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Analysis of the Current State of Automation of Hazard Detection Processes in BIM in Slovakia

Pavol Mayer *, **Tomáš Funtík**, **Jozef Gašparík** and **Peter Makýš**

Department of Building Technologies, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11, 810 05 Bratislava, Slovakia; tomas.funtik@stuba.sk (T.F.); jozef.gasparik@stuba.sk (J.G.); peter.makys@stuba.sk (P.M.)
* Correspondence: pavol.mayer@stuba.sk; Tel.: +421-908-785-110

Abstract: Building information modeling (BIM) brings several benefits to design and construction companies, especially in higher efficiency and quality of work. Several companies also use common data environment (CDE) systems, which speed up communication and collaboration between project participants. These can be used for occupational health and safety (HS) purposes and to increase the level of HS on construction sites. The first part of the article presents the state-of-the-art possibilities and approaches to implementing BIM in automatic or semi-automatic health and safety hazard detection. The following parts analyze the interviews with experts in BIM coordination, project management and health and safety in Slovakia and their answers to a survey, that covers the topic of safety hazard detection in BIM. The analysis shows that BIM is a suitable tool for increasing safety on construction sites, but there are several obstacles to achieving its full potential. The survey brings readers closer to the current state of the topic and the possibilities offered by BIM and CDE software in Slovakia. This paper, through the requirements and opinions of experts in BIM, project management and HS management, points out areas for further research and development of BIM software.

Keywords: BIM; health; safety; IFC; BCF; hazards; risks; CDE; 4D; collaboration

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1. Introduction

The level of digitization in construction companies grows each year because of the fast evolution of new functions in building information modeling (BIM) software, common data environment (CDE) systems and smart devices [1–5]. Some of these functions improve the automation of time-consuming processes and repetitive tasks, and some help connect databases, cloud systems and programs to make project collaboration easier and more effective [1,3]. Despite these facts, general and sub-contractors are slow to embrace digitalization. The main reason to start BIM implementation in these companies is a requirement from the investor. Others are driven by financial interests, because BIM can help them to be more effective and less erroneous in the pre-construction and construction phases. The first steps of BIM implementation are therefore focused on achieving these goals and not on other important topics, such as health and safety (HS) or environment [6–8].

Contractors often look upon meeting HS requirements as an obligation that slows them down and increases costs. Nevertheless, major construction companies promote their importance and strive to fulfill a zero-harm vision [9–12] because it is still one of the most dangerous industries worldwide [13–27]. Several studies have looked at the impact of injuries and fatal accidents on construction costs and losses for the state [28–30]. In addition, the costs for pre-construction HS planning, safety equipment purchases, rent and management are also significant. From the interviews and questionnaire presented in this paper, the effort spent on risk prevention is sometimes so time-consuming, costly and difficult that companies decide not to address risks, remain ignorant about hazards and only deal with them when they occur.

In the last decade, there are several approaches that use BIM and virtual reality for HS trainings [31–34], that combine GIS and BIM for HS modeling [35] or use real-time location systems [36–39] and computer vision-based object detection [40] with BIM for tracking people, with a purpose of increasing the level of occupational HS.

This level could be also increased through the integration of BIM and PtD (Prevention through Design) approaches, and much research has been conducted on automatic or semi-automatic HS hazard detection. Some authors [15,27,41] employed a PtD approach because in some countries, legislation already mandates the minimization of HS risks in the design phase of a project. A considerable number of risks could be eliminated during modeling if the software will be able to warn the engineer if a design element, shape or material could pose a danger during construction. Additionally, such modeling could eliminate the need for checking and problem-solving during pre-construction. On the other hand, since architects and design engineers already have so much responsibility, it will require additional specialized positions, and the design stage will take longer.

For the pre-construction phases, several risk- and hazard-checking methods in 3D or 4D BIM have been developed, most of which use Autodesk Revit, a 3D BIM program that provides an application programming interface (API) so that users can develop their own applications and integrate them into Revit. For HS purposes, applications that can identify risks, model HS equipment or provide HS code-checking were developed for 3D BIM software (e.g., Autodesk Revit, Trimble Tekla Structures, Rhino) and use their source native formats. Other methods are based on IFC (Industry Foundation Classes) open file format [15–18,23,35,41–47]. Users can also add some functions to software by a visual programming language environment, such as Dynamo or Grasshopper [48–50].

