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Integration of 4D BIM, PtD and databases to improve OHS and knowledge management in construction

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Abstract - The construction industry faces high incidences of accidents and injuries, resulting in project delays, additional costs, and loss of lives. In developing countries, conventional methods are employed to identify risks and prevent accidents due to limited familiarity with tools such as Building Information Modelling (BIM) and Safety and Health Management (SHM) models. Furthermore, the lack of knowledge retention and lessons learned hinders continuous improvement in safety. Previous research has proposed specific solutions to address these issues, including the integration of BIM in occupational risk management, the use of technology to store safety data, and the application of the Prevention through Design (PtD) approach. However, these solutions tend to focus on individual challenges. This paper introduces a novel methodology called Ultra Safety Design (USD), which comprehensively addresses OHS management in construction projects. USD combines the use of BIM, PtD, and a centralized database. BIM enables precise identification of hazards and risks during the design stages, facilitating the implementation of appropriate control measures. PtD promotes a proactive safety mindset by preventing risks from the design phase, and the centralized database allows for knowledge retention, information exchange, and referencing of previous projects, fostering a culture of continuous improvement. The study's results demonstrate effective risk mitigation, with a significant reduction in overall risk levels. The USD methodology proves to be an integral and effective approach to address OHS management in construction, integrating multiple tools and promoting continuous improvement in OHS practices.

***Keywords*:** Building Information Modelling (BIM), Integral approach, Risk management, Occupational Health and Safety (OHS) Management, Hazard identification, Continuous improvement, Prevention through Design (BIM), Ultra Safety Design (USD).

1 Introduction

The construction industry is of vital importance to a country's economic growth. Nevertheless, accidents and injuries in this sector are high, causing delays in construction, material damage, work absenteeism, increased costs, and even human losses [1]. Also, [2] mentions that the construction sector represents 10.45% of the total number of accidents reported during 2023 in Peru.

In developing countries, only traditional methods for hazard identification, risk assessment and accident prevention are applied in the design phase, due to the high lack of knowledge of BIM tools and new technologies/methodologies [3]. In addition, during the execution of a construction project there is often little knowledge in the application of worker safety and health (OHS) management models [4].

The lack of retention of OHS knowledge and lessons learned represents a major obstacle to continuous improvement in construction safety. Valuable information on incidents, accidents and best practices is lost as staff changes in companies, making it difficult to implement effective preventive measures in future projects and obstructing continuous improvement [5].

Regarding the investigation of these problems of lack of knowledge of BIM tools and methodologies, OHS management models and knowledge retention or lessons learned in OHS some authors proposed some solutions. For example, [6] develops a dynamic integration strategy for occupational risk management at the design stage in buildings constructed with the help of BIM methodology in Spain, which will help specialist and non-specialist workers in occupational safety and health (OHS).

This proposal allows to see the tolerance levels (high, tolerable and low) in the elements of a building project. [7], also suggests the application of BIM, but specifically of the Autodesk Revit tool that allows storing data related to risks and safety in construction.

On the one hand, [8] seeks to discover an improved proposal for improving OHS risk management under the application of PtD at the design stage. In addition, it creates a conceptual framework with patterns that allow analysing the feasibility of PtD design. While [9] conducts interviews with workers involved in construction who apply PtD and occupational safety and health (OHS) measures. This proposal allows understanding the situation of developing countries with respect to the application of Prevention through Design. On the other hand, [5] indicates that establishing a safety culture depends on the organization, since it must work consciously and ensure that workers can perform their work safely. Also, it highlights that, through continuous improvement and the application of these good practices such as OHS information management by database help to improve decision making in the identification of hazards and OHS risk assessment.

From this information, it can be seen that previous authors propose solutions that only focus on a specific problem. For this reason, the Ultra Safety Design (USD) methodology was created to address these challenges through integrated and complementary solutions. The integration of Building Information Modelling (BIM), Prevention through Design (PtD) and a centralized database through an SQL server has been proposed. The use of BIM allows a more accurate identification of hazards and risks during the design phases, facilitating the implementation of appropriate control measures. The application of PtD in the design process promotes a proactive safety mindset, preventing and/or minimizing risks from the outset. In addition, the implementation of a centralized database enables the retention and sharing of knowledge, including lessons learned and best practices. This fosters a culture of continuous safety improvement, where past projects serve as references and guidelines for future construction, improving safety awareness and compliance.

2 Case Study

This study was implemented in a 9-level building, covering an area of 461 m2, located in the district of Jesus Maria, Lima, Peru; executed by a private company between 2022 and 2023. The application of the methodology proposed in this study consisted of 4 phases: Input Data, in which all the required data from the building was obtained and filtered; 4D Simulations; Prevention through Design, in which risk management was carried out from an early stage of the project following the PtD guidelines; and Knowledge Management, which purpose is to store the management information from previous phases and use it to monitor and control during project's execution.

3 Tools and Methods

3.1 Phase 1: Input Data

In this first phase all the data that will be needed for the integration of BIM 4D were collected. First, all the 2D drawings in DWG format of the 9-story building were collected, then the list of activities was made in Excel, scheduling activities in the Microsoft Project tool in order to know the sequence and duration of the execution of the project. Secondly, based on the previous data, a 3D modeling of architecture, structure and sanitary facilities was developed using Autodesk's Revit software. Next, it performs the sectorization of the modeling of structures with the Autodesk Revit tool. This starts by creating a parameter called "SECTOR", then it is divided into 3 sectors, taking into account that the metrics are similar for each sector, for this we help us with the command "Divide Parts", then, in "Visibility and Graphics" a color filter is created for each sector, in this case sector 1, sector 2 and sector 3 with their corresponding colors in order to perform a sequential and orderly simulation.

