Expert System for the Prevention of Occupational Risks in Construction - Residential Buildings

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Abstract **– Construction companies consider it a priority to prevent occupational accidents and diseases, despite this, accidents in this sector prevail. This study presents OHSYS, an expert system specialized in the prevention of occupational safety in the construction of residential buildings, which evaluates a building project and it is recommended to security officer, actions to mitigate occupational risks. The results show that the number of recommendations increases on average by 7 and 13 for OSH levels of 90% and 100% when using OHSYS. In addition, the satisfaction, usability, and efficiency survey applied to 10 experts show that OHSYS has a very high score (4.5 out of 5).**

Keywords **– expert system, building, occupational safety, regulations, occupational hazards.**

1. Introduction

The construction industry accounts for 13% of the world's GDP ($10 trillion) with projected growth of $15.5 trillion by 2030 led by China, India and the USA [1]. The subsector of residential building construction, in 2017, billed $4,171.3 billion, and it is estimatedthat by 2022 it would reach $6,800.9 billion with an annual growth rate of 10.3% [2]. For [3], this subsector delivers a value added of 23% to industry and is the third with the highest productivity below the industrial and civil sectors. However, this industry is one of the most dangerous due to its high rate of occupational accidents, reaching 20.5% and 11.6% in occupational deaths and non-fatal accidents, respectively, in Europe, in 2018 [4], and 19.89% of occupational deaths with a cost of $1.29 billion and $87.62 million for accidents in the USA, in the year 2019 [5]. Work-related hazards stem from unsafe working conditions and unsafe work behaviors [6], [7] defines risks as the likelihood of harm or injury to specific people or groups exposed to the hazard (a risk is created by a hazard). For [8], the risk factors that most influence safety in the sector are lack of coordination, poor work and organization, economic and time pressure, low involvement of workers in safety, inadequate training, poor selection and use of equipment, and low awareness. In addition, it is observed that the design of safety in construction can help reduce risks, as 42% of accidents are related to this task. It is estimated that the violation of occupational safety and health (OSH) management represents 4% of the world's Gross Domestic Product each year [9]. In recent decades, countless efforts have been made to promote safety and health in work environments worldwide through regulations and compliance with the measures correctly implemented. This is because it has been proven that the creation of a culture of safety prevention reduces the risk of incidents, as they register 64% fewer security incidents and 58% fewer hospitalizations [10]. In addition, information technology reduces the complexity of processes in organizations [11]. Therefore, the prevention of occupational risks is one of the main concerns in many countries since occupational accidents represent a significant source of risk. Therefore, companies must have a culture of prevention that allows identifying the risks involved in the work of

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workers to establish adequate control measures and reduce their risk.

An alternative for security prevention is expert systems (ES), for their ease of processing standards (explicit knowledge). Determining risks in an automated way, as done by an expert, contributes to the improvement and compliance of regulations [12]. In the literature on ES in the building construction sector, works are oriented to the solution of problems of structural and economic projects with the support of vibration and temperature sensors [13], and the evaluation of costs used in the construction of small and medium buildings [14]. In addition, the fuzzy logic technique in [15], is used to select construction projects based on the previously established sustainability criteria, and in [16], the same technique is used to assess the risks of cost overruns. Other studies focus on the quantification of risk [17], and on the effective repair of building construction materials using 3D modeling techniques [18]. However, these studies and those in the literature have not been oriented towards the management of occupational safety based on regulations and the monitoring of compliance with these. OSH standards are overlooked even though they are increasingly recognized by governments and international organizations as an important part of public health [19]. Standards in different countries, in general, are based on good practices and recommendations that help reduce occupational accidents, improve social and economic development, labor productivity and the environment.

In this study, an ES called OHSYS is proposed for the prevention of occupational risks in the construction of residential buildings, which is based on current Peruvian regulations and experiences of experts on OSH, which evaluates the level of compliance with the standards, and recommends mitigation actions to achieve a desired percentage of compliance. To validate the system, a case study was conducted in a Peruvian construction company and an expert trial.

This paper is organized as follows. Section 2 presents the state of the art on the ES developed in the residential building construction sector. The proposed model and its components are described in section 3. Section 4 shows the implementation of the system. Section 5 presents the validation and results. Finally, in section 6, the conclusions are presented.