On-site conditions and HS risks constantly change as construction progresses, so HS equipment needs to be installed, removed or transferred to another floor, so the risk level varies according to the type of process, time of the day, season, number of workers and tools. This is why it is good to look at HS risks in the context of the construction schedule. Several authors predicated their hazards' detection on 4D BIM [14,19–24,33,51–56], and some of the most significant research was conducted by Zhang et al. [14,20,21,51] in Trimble Tekla Structures software [57], where potential falling hazards were detected, and HS equipment was modeled, installed and removed in a 4D simulation based on a construction schedule. Others [22,52–54,56] mostly used the 4D BIM software Bentley Synchro PRO [58].

These approaches, though, have shortcomings that can include the following:

- The lack of hazard and risk databases that are connected to exact materials, elements or construction processes and correspond to local legislation, which differs from country to country. If they do exist, they are hardly readable by a computer or applicable to the BIM-based code-checking without manual database adjustment. The issues associated with BIM-based code-checking are detailed in [59].
- The lack of open BIM solutions based on IFC or BCF (BIM Collaboration Format) formats. The methods mentioned above were mostly run on one program (e.g., Autodesk Revit). Every BIM engineer uses a variety software, so these solutions are not applicable for every user or region.
- The lack of solutions based on CDE or BIM coordination software.
- The lack of HS BIM libraries.

Despite the progress in BIM applications, plug-ins and algorithms, there is still a lack of commercially available specialized HS BIM software. A few companies are developing HS BIM software for safety equipment [60–62] or hazard sign [63,64] modeling, but they are still missing functions for hazard detection, risk calculation, modeling automatization or basic options settings (e.g., English language). There is also software for BIM rule-checking, such as Solibri [65], or several systems for national regulation compliance-checking, but these are not intended for HS construction hazard detection. Some of these can be customized by users, but this requires the creation of a computer-readable database from existing HS regulations [59].

To analyze the current state of the use of BIM in hazard detection and the adaptation of available technology and software to solve this issue in Slovak construction companies, the research team decided to develop a questionnaire. The second purpose of the survey was to analyze the current state of technologies and processes used for transfer of information about hazards to the on-site person responsible for HS (e.g., project manager, HS coordinator). The last goal was to record and analyze requirements and recommendations from respondents, which could be used in further research, or in application and software development.

The aim of the research is to use the collected data to develop an efficient method for HS hazard detection and transference of the information about the hazards to the on-site person responsible (e.g., project manager, HS coordinator) as quickly as possible. The higher efficiency and digitization that comes with these processes also has a direct impact on economic and environmental sustainability. Hazard prediction can lead to improved construction planning that avoids actions connected with unplanned preventions or accidents. Fewer HS incidents means healthier people, and that directly enhances the gross domestic product (GDP). In addition, less paperwork, which is still common in HS control processes, and higher computer operations efficiency will reduce the carbon footprint.

2. Materials and Methods

To collect Slovakian data on BIM usage for hazard detection and information transfer, a survey in the form of a questionnaire was used, but due to government regulations concerning COVID-19 in February 2021, an electronic questionnaire was chosen.

2.1. Selection of a Data Collection Method

Two methods of data collection were considered. The first was a mass survey in which an electronic questionnaire would be sent to a large number of construction companies and respondents belonging to several associations, unions or chambers of civil engineers. However, based on statistics from the survey of BIM association Slovakia from September 2020, 29.7% of 1727 respondents worked for construction companies and only 9% of them used BIM in their projects, 35% of them were interested in BIM and the rest did not use BIM [6]. Based on these data [6], such a questionnaire would probably lower the professional relevance of the answers to BIM, VDC (Virtual Design and Construction) and digitization. The second method was to collect more relevant and detailed data from a smaller sample of construction specialists (BIM managers, project managers, safety coordinators) from construction companies that already use BIM, since their level of knowledge about construction digitization is higher than would be found in a broad market sample. Data collected by the second method should be more applicable for the further research and BIM software development.

