, deletions or revisions to project goals or scope are considered as changes regardless of whether they increase or decrease the project cost, quality or schedule [6]. Project manager needs to predict changes in a timely manner. According to Kartam [7], conflict will be minimized when problems are found at the earliest possible stage of a project thereby enabling implementation of the counter measures. The changes in construction projects are implemented in its design and planning through a complex and iterative process, which may extend over a long period. Impact of these changes on the project often becomes clear only at the end of this process [8, 9]. Malekitabar [10] and Ning [4] revealed that 46.8% of accidents are related to the design chosen for safety measures and that certain risks can be avoided by making minor changes to the design. Thus, more attention must be paid to safety planning in the preconstruction stage to improve safety management more effectively. In Slovakia, safety management is processed by plan of occupational safety and health (OSH). The OSH plan is a part of construction management documentation in planning construction projects (Table 1). OSH Plan on the construction site is a document containing data, information and procedures prepared in detail necessary for ensuring safe and healthy work during construction [11].

Table 1. Construction management documentation for planning a construction phase.

Evaluated aspect	Required document
Time	Schedule of construction works
Cost	Budget
Quality	Quality control plan for construction realization
Building site	Construction site layout planning Plan for occupational safety and health (OHS) Plan of measures for eliminating the impact of the winter season for construction plan

Not only time, cost and quality are important for construction project management, but also the plans in the field of safety, construction equipment and measures for eliminating the impact of the winter season on construction as a part of construction management documentation. Therefore, Kozlovská et al. [12] researched the level of processing construction management documentation in Slovak construction companies. This research analysed data collected during four years - 1996, 2003, 2008 and 2013. The research was completed by the latest results of the same questionnaire survey in 2018. Respondents (construction experts) were asked by personal questioning to answer questions related to construction management documents. This study has analysed selected six construction management documents processed in Slovak construction companies depending on time. One of them was a plan of occupational safety and health. The questionnaire mentioned above contained questions related to the processing of the documents and the respondent had a scale of possible answers: always, sometimes and never documents are processed. The share of answers (in per cent) for question “Do you create a plan of occupational safety and health?” is shown in Figure 1.

Specifically, it is possible to argue that the trend of OSH plan processing has improved compared to the results of 1996. On the other hand, since 2008 the level of OSH plan processing has remained the same. Construction companies are aware of the importance and need to process the OSH plan, which provides analysis of construction and safety risks and presents an effective tool for construction safety risks elimination. It can be assumed that it is affected by Act no. 147/2017 Coll. Occupation

safety and health in construction [13]. Under this act, prior the beginning of the construction works on the building site must be, besides the project documentation, also the construction documentation (including construction methods and OHS requirements for safe work performance). Processing of OHS requirements for particular construction works provides information for OSH plan.

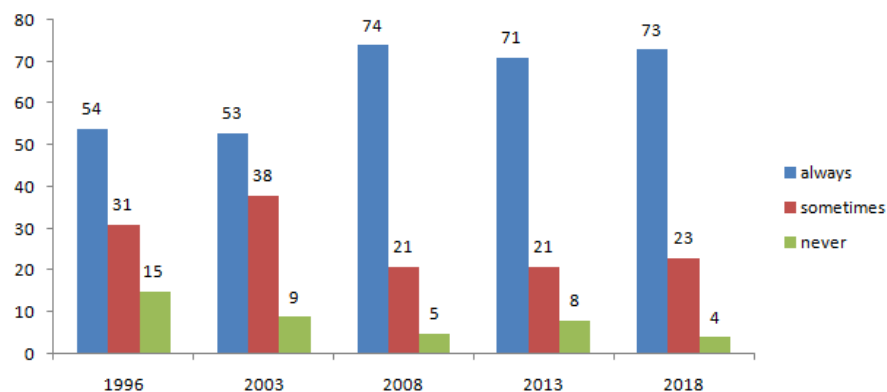


Figure 1. Chart of answers (in %) to the question: “Do you create plan of occupational safety and health?”