2. Expert Systems in the Construction of Buildings

ES are computer systems that mimic the decision-making capacity of an expert for solving complex problems through the reasoning of knowledge [20], [21]. These systems include three main components: (a) Knowledge base, contains the knowledge (rules) that allows the mechanism to draw conclusions, these are the system's responses to user queries [21]; (b) Inference mechanism, makes inferences for decision making based on rules given in the knowledge base and an algorithm such as Markov [22] or Rete [23]; (c) Factual basis, which refers to the data of the problem. Other components of the expert system are [21] the knowledge acquisition module, which represents the means for the expert in the area to introduce knowledge into the system; the user interface, which facilitates the communication of the user and the ES; and the explanation module, which makes it easier for the user to function and reason the system.

A search for ES in the construction of residential buildings in journals indexed in Scopus and Web of Science using the string ('expert system') AND (security OR safety OR assurance) AND (building OR construction OR structure OR edification) AND (monitor* OR control* OR supervis*) shows in Table 1., that there are few studies in this subsector, and none for the prevention of occupational risks.

Table 1. Expert Systems in the construction of buildings

ES	Description
Structural health of a building	It monitors residential buildings based on vibration and temperature, detecting safety and reliability conditions with 94.4% accuracy [13].
Investment in construction	It presents multiple building design decision paths based on economic and energy rules. The design of the inference engine helps to compare, choose, and track design paths [14].
Selection of construction projects	It uses an integrated multi-criteria decision-making approach using an expert system based on fuzzy rules to select the best sustainable construction project [15].
Risk of duration of a project	It presents a simulation-based approach to quantifying the duration risk of a hotel renovation project to estimate delay risks and predict the actual duration of the project [17].
Deterioration of patrimonial elements	Analyzes the repair and maintenance of heritage buildings identifying failures in the process, uses Building Information Modeling (BIM) [18].
Tender for construction projects	Improves bidding decision making in construction projects through an approach based on qualitative (rules), and quantitative factors (fuzzy) [30].
Risks in the choice of construction personnel	It reduces the risk of failure in selecting a contractor for design and construction in open tenders, providing the lowest bidder [31].

In addition, there are expert systems for other subsectors of construction, including those that address the analysis of the state of bridges [24], [25], deterioration of road pavements [26], budget in the process of assembling turbines of a specific structure [27] and in bridge design projects [28] and evaluation of accidents in tunnel excavations [29].

3. OHSYS Design

The ES for the prevention of occupational risks in building construction (OHSYS) recommends to the occupational safety officer the actions to mitigate the occupational risk in building construction projects. OHSYS is based on OSH norms and standards. Figure 1., shows its architecture consists of 5 main components: user interface, inference engine, fact base, knowledge base, and knowledge acquisition module.

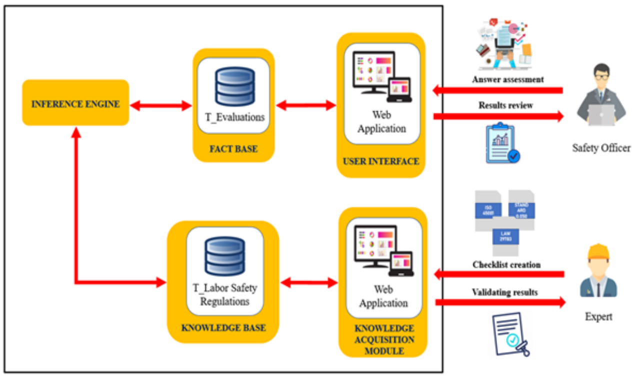


Figure 1. OHSYS Architecture

OHSYS contemplates two types of users: safety officer, and the expert in occupational safety. The security officer is a staff with domain in OSH designated by the organization who will use the expert system through the user interface, and the occupational safety expert is an OSH specialist who is responsible for managing (insert, update, delete) all OSH knowledge in the knowledge base through the knowledge acquisition module.

The operation of the system is as follows: First, the safety officer through the system interface records the details of the construction project and answers a questionnaire on OSH, all of these are recorded on the fact base. Second, the system, through the inference engine, knowledge base and fact base, evaluates the safety level of the construction project, displays the results of the evaluation, and requests the desired safety compliance percentage.

Third, the security officer records the percentage of security compliance. Fourth, the system through the inference engine, the knowledge base and the fact base, determines the mitigation actions to carried out to comply with the desired compliance percentage that are shown to the security manager through the user interface. For the operation of the system, the occupational safety expert is required to have recorded all the knowledge, both experience and standards, in the knowledge base.