In 2020, the population of Slovakia was approximately 5,460,000 [66], and the number of construction companies at the time of writing was approximately 44,600 [67]. As already mentioned, BIM adoption in Slovakia is low [6], but there are companies where the level of BIM implementation is high. Despite these statistics, and the expected small survey sample, the second method was chosen. In addition to the electronic questionnaire, it was decided to conduct personal interviews in the form of a video call so that the topic, research goals and some questions could be explained better and to foster more detailed discussion and information. Misunderstandings, or knowledge gaps (for example of technical terms), were eliminated, which led to more accurate results. In addition, the data obtained from experts are comparatively more useful for research and BIM software development. Unfortunately, only a few companies and specialists in Slovakia have reached this level.

Based on the decision to develop a questionnaire and syllabus for the interview, a process map of the research (Figure 1) consisting of five main steps was prepared: literature search, survey preparation, survey execution, analysis of results and use of results. These steps contained subprocesses that are described in the next sections.

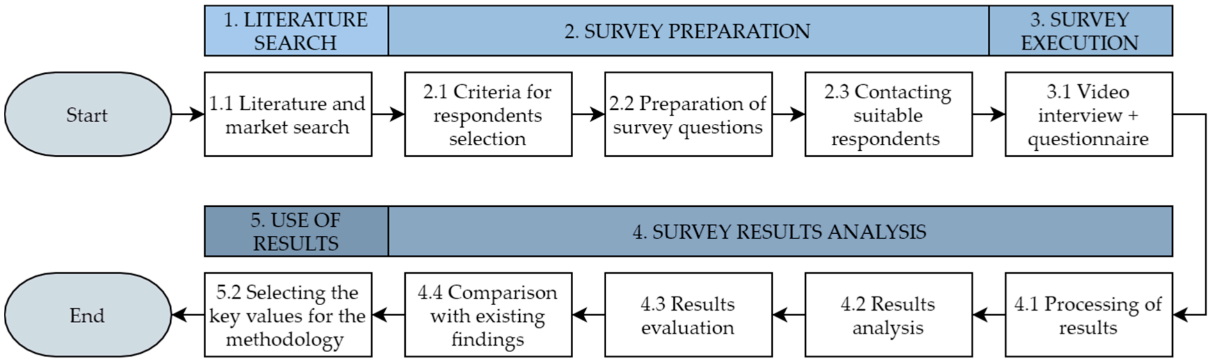


Figure 1. Process map of the research methodology.

2.2. Criteria for the Selection of Respondents

Initially, the criteria (Table 1) were set, which should be met by the respondent for inclusion in the examined sample. The first condition was that the respondent had to work for a general contractor, because in Slovakia the general contractor is responsible for on-site HS both during preparation and construction. For several reasons, designers do not use the PtD approach, in contrast to other countries such as Great Britain, Singapore, Australia, the USA and China [15]. Firms specializing in HS inspection during construction were excluded since their participation is minimal. These companies rarely use BIM, and inspectors are forced to fill in e-forms and assign HS tasks to other responsible persons on-site mostly when the general contractor uses a CDE system. Larger general contractors have HS coordinators as members of the team that prepares the construction schedule, quantity take off and cost estimation, so they use BIM more regularly.

Table 1. Criteria for selection of respondents for questionnaire and interviews.

No.	CRITERIA
1.	Respondent must work for a general contractor.
2.	Respondent must work in one of the following positions: BIM coordinator/manager, project manager/site manager or health and safety coordinator/inspector
3.	Company where respondent works must use BIM on their projects or expect to use it within 1 year and be ready for implementation at present (BIM knowledge, specialized BIM positions)

To be included in the survey (Table 1), the chosen professional must work in one of the following positions:

- BIM coordinator/manager: implement BIM in the company and on the construction site, create exchange information requirements (EIRs), BIM execution plans (BEPs) and BIM manuals, manage, check and create building information models and perform other activities related to BIM.
- Project manager/construction manager: responsible for organizing the construction processes, HS, construction costs and implementing on-site digitization.
- Health and safety coordinator: responsible for preparing the HS plan and ensuring compliance with HS on the construction site, which includes mentoring and administrative responsibilities.