1.2. Construction safety risks

Literature on construction safety was analyzed to capture risks that affect safety at the construction site and the measures that can be taken to mitigate or reduce unsafe conditions. Due to differences in the construction industry and environment in different countries, there are some discrepancies in the results concerning safety factors [14]. Safety risks can be divided into several different categories:

- Identification of key factors of 100 accidents which include five categories: worker and work team, workplace, material, equipment and front line managers and supervisors. These five aspects contribute to forming a hierarchy of causal influences in construction accidents. It has also been proposed that front line managers and supervisors are the key individuals in accident prevention which implies that monitoring is important for construction safety [15],
- Influence of psychosocial factors on the health and safety of construction workers [16],
- 25 key risks were ascertained to understand the key risks on construction projects in China. Some strategies were developed to manage these risks. In addition, it was concluded that clients, designers and government bodies must assume responsibility to manage their relevant risks and work cooperatively from the feasibility phase throughout the project. Only this comprehensive responsibility and cooperation will help to avoid potential risks over time. Meanwhile, contractors and sub-contractors with solid construction and management experience should be addressed to minimize the risks and carry out safe, efficient and high-quality activities [17],
- Two success attributes and one failure attribute affecting schedule performance were identified from 55 attributes using a two-stage factor analyses separately on construction projects in India [18],
- The impact of historical, economic, psychological, technical, procedural, organizational and environmental issues is closely linked with the level of site safety discussed. The top five important factors associated with site safety were identified as management talks on safety, provision of safety booklets, provision of safety equipment, ensuring safe environment, and appointing a permanent on-site safety representative [19].

In Slovak construction conditions, construction safety risks are mainly divided according to the Slovak legislative frame into nine categories: (i) construction site risks, (ii) risks for earthworks, (iii) risks of concrete works and works related to them, (iv) risks of masonry works, (v) risks of assembly

works, (vi) risks of work at heights and above free depth, (vii) risks of demolition and reconstruction works, (viii) machinery risks, (ix) risks related to construction works [13]. These risk categories depend on the type of construction process.

1.3. Construction safety risks assessment

Identification, assessment and reduction of risks are some of the most important issues of occupational safety to address health and safety problems effectively. Currently, there is a variety of methods used to assess risks in the workplace: quantitative and qualitative or their combination. However, there is no single and efficient model for the risk assessment and management [20]. Risk assessment is the process of evaluation the risks arising from a hazard, taking into account the adequacy of any existing checks and deciding whether or not the risk is acceptable. Several methods to perform risk assessment are available ranging from expert to participatory methodologies and from simple to complex methods. Risk assessment involves evaluating, ranking, and classifying risks. Risk assessment provides an understanding of risks, their causes, consequences and their probability. Risk assessment provides decision-makers and responsible parties with broader understanding of risks that could affect achievement of objectives and adequacy and effectiveness of checks already in place. This provides a basis for decisions about the most appropriate approach to be used to treat the risks also in construction industry. Methods used in analyzing risks can be qualitative, semi-quantitative, or quantitative.

Construction safety risk assessment consists of the following steps: risk identification; risk analysis – consequence analysis; risk analysis – qualitative, semi-quantitative or quantitative probability estimation; risk analysis – assessing the effectiveness of any existing checks; risk analysis – estimation of the risk level; and risk evaluation. Many authors identified as selected methods for risks assessment the following ones: brainstorming, Delphi technique, checklists, preliminary hazard analysis (PHA), Hazop (HAZard and OPerability study), toxicity assessment, structured /what-if” technique (SWIFT), scenario analysis (SA), business impact analysis (BIA), root cause analysis (RCA), failure modes and effects analysis (FMEA) and failure modes and effect and criticality analysis (FMECA), fault tree analysis (FTA), even tree analysis (ETA), cause-consequence analysis, cause and effect analysis, layers of protection analysis (LOPA), decision tree analysis and human reliability assessment (HRA) [21]. The most widely used method of risk assessment in construction practice is the point method assessment [22]. This method is commonly used also in the Plan of OHS in Slovakia [22].

2. Case study

The first idea to think about when carrying out a risk assessment is “How likely it is that someone can be harmed by this hazard? ”Probability of someone being harmed varies depending on the environment, the work activities and frequency of being exposed to the hazard.

The following chapters set out the methodology for risk assessment for construction of the administrative building – DuettBusiness Residence (Figure 2) by point method assessment. It is located in Košice, Slovakia.

2.1. Object description

Administrative building - DuettBusiness Residence is located at the junction of the Osloboditeľov Square and Jantarova Street in the busiest part of Košice (Figure 3). It is situated on the northern edge of the city part of the plain with a flat nature on an uninterrupted area. The terrain of the territory is flat with a slight decline towards the east and southeast. The proposed area should be linked to the existing development of the urban part considered.