3.1. *Knowledge Base*

This component is given by a container that stores the knowledge about OSH given by the norms and standards in force in Peru, and which are shown in Table 2. Each regulation and standard are composed of a series of requirements of different criteria or categories of OSH. Additionally, it contemplates the experience of 10 specialists in the area, who provided 100 personalized requirements on OSH.

Table 2. OSH Regulations and standards in Peru

Name	Description	Rules
Law 29783	Called the "Health and Safety at Work." Its objective is to promote the culture of prevention, establishing minimum standards for workers [32].	28
ISO 45001	Specifies the requirements for an OSH management system (OSMSM) and provides guidance for its use. It is used to improve, minimize risks, eliminate hazards, seize opportunities, and address nonconformities [33].	253
Standard G.050	Called "Safety during Construction", it details the minimum essential safety considerations in the civil construction [34].	246

3.2. *Inference Engine*

This component represents the programmed logic that will generate conclusions from information sources [35] and performs two important tasks: First, it evaluates OSH for a construction project including the work team; Second, it provides the actions to be taken to achieve a desired OSH compliance percentage. To perform these tasks, the inference engine applies the knowledge given in the knowledge base to the data given in the fact base.

3.3. *Security Officer Interface (GUI)*

Through this component, the interaction between the security manager and the system is managed intuitively and with adequate usability. The user will be able to answer the questionnaire to evaluate the OSH of a construction project, view the evaluation report, record the desired OSH compliance percentage, and see the mitigation actions to achieve that percentage.

3.4. Knowledge Acquisition Facility (KAF)

Through this component, the occupational safety expert is allowed to manage (insert, update, and delete) the knowledge (standards and experience) about OSH in the system.

3.5. Fact Base

This component stores the data on a construction project to be evaluated, and on which the inference engine will suggest actions for the prevention of accidents. These data are the evaluation criteria, requirements, the level of risk, justifications, evidence, and response according to the level of compliance.

4. OHSYS Implementation

The OHSYS expert system that recommends OSH actions to mitigate occupational risk in construction-building construction projects is described below.

4.1. Architecture

The OHSYS technology architecture shown in Figure 2., connects its components and points out the programming language technologies, libraries, platforms, and operating system used in each component. In addition, the main access of users to the system is evident, it is worth mentioning that the administrator is the only one with access to the backend, while the access of the other users is through the frontend. On the other hand, the backend uses Azure services, such as the .NET framework with the Java language and the mapping algorithm that is developed using the JavaScript language. Additionally, the technology involved for the frontend is the Vue.js framework, as well as the Apexchart and Ant Design libraries for reports.