The last criterion is that the company where the respondent works must use BIM on its projects or undertake to implement one within one year, in which case it should already have created specialized BIM positions or have dedicated employees with the necessary BIM expertise.

Recommendations and contacts for companies meeting the criteria (Table 1) were obtained from the BIM Association Slovakia [68], which is a member of the Construction Classification International Collaboration (CCIC) [69]. The association brings together companies to support the implementation of BIM, organizes BIM events for students and professionals, develops recommended national standards in specialized working groups and has members in CEN/TC 442 working groups [70].

A total of 18 people meeting the criteria were contacted for the survey (Table 1). A more detailed specification of the respondents can be found in Table 2.

Table 2. Number of selected professionals based on criteria presented in Table 1.

Work Position	No. Candidates Asked	No. Questionnaire Participants	No. Interview Participants
BIM coordinator/manager	7	6	6
Project/site manager	7	6	6
HS coordinator	4	3	2

2.3. Preparation of Survey Questions and Syllabus for the Interview

An electronic questionnaire was prepared from acquired theoretical knowledge of hazard detection in BIM [15,17,20–24,42–46,51,52], and practical knowledge with BIM management based on experience in the construction industry in Slovakia. It was composed of 33 questions connected by logical links, so that it was possible to exclude inappropriate respondents (e.g., if they did not perform preparation and control of HS on their projects or did not use BIM on any project). The logical links also made it possible to analyze the reasons for some of the answers, e.g., reasons for not using BIM for HS purposes or, conversely, to specify how companies performed a given process.

The questionnaire consisted of six sections:

1. Introduction, containing questions concerning the job position, confirmation of HS inspections on the construction site and of the use of BIM.
2. Detection of hazards.
3. Software used for hazard detection.
4. Transfer of information about hazards to the person responsible.
5. The current situation in occupational health and safety control on the construction site.
6. The importance of the topic and its future.

The video interview was used to explain the research topic and the purpose of the survey and to eliminate technical problems with the electronic questionnaire. It also allowed the analysis of specific questions and answers and developed the discussion, which led to further information.

The interview guidelines were:

1. Introduction—explanation of the topic and goals of the research.
2. Explanation of the chapters, scope and duration of the electronic questionnaire.
3. Explanation of the functions of the electronic questionnaire (e.g., logical links, moving to another question).
4. Execution of the questionnaire—explanation of questions if needed and detailed discussion of specific questions.
5. Final discussion.

In this paper, only questions related to hazard detection, found in units 1–2 and partially in 6, interpreted in the form of graphs and tables processed using Microsoft Excel software, were analyzed (the published order of questions and survey results differs from the original order in the questionnaire).

2.4. Contacting Suitable Respondents and Information about the Survey Sample

A total of 18 people—7 BIM coordinators/managers, 7 project managers and 4 safety coordinators—were contacted, and of these, 15 filled in the electronic questionnaire and 14 took part in the video call. A detailed representation of individual job positions in the survey is provided in Table 2.

Statistical information related to the representation of men and women in the survey, their age, highest education level and length of work experience in a specified or similar job position is provided in Table 3.

Table 3. Statistics and information about selected professionals based on criteria presented in Table 1.

Variables		Percentage of Participants	Number of Participants
Sex	Male	100.00%	15
	Female	0.00%	0
Age	<30 years	33.33%	5
	30–40 years	40.00%	6
	4–50 years	20.00%	3
	>50 years	6.67%	1
Work Experience	<5 years	33.33%	5
	5–10 years	40.00%	6
	>10 years	26.67%	4
Educational Level	High school	13.33 %	2
	Bachelor's degree	13.33%	2
	Master's degree	60.00%	9
	Ph.D.	13.33%	2

Table 4 shows the numbers and percentages of respondents categorized by annual sales in 2020 and the number of employees in 2021 in the companies where the respondents worked.

Table 4. Statistics of annual sales and number of employees of the companies where respondents work.