Objects of the administrative building consist of a reinforced concrete monolithic structure with non-watertight ceilings. The building has two underground floors with structural heights of 2.94 m and 4.6 m, ground floor with a construction height of 4.09 m, nine floors with a structural height of 3.44 m and superstructure above the elevator shafts with a design height of 2.82 m. The entire building has

twelve floors. Underground floors are used for parking and a business unit; the aboveground floors are used for renting office space. Aboveground floors consist of two separate towers of the Duett I tower and the Duett II tower. The underground floors are constructively designed as a white bath as an object formed by two dilation units located on a common undiluted base plate. The roofs of the two height parts of the tower Duett I and Duett II are designed as flat, partly sloping roofs.



Figure 2. Duett Business Residence visualization.

The two high-rise parts of the building will be covered with an aluminium column-beam façade system with a broken thermal bridge with transparent parts. Double-glazing will insulate windows and glazed walls. The windows will be fitted with integrated aluminium blinds.

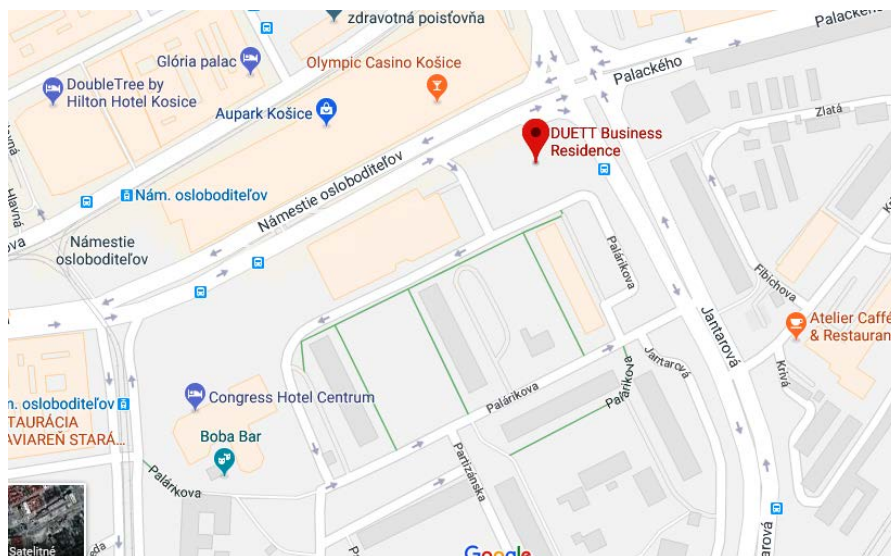


Figure 3. The situation of the construction project.

Generally, the construction site of administrative building is characterized by the development of the construction process:

- Limited possibilities of setting up inputs and outputs,
- Lack of storage areas,

- Limited area for the development of an intra-state communication system,
- Limited area for the location of the operating, production and social facilities of the building site, and it can be assumed that the above-mentioned building site is complex in terms of the development of the construction process.

Coordination of the execution of tasks in the execution of work on the site in terms of security and security health and safety at work is ensured by the safety coordinator whom the building manager should be responsible to. The "Duett business residence" (natural person authorized to perform the activities of the contractor must not be the safety coordinator on the building site on which the constructor works), the natural person authorized to perform the construction supervision or the authorized Security Technician.

Coordination includes in particular:

- Applying general principles of prevention and safety and health protection, requirements for technical or organizational solutions to design work that are carried out simultaneously or are followed up,
- Adherence to the occupational safety and health plan and its adaptations which take account of the work process in the light of changes in work,
- Collaboration between site builders, especially if they work at a joint workplace and work on their workplace, work guidance with regard to employee protection, prevention of accidents and other health hazards.

2.2. Methodology of risks assessment

The point method assessment was used to assess the risks at DuettBusiness Residence.

The risk is a complex concept, which covers the accident probability and the estimate of possible side effects of this accident. There are several types of risks: risk in the work environment, identified risk, unwinding (unexpected) risk and risk of environmental pollution. By its nature, risk can be controlled, if there is a legal basis for risk assessment, methodological support and assessment procedure as well as certain special requirements for risk reduction: Probability, which determines whether the adverse event will occur; Unintended consequences of the accident; the expected consequences or mathematical probability of consequences; Deviation from the acceptable level of risk (adverse effects), which the investors are willing to tolerate or endure. The methodology of risk assessments presents a general function of the consequences or probability of the adverse event. There is a risk defined as the degree of adverse effects arising from a hazard taking into account the probability of damage and side effects: Risk = Probability x Consequences, or

$$R = p \cdot Q, \quad (1)$$

where p is probability (probability of an accident) and Q is consequences (amount of the loss).