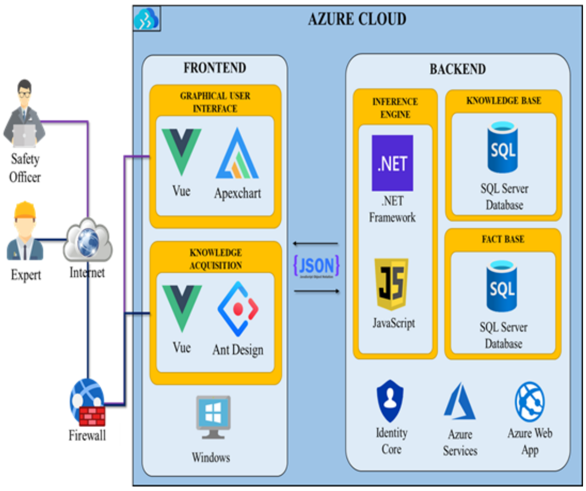


Figure 2. OHSYS Architecture

4.2. Database

SQL Server was used as the database manager. It stores the information collected from the OHSYS fact base and knowledge base information, some of rules are given in Figure 3. Additionally, it connects with Azure to store the evidence entering the system.

```
//The new compliance percentage is calculated
if(objectPriority[j].criteriaResult.score / objectPriority[j].criteriaResult.numberQuestions != 1) {
    criteriaResult[i].score = criteriaResult[i].score + 1 - objectPriority[j].evidence.replyItem
    criteriaResult[i].percentCompliance = (criteriaResult[i].score / criteriaResult[i].numberQuestions) * 100
    percentComplianceTotal = calculatepercentComplianceTotal(criteriaResult)

//The new percentage is greater than or equal to the desired percentage
if(parseFloat(percentComplianceTotal) >= limit) {
    //Validate that it is within the margin of error
    const isValid = parseFloat(percentComplianceTotal) - limit
    console.log("valid", isValid)
    if(isValid <= parseInt(margen)) {
        return res.status(200).json({ objResult, percentComplianceTotal })
    } else {
        //the added criterion is removed
        criteriaResult[i].score = criteriaResult[i].score - 1 + objectPriority[j].evidence.replyItem
        criteriaResult[i].percentCompliance = (criteriaResult[i].score / criteriaResult[i].numberQuestions) * 100
        percentComplianceTotal = calculatepercentComplianceTotal(criteriaResult)
        objResult.pop()
    }
}

//If the desired percentage is not reached in the end
if (i == criteriaResult.length - 1 && j == objectPriority.length - 1) {
    return res.status(200).json({ objResult, percentComplianceTotal, message: 'The percentage was not reached, this is the closest approximation.' })
}
```

Figure 3. OHSYS knowledge base rules

4.3. Development

- OHSYS was developed for the web environment using the Node language.js with the .NET Core framework and Vue.js In addition, the Apexchart library and Ant Design supported the reports, and the design of the interfaces are shown in Figure 4., which includes the functionalities of evaluation of a project, evaluation report, record of desired percentage of compliance and the treatment plan (made up of mitigation actions) to achieve this percentage. On the other hand, the mapping algorithm for the inference engine is developed in the JavaScript language and was integrated into the web system using an API (Postman). In addition, the use of Azure Storage services (SQL Server) was used to manage the documentation stored in the system with which the fact base and the knowledge base were implemented.

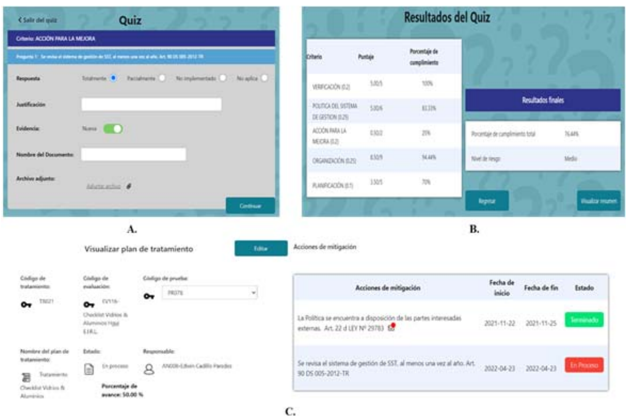
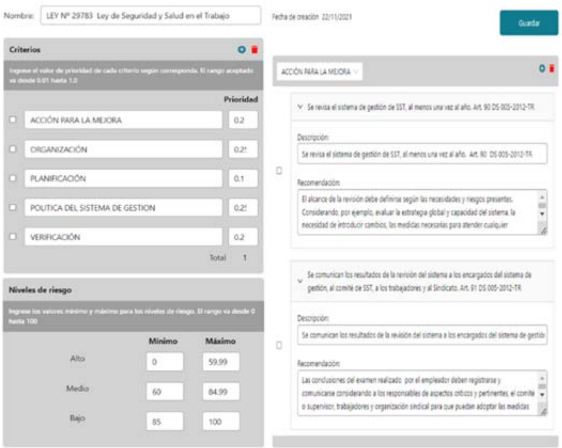
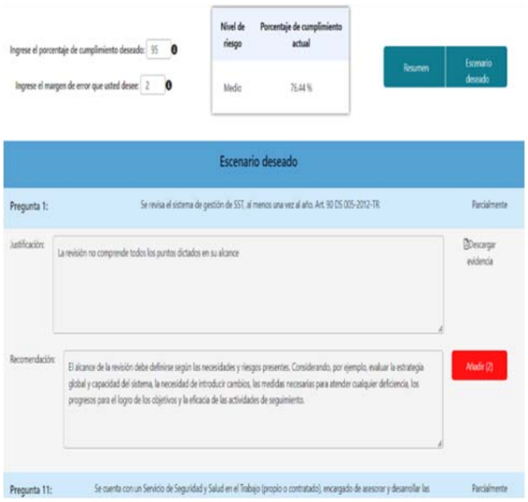


Figure 4. OHSYS Interface: A) Quiz; B) Evaluation results; C) Treatment plan

OHSYS KAF was implemented using Vue.js framework, Apexchart and Ant Design libraries, and includes checklist registration functionalities are shown in Figure 5A., and risk mitigation actions in Figure 5B. The record of the verifications includes the details of the occupational safety regulations, the evaluation criteria, and the classification of the level of risk to be evaluated. On the other hand, mitigation actions represent the activities recommended by the ES carried out to comply the desired percentage.