Company Statistics	Percentage of Participants	No. Participants
Annual sales in 2020 $\geq$ EUR 150 million	13.33%	2
Annual sales in 2020 = EUR 100–150 million	6.67%	1
Annual sales in 2020 = EUR 50–100 million	13.33%	2
Annual sales in 2020 = EUR 25–50 million	60.00%	9
Annual sales in 2020 = EUR 0–25 million	6.67%	1
No. employees in 2021 = 1000–1999	6.67%	1
No. employees in 2021 = 500–999	26.67%	4
No. employees in 2021 = 200–499	46.67%	7
No. employees in 2021 = 100–199	13.33%	2
No. employees in 2021 = 50–99	6.67%	1

Figure 2b is a map of Europe with the highlighted territory of Slovakia and Figure 2a is a map of Slovakia with the number of respondents categorized by the city where the company headquarters are.

2.5. Survey Execution

The video call interviews, in which the respondents answered 33 questions connected by logical links, took place from 3 February to 3 March 2021. The number of interviews was 14—one respondent completed only the electronic questionnaire. The syllabus of the interviews presented in Section 2.3 above was not changed. The average duration of an interview was approximately 45 min, depending on the length of the discussion with individual respondents.

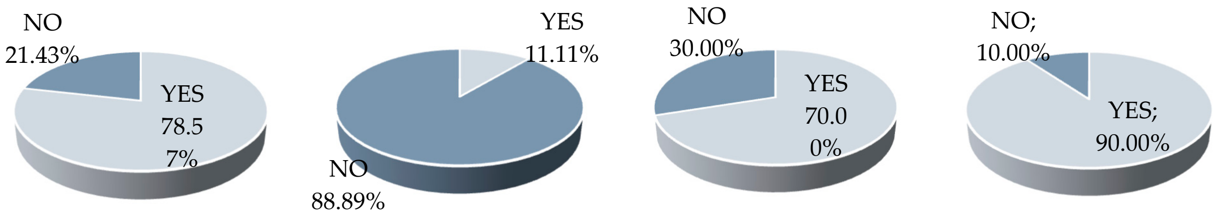
(**a**) (**b**)

Figure 2. (**a**) Map of Slovakia with the number of respondents and name of the cities where the headquarters of the companies are located. (**b**) Map of Europe highlighting Slovakia.

3. Results

3.1. Survey Introduction

At the beginning of the electronic questionnaire, 100% of respondents said that HS inspections were being carried out on their company's projects. If the answer had been negative, they would have been excluded. It turned out that 93.33% of respondents currently use BIM where they work. To the question in Figure 3a, 78.57% of the remaining respondents answered that they also used BIM for purposes that were at least partly related to HS (e.g., if the construction manager thought about securing the workplace when viewing the 3D BIM during scheduling and preparation of a construction process). The negative answers were justified by citing, for example, the high costs and the lack of experts. These reasons corresponded to the lack of BIM positions and low-level BIM implementation [6]. Nevertheless, 78.57% of the respondents (Figure 3a) considered BIM to be a proper tool for increasing the HS level and using it for this purpose, at least partly.



(a) (b) (c) (d)

Figure 3. Responses to the questions: (**a**) "Do you use BIM for health and safety processes in your company?" (**b**) "Do you use BIM for hazard detection during the design processes?" (**c**) "Do you use BIM for hazard detection during construction preparation?" (**d**) "Do you use BIM for hazard detection during construction?"

3.2. Questions Related to BIM Hazard Detection

For the questions in Figure 3b–d, the respondents said that they did not use BIM for risk and hazard detection during the design stage (Figure 3b—88.89%), but only during construction preparation (Figure 3c—70.00%) and construction (Figure 3d—90.00%).

The most common hazards were manually detected by members of the pre-construction team when they worked with 3D BIM during pre-construction planning. The most common reasons for not detecting dangers in individual phases included personnel, time and financial difficulties or no access to BIM. The results of Figure 3b,c also showed the low implementation of the PtD approach and that the general contractor was involved in preparations mostly just before the construction began.

However, the answers to the question in Figure 4 were the opposite, in which up to 53.33% of all respondents said that hazard detection should be performed in all phases: design, pre-construction and construction. Another 33.33% answered that it should start in the pre-construction stage.