Table 2. Numerical risk assessment matrix.

probability "p"	consequence "Q"			
	1	2	3	4
1	1	2	3	4
2	2	4	6	8
3	3	6	9	12
4	4	8	12	16
5	5	10	15	20

Combination of parity parameters and negative effects determines the value of the risk R. The risk defined by the spot method is determined based on numerical risk assessment matrix (see Table 2).

The probability value “p” in case study varies from 1 to 5, where 1 is a very low probability of occurrence of the phenomenon (almost excluded - almost impossible to endanger), 2 is low probability – (occurrence of phenomenon is unlikely or possible - very rare threats), 3 is medium probability – (occurrence is sometimes created during the lifetime of the device, activities - rare threats), 4 is high probability – (rise occurs several times over the lifetime of the device, activity-time threat), 5 is a very high risk (a very frequent threat).

The consequences value “Q” in case study varies from 1 to 4, where 1 is negligible consequence – (less than easy injury, negligible system failure), 2 is less significant consequence – (minor injury, onset of occupational disease or less damage to the system, financial loss), 3 is critical consequence – (heavy accident, occupational disease or extensive system damage, production losses, large financial losses), 4 is catastrophic consequence – (killing as a result of an accident at work or total destruction of the system, irreparable losses).

The values “p” and “Q” are set by technicians based on their previous experience and conditions (spatial, technical, constructive, time and cost) on particular site. The crucial point of safety risks assessment is the subjectivity among technicians in the assignment of all the values, from the ranges in the probability and the consequences as well as the final risk classification.

Formula (1) is the basis for a number of quantitative risk analysis methods and can be applied to each adverse event. Thus, by summarizing the risks in all cases, it is possible to assess the overall risk of the operation. By contrast, the probability is characterized by relative frequency – for example, the incidence of certain accidents in a certain amount of time divided by the total number of cases throughout the whole period of time. Consequences, which are caused by the impact of adverse events, must be assessable; the concept of the particular situation must be formulated in commonly used terms:

- Health effects (for example, fatalities, injury, disease), effects on the environment (such as loss of resources, endangered species),
- Costs (for example, asset loss, loss of productivity, unproductive use of people's life years, the programme deadline delay).

The resulting rate of risk determined by Formula (1) was divided into four levels as can be seen from Table 3.

Table 3. The resulting rate of risk “R”.

“R” Value	Characteristics
1-3	Acceptable - system is safe, common procedures
4-11	Moderate -system is safe with training of attendants, tours, etc.
12-15	Unwanted - the application of protective measures
16-20	Unacceptable - the system is unacceptable - Immediate application of protective measures, shutdown of the system

The greatest risk is the very high level of catastrophic outcome and very high probability of occurrence of an event that was assigned a value of 20. The most favourable condition is 1.

3. Results and discussion

At the Duett site, 65 sources of danger were assessed. The evaluation was processed as a table (example can be seen from Table 4). The table was divided into five columns representing: source of danger, danger, threats, rate of risk (Q, p, R) and safety precautions.

It can be seen, that the rate of risk is “R=6” which means “Moderate risk” (based on the Table 3). It has been found that the risk is of higher value than the acceptable risk, it is necessary to propose measures to reduce or eliminate it completely. The risk can only be eliminated if the source is removed - danger, or the threat is eliminated (people from the hazardous area are excluded), but in most cases it is not possible. Therefore, if there is a risk in the system under consideration that creates a risk with a higher risk than is acceptable and it is assumed that it will cause injury or damage sooner or later, risk reduction measures should be taken.

Table 4. Risk analysis on the Duett site - an example.

Source of danger	Danger	Threats	Rate of risk			Safety precautions
			p	Q	R	
Ironworks - in general	Sharp edges, rim edges, concrete steel, production reinforcements	Snapping, stabbing, cutting of a hand or other part of the body of the employee at the end of the rod, sharp edge, protruding fittings	2	3	6	<ul style="list-style-type: none"> • Provide employees with working footwear, working clothes, working goggles, helmets, • Protect eyeglasses and ensure their correct use • Maintain free handling and service passages, aisles and communications • Observe the correct working procedures for manual handling of the material • Ensure correct storage and storage of concrete steel and manufactured fittings in specified profiles, as appropriate and material fixation

In the previous chapter, four risk levels were used to determine the risk precautions:

- Acceptable risk,
- Moderate risk,
- Unwanted risk,
- Unacceptable risk.