A.



B.

Figure 5. System KAF: A) Checklist registration; B) mitigation actions

5. Validation

Validation of the ES was conducted through a case study and a trial of experts in Lima, Peru. Most Peruvian construction companies consider occupational safety and risk management as a priority, but only 46% implement it [36]. The objective of this section is to determine whether the use of OHSYS contributes to improving monitoring services, evaluation of occupational safety regulations, and streamlining the processes of registration of evaluations and treatment plans.

5.1. Case Study

The study company that is denoted by EER is a medium-sized construction company in the residential building subsector that has around 100 workers, has a 23-year presence in the sector, and presents a wide portfolio of projects, covering the planning and execution of shopping centers, industrial buildings, corporate, hotel and residential buildings, the latter of interest in this study. EER has three business units related to construction, real estate development and hospitality. The area in charge of auditing and analyzing the safety reports in residential buildings is made up of a division of fifteen people, who ensure the following security objectives:

- Improve compliance in the delivery of projects
- Reduce the non-conformity of projects prior to their delivery
- Reduce the impact and impact of the environment
- Reduce accident rates

Implementation of OHSYS in the EER

OHSYS was implemented in the EER company through six steps. Initially, the BD, frontend, and backend servers were configured. In addition, the system was deployed to Azure Web Services. On the one hand, functionality tests were conducted with expert EER users. On the other hand, it was verified that the data had been stored correctly. Finally, the reports were generated from the data obtained.

Occupational Risk Assessment Process Flow

The occupational risk assessment process that follows EER consisted of 16 tasks, after the implementation of OHSYS, 3 of these were performed by the system as shown in Figure 6. The most remarkable task being the generation of mitigation actions, this allows to reduce the time spent in analysis to propose answers to improve the compliance obtained from an occupational risk assessment.

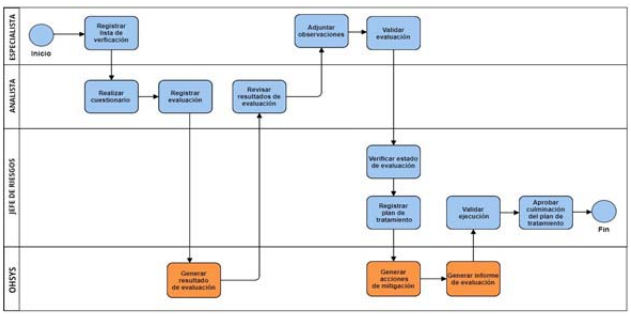


Figure 6. Flow of the occupational risk assessment process

Experiment on 8 Building Projects

8 full project audit reports provided by EER were considered, following a review of 30 reports of recently executed projects in the country. These projects correspond to the category of residential buildings and are composed of approximately 100 workers, which is why it was considered an OSH plan and were based on the three regulations that were evaluated by OHSYS. In particular, the PR03 project, which is also denoted as the HYS Pasco project, was evaluated by OHSYS through Law 2978 for audit compliance. This evaluation obtained a percentage of occupational safety compliance of 84.21%, so the system recommended a treatment plan of 31 actions for a goal of 100% occupational safety, 6 of which are shown in Figure 7. Similarly, the other 7 projects were evaluated, considering a safety level of 90% and 100% for the recommendations. OHSYS was compared to the traditional form that was given by the audit reports provided by EER, who considers a security level of 90 to 100%.