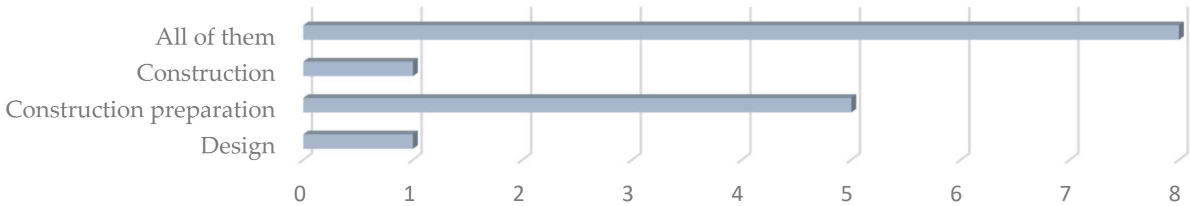


Figure 4. Responses to the question: "What stage do you think is the most appropriate for applying detection so that it directly increases the level of health and safety on the construction site?"

3.3. Questions Related to Software Used for Hazard Detection

Regarding the question in Table 5, on the method of hazard detection and the type of software used, respondents stated that none of them performed detection automatically. Methods developed in the solutions mentioned in the introduction or similar automation processes of hazard detection or HS equipment modeling in 3D or 4D BIM were therefore not yet implemented. The CDE systems were among the most widely used software for manual detection because their hardware requirements are low, are user-friendly and are more-or-less implemented in the companies where the respondents worked. The use of 2D drawing viewers in portable document format (PDF) or drawing (DWG) format in CAD software is also common.

Table 5. Responses to the question: "What kind of software do you currently use for manual hazard detection?" [1].

Software Type	BIM Coordinators	Project Managers	Safety Inspectors	Total
No manual detection	0	0	1	1
Visualizations (image, video)	1	1	0	2
2D plans viewer	2	2	0	4
BIM software for modeling	2	0	0	2
IFC viewer	2	0	0	2
BIM software for coordination	3	0	0	3
3D/4D BIM software	2	1	0	3
CDE software	4	3	0	7

[1] More than one answer could be selected.

The popularity of CDE systems among users can also be observed in the answers to the question in Table 6: "What type of software would be the most appropriate/practical/effective for automatic hazard detection?"

Table 6. Responses to the question: "What kind of BIM software would be the most appropriate/practical/efficient for automatic hazard detection?" [1].

Software Type	BIM Coordinators	Project Managers	Safety Inspectors	Total
BIM software for modeling	0	1	1	2
BIM software for coordination	5	2	1	8
3D/4D BIM software	4	1	1	6
CDE software	6	4	1	11
I do not know	0	1	1	2

[1] More than one answer could be selected.

The respondents, especially BIM coordinators, said the second-most suitable was BIM software for BIM coordination (e.g., Solibri). In this type of software, it is possible to check the geometry and non-graphical information semi-automatically based on rules set by the user. Therefore, because of these built-in functions or extensions, which are programmable via an API environment, this kind of BIM software is suitable for implementing automated hazard detection.

3.4. Questions Related to the Importance of the Topic and Its Future (Hazard Detection)

At the end of the questionnaire, the respondents answered questions concerning the significance and future of the topic (Figure 5). The vast majority, 93.33% (Figure 5a), answered that people who are responsible for HS on the construction site should use BIM to detect hazards. At the same time, they thought that increasing the efficiency of hazard detection would directly influence the increasing use of BIM by those responsible (Figure 5b). It is the demanding and quantitative manual work that discourages companies from these activities, most of which do not even perform them, and they deal with the hazards only when they occur on the construction site.