Standard procedures and principles were used that allow for systematic approach to designing measures. By analyzing the safety risks at the Duett site, it was concluded that the risks at Duett site were assessed as moderate (values 4-11). In summary, the measure risk “R” value 4 was assigned for construction site risks, machinery risks and risks of demolition and reconstruction works. Construction site preparation due to its location, spatial conditions of the site and the surrounding area did not present an increased safety risk. Moreover, no demolition or reconstruction works were necessary to be carried out before the construction. The contractor of Duett construction was an experienced construction firm, which was able to provide reduced safety risk associated with the used construction machinery. Other groups of safety risks - risks for earthworks, risks of concrete works and works related to them, risks of masonry works, risks of assembly works and risks of work at heights and above free depth have reached measure risk “R” value 6. It should be emphasized that safety risk assessment is marked by a considerable degree of subjectivity among technicians in the assignment of all the values (“p”, “Q” and “R”). Therefore, safety risk assessment presents an assumption for

reducing the safety risks at the construction site. A slight safety risk means that the system is safe with the trained operator, tours, and so on. Audit results, results of own evaluation, or form of feedback can also be used as risk elimination measures. Based on the risk assessment, measures to eliminate the risks of the Duett construction were established (example can be seen from Table 5). In this way, a proposal was made to eliminate the risks of the Duett construction, which should prevent occurrence of hazards of the critical objects located on the site or its immediate vicinity.

Table 5. Measures to eliminate the risks of the Duett construction.

Source of danger	Threats		Elimination of risk
Ironworks - in general	Snapping, stabbing, cutting of a hand or other part of the body of the employee at the end of the rod, sharp edge, protruding fittings		Ensure caps with hats or boards 

For effective planning and management of the construction process by the plans, it is currently necessary to use more sophisticated ICT tools [23]. The tool for integrated design of construction is Building Information Modelling (BIM). Automatic identification of construction safety issues using BIM requires an understanding of the safety risk factors that are detectable during the design, preconstruction and construction phase. However, BIM-based risk management has not been commonly used in real environment [24]. Currently, as reflected in the literature, there are many proposals to use BIM technology to assist different construction management tasks [25]. BIM could not only be used to support the project development process as a systematic risk management tool, but it could also serve as a core data generator and platform for allowing other BIM-based tools to perform further risk analysis [10]. Unfortunately, absence of communication between designers and contractors is common in traditional design-bid-build projects because the entire project has been designed before a contractor is selected [26]. Integrated project delivery methods (e.g. design-build), where design and construction are performed concurrently by the same organization, facilitates safety collaboration between design and construction professionals. The BIM platform for mutual sharing of construction information has to be used for proper safety risk management. Through the use of BIM, conventional 3D or four-dimensional (4D) models become an nD model that incorporates multiple safety risk aspects of design of information required at each stage of the lifecycle of a project by Prevention through Design (PtD). Detailed processing of the OHS plan provides not only a tool for safety risk management but also input information for building information model of a particular construction. Building information model as a part of Prevention through Design presents a space for collaboration among designers and constructors in the field of safety risks on construction site.

4. Conclusion

When comparing workplace accidents in the EU over a period from 2008 to 2016, construction sector presented the highest number of fatal accidents. The complexity and uncertainty inherited in the nature of the construction industry requires safety planners to adopt technologies as recent and innovative as available to make sure they cover predictable unexpected events as much as possible. This article represents the processing of OHS plan by common methods at particular construction site – Duett

construction. Based on the analysis of constructive, technological, time, costs, space, environmental and qualitative requirements of stakeholders, the assessment of safety risks was processed. The risks at Duett were assessed as moderate. Considering the risk assessment, measures to eliminate the risks of the Duett construction were established. A proposal was made to eliminate the risks of the Duett construction, which should prevent occurrence of hazards of the critical objects located on the site or its immediate vicinity. Safety risk assessment and way of its elimination presents the inputs information into one dimension of building information model, which should be an integral part of integrated building design.

Sustainability considers the environmental, economical, social and resource impacts of construction as well as implementation of its principles throughout the building lifecycle. Construction workplace safety and health is an integral aspect of sustainable construction management. Protection of human resources must be factored into measurements of sustainable construction. In order for a construction process to be truly classified as sustainable, worker safety and health throughout the constructed building's lifecycle should be addressed [27]. Integration of safety risk assessment and proposal of its elimination as one dimension of BIM can contribute to sustainable construction in all aspects of the construction.

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