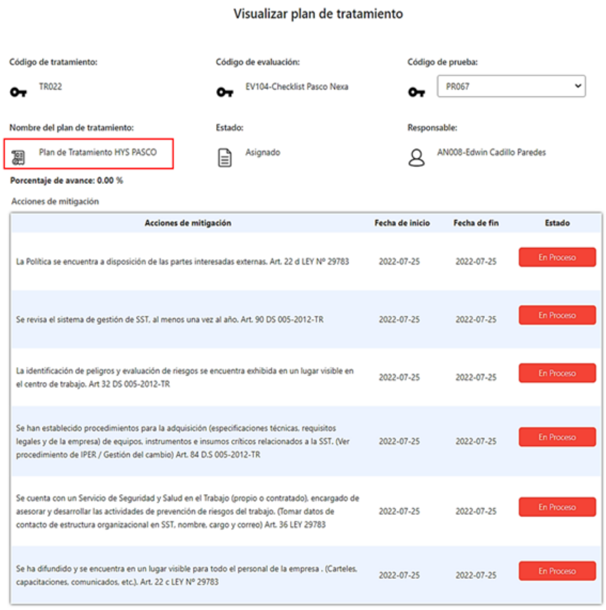


Figure 7. Treatment Plan Registration Interface

Results of experiment

In Table 3., the results on the evaluation of occupational safety show that the traditional evaluation and using OHSYS coincide, the average level of security of the projects being 88%, which shows that the knowledge base is correct. On the other hand, the number of recommendations given by the system is an average greater than 7 and 13.5 for the safety levels of 90% and 100% respectively, i.e., increases the recommendations, which allows the improvement of the occupational safety level.

5.2. Expert Judgment

This section details the tests performed with 10 experts selected for validation. These were conducted through virtual meetings in which all the functionalities of the system were presented.

Participants

10 occupational safety specialists who were contacted through LinkedIn participated, all of them, according to their profile as shown in Table 4., with at least 3 years of experience in occupational safety, and with knowledge in occupational safety regulations and OSH law.

Instrument

To evaluate OHSYS, as shown in Table 5., a 15-question Microsoft Forms questionnaire was developed that includes 3 sections: satisfaction, usability, and efficiency, with a Likert scale for the answers of 5 alternatives (1: nothing; 2: little; 3: neutral; 4: high and 5: very high).

Experiment

The videoconference of 1 hour was held with 3 to 4 participants at a time for the presentation of OHSYS, its purpose, modules, functionalities, and advantages. Access to the system was granted and activities were conducted (safety management, risk assessment management, risk treatment management and report management) of the expert and safety officer profiles were repeated by the participants. Moreover, a project previously registered through the system was evaluated. During the presentation, questions were answered. At the end of the presentation, the questionnaire of satisfaction, usability and effectiveness was applied, previously sent to their emails.

Table 3. OSH Regulations and standards in Peru

Evaluation	Compliance achieved		Recommendations		
	Traditional	OHSYS	Traditional (90% - 100%) *	OHSYS**	
				90%*	100%*
PR01	82.00%	82.11%	4	25	28
PR02	85.00%	84.49%	3	25	30
PR03	84.00%	84.21%	3	15	31
PR04	91.00%	90.97%	1	0	5
PR05	88.00%	87.82%	1	5	9
PR06	94.00%	93.44%	1	0	7
PR07	88.00%	88.08%	4	6	10
PR08	92.00%	91.62%	3	0	8
Average	88.00%	87.84%	2.5	9.5	16

***** *Desired security levels*
******The recommendations given by the system do not consider the repetition of the same to comply with more than 1 requirement*

Table 4. Profile of the participating experts

Id	Academic Degree	Labor area	Years of experience	Main function
EX01	Bachelor of Systems Engineering	Occupational safety	3	Risk management planning
EX02	Industrial Engineer	Occupational safety	5	Direction of the Health and Safety Committee
EX03	Environmental Engineer	Occupational safety	5	Management of Occupational Safety Regulations
EX04	Occupational Health and Safety Engineer	Occupational Health and Safety	6	Enforcement of the Occupational Safety and Health Act
EX05	Bachelor's in industrial engineering	Project Management	3	Training and/or experience in working at height
EX06	Bachelor's in environmental safety engineering	Occupational safety	3	Monitoring compliance with OSH programs
EX07	Environmental Engineer	Occupational safety	4	Management of regulations at work
EX08	Occupational Safety Engineer	Occupational health	7	Direction of the Health and Safety Committee
EX09	Occupational Health and Safety Engineer	Risk management	10	Direction of the Health and Safety Committee
EX10	Industrial Engineer	Occupational hazards	15	Occupational risk analysis