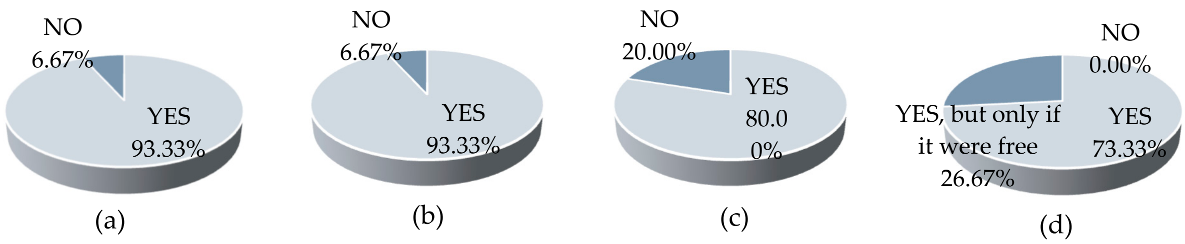


Figure 5. Responses to the questions: (**a**) "Do you think that people responsible for HS on construction sites should use BIM for HS hazard detection?" (**b**) "Do you think that increasing the efficiency of hazard detection would directly increase the usage of BIM for hazard detection by those responsible?" (**c**) "Do you think that an increase in hazard detection efficiency would directly increase the HS level on the construction site? (**d**) "If there were a tool for automatic hazard detection in BIM, would you use it?"

However, respondents are aware of the risks of such actions and up to 80% of them (Figure 5c) thought that if these processes were made more efficient and carried out, it would directly increase the level of safety on the construction site.

As mentioned at the conclusion of the Introduction, there is a lack of commercially available solutions (e.g., plug-ins) or stand-alone software that would allow companies to use the software they currently use in their work for HS issues. At the same time, all respondents stated that they would use such a tool or software, and 73.33% (Figure 5d) would be willing to pay for it.

4. Discussion

4.1. Key Findings and Comparison with Existing Approaches

Many respondents partly use CDE for manual hazard detection by working with 3D models, or by making HS e-forms from site inspections. CDE systems are the source of all information about the project, are user-friendly, easy on hardware and accessible from anywhere through smart devices. It is therefore relatively logical to concentrate information about HS risks and hazards to this one-source-of-truth environment.

However, the programming of hazard detection functionality in BIM software for coordination and rule-based checking is probably easier than in CDE systems. This kind of software was also identified by respondents as suitable for hazard detection. BIM coordinators use these programs to check the geometry and non-graphical data of BIM (e.g., collision detection). They also mostly support the IFC and BCF formats, so it does not matter in which software the building information model was created. That is an important feature for construction companies because they receive models from architects and designers who work in various BIM design software (e.g., Autodesk Revit, Graphisoft ArchiCAD, Trimble Tekla and other applications). Exporting to BCF format allows users to share checking results between different BIM software and CDE systems. This process is therefore suitable for a wide range of users.

Even though it is relatively easy to create additional functionality for hazard detection in BIM design software using an open API environment or visual programming environment, such as authors in [15,17,18,23,41] did, the respondents identified this kind of software as appropriate in only two cases. This was mainly due to the need for more experienced BIM users (i.e., not the HS coordinator), a limited user base and a native file that is less suitable for software interoperability and multi-stakeholder project collaboration.

It follows from the above that the issue of hazard detection should be resolved by developing the plug-ins or extensive workflow that will work with BIM software for coordination and CDE systems based on open BIM formats such as IFC and BCF. If the solution (plug-in or workflow) will use widely popular BIM software, its adoption by the companies could be more successful. In [71], the authors identified and analyzed the reasons for the slower implementation of BIM technology in construction projects in Eastern European countries. The analysis shows that in Poland, which is a neighbor country of Slovakia, it is mainly because of the people, their lack of knowledge and awareness and reluctance to change. The second main reason was low prices for construction documentation that does not cover the expensive software, employee training and payment of BIM specialists [71]. The same problems are shared by construction companies in Slovakia and probably in other Eastern European countries such as Czech Republic, Hungary, Ukraine, Southeast European countries and so on, because of their similar history, thinking, politics and economies. This underlines the need for a solution that will simplify the processes without significant additional costs.

4.2. Implications to Practice and Contribution to Knowledge

The results from this survey changed the approach to solving hazard detection in BIM. Past approaches, presented in the Introduction, solved the automation of hazard detection but did not verify if the software, in which the plug-in was developed, was used by the construction companies or by the people who are responsible for HS. Software such as Autodesk Revit, Trimble Tekla or Bentley Synchro PRO are huge applications with hundreds of functions, often not very user-friendly and requiring long daily use experience, which is not very suitable for positions such as HS inspectors and project managers.

A significant and inseparable part of the topic of hazard detection in BIM is also the transfer of information about the hazards to the person responsible. Detection can be performed by people in other positions (e.g., BIM coordinator), but the results have to be transferred to others (e.g., HS inspector). That is possible by different methods (video simulation, schedule, BCF), but what is the most effective way? How long does it take to transfer a report from a program and how long does it take to take action, such as installing a barrier, to avoid the hazard? This survey covered these issues, but the results from the interviews are currently being analyzed and will be published later.

The data showed that researchers and software developers should concentrate more on solutions based on an open BIM approach and using available software for BIM coordination or CDE systems, which are exceedingly popular. Based on these results, a method for HS hazard detection and transferring information to the person responsible is in development and will be published later.

4.3. Impact of Digitization of Health and Safety-Related Processes on Sustainability

The effect of occupational health and safety-related task inefficiencies on sustainability must not be overlooked. HS activities are inseparable from other tasks, but they are not often part of the schedule, which is why they surprise project managers and are often the reason for delays and extra work, and this usually produces hasty decisions, inefficient workflow and increased costs. When an injury happens because of undetected or unprotected hazards, the consequences are even worse: delays, investigations and extra work. If the injury is fatal, the country loses a healthy person, who creates value and has a positive impact on GDP. If a family loses a breadwinner, the country must support the survivors. Safety accidents create several other events with a negative impact on the economy and the environment.

Another reason for a higher effectivity is the environmental impact. As already mentioned, if construction were planned in more detail, there would be fewer surprises and less extra work. That would have a large impact on CO_2 production and cost effectiveness. Additionally, HS checking processes are often performed manually, using old technology (paper forms, old cameras), which has a significant carbon footprint. With the development of paperless digital solutions, automation and smart devices, the production of CO_2 could be reduced significantly.

5. Conclusions

Despite the advanced development of new software and functions in BIM, the field of hazard detection offers relatively high potential for research and development based on free and open IFC and BCF formats. Although significant research in this area has been carried out, there are currently only a few commercially available software programs that model construction site equipment or HS equipment and signs.

Countries such as the USA, Singapore, Australia and the UK have supported and developed PtD methodologies, techniques and databases for several years [15,18]. Even though the PtD approach is required from architects and design engineers by Slovakian Government Regulation No. 396/2006 (based on the directive of the Council of Europe No. 92/57/EEC) [72], it is not common in Slovakia probably due to the reasons presented in [6,71–76]. From the analysis in Section 3, Slovak construction companies, which already use BIM, would be interested in a user-friendly and effective solution to HS planning and hazard detection, and even be willing to pay for it. Currently, they do not carry out these detections, because are too time-consuming. Most believe that such effectiveness would also increase the level of on-site HS and that people responsible for HS should perform the hazard detection [77–79].

The largest number of respondents would welcome a hazard detection function in the CDE because the use of cloud CDE systems by several Slovak general contractors has increased. The second most popular answer was BIM software for coordination, such as Autodesk Navisworks or Nemetschek Solibri. This is in contrast to previous approaches presented in Section 1 and discussed in Section 4 that for this purpose used BIM software for design, or 4D BIM software. Given that CDE is still a relatively new type of software worldwide, it can be assumed that a solution based on its use (including open file formats IFC and BCF) could be well-received by construction companies globally [80–82].

Among the obstacles to the successful solution of this problem in Slovakia and elsewhere is the absence of databases containing lists of construction activities and associated hazards. There are also no tools that can automatically process text from standards and legislative regulations into a computer-readable format that can be used for rule-checking compliance.

The main shortcoming of this analysis is that the survey sample was small, yet that reflected the state of Slovak construction companies that use BIM and CDE systems and smart devices. Other deficiencies were the lack of context for answers to the questions concerning the transfer of hazard information to the responsible personnel. The analysis of these results is the subject of current scientific research and will be published in a future paper. Both analyses will be used to develop a hazard detection methodology based on the respondents' recommendations and open BIM formats such as IFC and BCF.

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