Table 5. Satisfaction, usability, and efficiency questionnaire

Dimension	ID	Question
Satisfaction	Q01	Are the interfaces attractive with respect to the design and content displayed?
	Q02	Is the system intuitive and is the information displayed simply?
	Q03	Are the buttons descriptive and do they correspond to their function?
	Q04	Is the system's color palette balanced?
	Q05	Are the interfaces related to function names?
Usability	Q06	Does the system represent an actual situation of occupational hazards?
	Q07	Do the functions presented meet your objectives?
	Q08	Are the reports presented in the system relevant for monitoring?
	Q09	Does the system comply with the verification of occupational safety regulations?
	Q10	Does the system comply with the optimization of processes in occupational risks?
Efficiency	Q11	Is the system easy to navigate through each interface?
	Q12	Does the system present permission validation according to the assigned role?
	Q13	Does the system handle error detection through messages?
	Q14	Do the terms used present a standard and consistency for further understanding?
	Q15	Does the system allow recognition instead of remembering the actions to be performed?

Results of Expert Judgment

In Table 6., the results of the satisfaction, usability, and efficiency questionnaire show that OHSYS has a very high average score (4.5 out of 5) with respect to these three dimensions. In the satisfaction dimension, it obtained a high score for its intuitive handling and simplicity (Q02) and a very high score on the remaining questions, that is, the interfaces are attractive (Q01), buttons are descriptive (Q03), balanced color palette (Q04) and related to their function (Q05). In terms of usability, it obtained a very high score in all questions, i.e., the system represents the reality of the OSH area (Q06), meets its objective (Q07), monitoring through reports (Q08), verifies OSH regulations (Q09) and process optimization (Q10). In the dimension of effectiveness, it obtained a very high score in all questions, that is, the system presents ease of navigation (Q11), validation of permissions for each profile (Q12), error detection (Q13), standardization of terms (Q14) and recognition of steps to follow (Q15).

Table 6. OHSYS satisfaction, usability, and efficiency results

Dimension	ID	Specialists										Average		
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10			
Satisfaction	Q01	4	4	5	5	4	4	5	4	5	5	4.50	4.44	4.5
	Q02	4	4	4	5	4	4	4	4	4	5	4.20		
	Q03	5	5	5	5	5	4	4	4	4	5	4.60		
	Q04	5	4	4	5	4	4	5	4	5	4	4.40		
	Q05	4	5	4	4	5	5	4	5	5	4	4.50		
Usability	Q06	5	4	5	4	5	4	5	4	4	5	4.50	4.58	
	Q07	4	4	5	4	5	5	5	5	5	4	4.60		
	Q08	4	4	5	5	4	5	5	5	5	5	4.70		
	Q09	4	4	4	4	4	5	4	5	5	5	4.40		
	Q10	5	4	5	5	5	4	5	5	4	5	4.70		
Efficiency	Q11	4	4	4	5	5	4	5	5	4	4	4.40	4.44	
	Q12	4	5	5	4	5	4	5	5	5	5	4.70		
	Q13	4	4	4	4	5	5	4	5	5	5	4.50		
	Q14	4	4	3	4	5	5	4	5	4	5	4.30		
	Q15	3	5	4	4	5	5	4	4	5	4	4.30		

6. Conclusion

This study has described the development and evaluation of an expert system called OHSYS for the prevention of occupational risks in the construction of residential buildings. OHSYS offers to the occupational safety officer the actions to mitigate the occupational risk in building construction projects, is based on OSH norms and standards, and consists of 5 main components (user interface, inference engine, fact base, knowledge base, and knowledge acquisition module). OHSYS was implemented in a web environment using Node.js, the Apexchart and Ant Design libraries, JavaScript, the Postman API, and SQL Server. Unlike other expert systems, OHSYS is the only one specializing in the prevention of occupational safety in the construction of residential buildings. In addition, it allows the monitoring of compliance with standards, automates risk assessment, and provides mitigation actions.

The results of the case study on 8 projects of a real company, in Lima, shows that the traditional evaluation and through OHSYS coincide, obtaining an average level of job security of 88%, that is, OHSYS presents a correct knowledge base. In addition, it increases the number of recommendations on average of 7 and 13 for the safety levels of 90% and 100%, respectively, which allows to improve the level of occupational safety. On the other hand, the results of the satisfaction, usability and efficiency survey applied to 10 OSH experts show that OHSYS has a very high score (4.5 out of 5).

As a future work, it is intended to include a coverage algorithm (set covering) to determine the least number of recommendations that allow to achieve a desired level of occupational safety with lower cost.

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