3.2 Phase 2: 4D Simulations

During the second phase, after completing the 3D modeling and sectorization in Autodesk Revit, the next step is to export the file to an .nwc format for 4D simulation in Navisworks. This was synchronized with the schedule made in phase 1 in order to simulate it and observe in real time the execution of the project, from the design phase. In this way, identify the hazards of the case study from the design stage. The simulations were carried out by the team of professionals in charge of health and safety management on the project.

3.3 Phase 3: Prevention through Design (PtD)

Due to the amount of data to be handled, an application was developed in Microsoft Excel oriented to OHS management based on the PtD initiative and processes, such as hazard identification, initial risk management, risk mitigation mitigation and residual risk management. This spreadsheet has tools such as IPERC (Hazard Identification, Risk Evaluation Evaluation and Controls), Residual Risk Management (RR), Requests for Information on Previously Taken Controls (RFI), (RFI), Lessons Learned (LA) and a search engine that allows filtering elements according to what is required. Functions such as advanced filters, lists, conditional formatting, tables, macros and Visual Basic programming were used to develop the template. From the simulations performed in Phase 2, activity-based hazards were identified and served as input data for the IPERC tool. Through this, the characteristics and properties of the hazard were determined, we assigned an initial risk factor (RF - CS) based on exposure, probability and severity indexes granted by the Peruvian Law N° 29783 on Occupational Safety and Health Management (Fig. 1). Subsequently, according to the type of hazards, mitigation controls were selected to reduce the risk factor, obtaining a lower risk factor (RF - FS). Table 1 presents a reference sample of the risks evaluated using the IPERC tool. Then, both risk factors (RF-CS & RF-FS) were compared using the RR tool in order to check the effectiveness of the controls taken. If the remaining residual risk is less than 30% and thus the risk reduction ratio is greater than 70%, the mitigation was effective.

Exposed Workers Index

Index	Exposed Workers
1	1 - 5
2	6 - 10
3	11 - 20
4	More than 20

(a)

Exposure Index

Index	Level of Exposure	Meaning
1	Sporadic	Irregularly
2	Occasional	Sometimes on a weekday and for a short period of time
3	Frequent	Several times during a weekday and for a short period of time
4	Continuous	Several times on weekdays and for extended periods of time

(b)

Training Index

Index	Exposed Workers
1	Trained employees, know the danger and prevent it.
2	Partially trained personnel, aware of the danger, but who do not take safety measures.
3	11 - 20

(c)

Existing Procedures Index

Index	Procedures Index
1	Exist, are satisfactory and sufficient
2	Partially exist, are not satisfactory or sufficient
3	Don´t exist

(d)

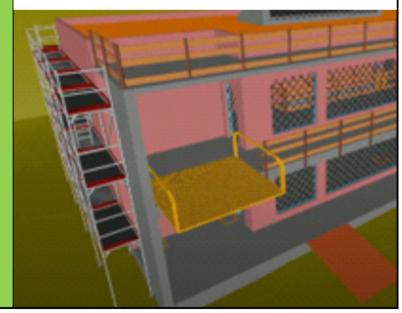
Severity Index

Index	Severity Level	Meaning	
		Personal Damage	Material Damage
1	Mild	Small injuries that do not require hospitalization	Repairable, no need to stop the process
2.5	Serious	Injuries or illnesses with temporary disability	Process stop is required to perform the repair
6	Severe	Serious or irreversible injuries or illnesses with permanent disability.	Partial system destruction
10	Mortal/Cathastrofic	1 dead or more	Total system destruction

(e)

Fig. 1: OHS Indexes. Probability Index = (a + b + c + d). RF = Probability * Severity (e)

Table 1: Hazard Identification and Risk and Controls Evaluation (IPERC)

ID	Activity	Hazard	Type of Hazard	Risk	Probability CS	Severity CS	Risk Factor	Controls	Probability FS	Severity CS	Risk Factor	BIM 4D controls
1	concrete pouring of slabs	Dynamic muscle work	Ergonomic	Physiological problems	10	6	60	Training of personnel on safe working procedures at heights and perimeter safety netting.	8	1	8	
2	Exterior Wall Painting	Work at heights greater than 1.80 m	Physicist	Possible drop to unevenness (≥ 1.80 m)	9	10	90	Training of personnel on safe working procedures at heights. Use of standard scaffolding and perimeter safety netting.	7	2.5	18	

3.4 Phase 4: Knowledge Management App

Despite the efforts to apply new technologies to occupational safety and health (OHS) management, it is often observed that the information gathered is lost over time, hindering continuous improvement. To address this issue, a relational table (SQL) data server has been developed on the Microsoft Azure platform. This server will be populated with data from an application created in Microsoft Excel during Phase 3. By storing the information from previous phases, it will be readily available in real-time without the need for physical storage hardware. The data can be organized, classified, and visualized in various ways, promoting continuous improvement. Azure servers were chosen for their reliability, ease of use, and security features. Additionally, they offer seamless integration with other Microsoft applications like PowerApps, PowerAutomate, and PowerBI. This allows for further customization of the server and enhances connectivity between different platforms. Overall, this approach aims to enhance OHS management and facilitate the use of data for future projects.

In PowerApps, an application was created to visualize the information of the previous phases during the execution of the project in order to monitor and control the OHS management (Fig. 3). As a result, the key performance indicators (KPI) of the Peruvian OHS standard G-050 such as Monthly Frequency Index (IFm), Monthly Severity Index (IGm), Accumulated Frequency Index (IFa), Accumulated Severity Index (IGa), Accidentability Index (IA) were affected.

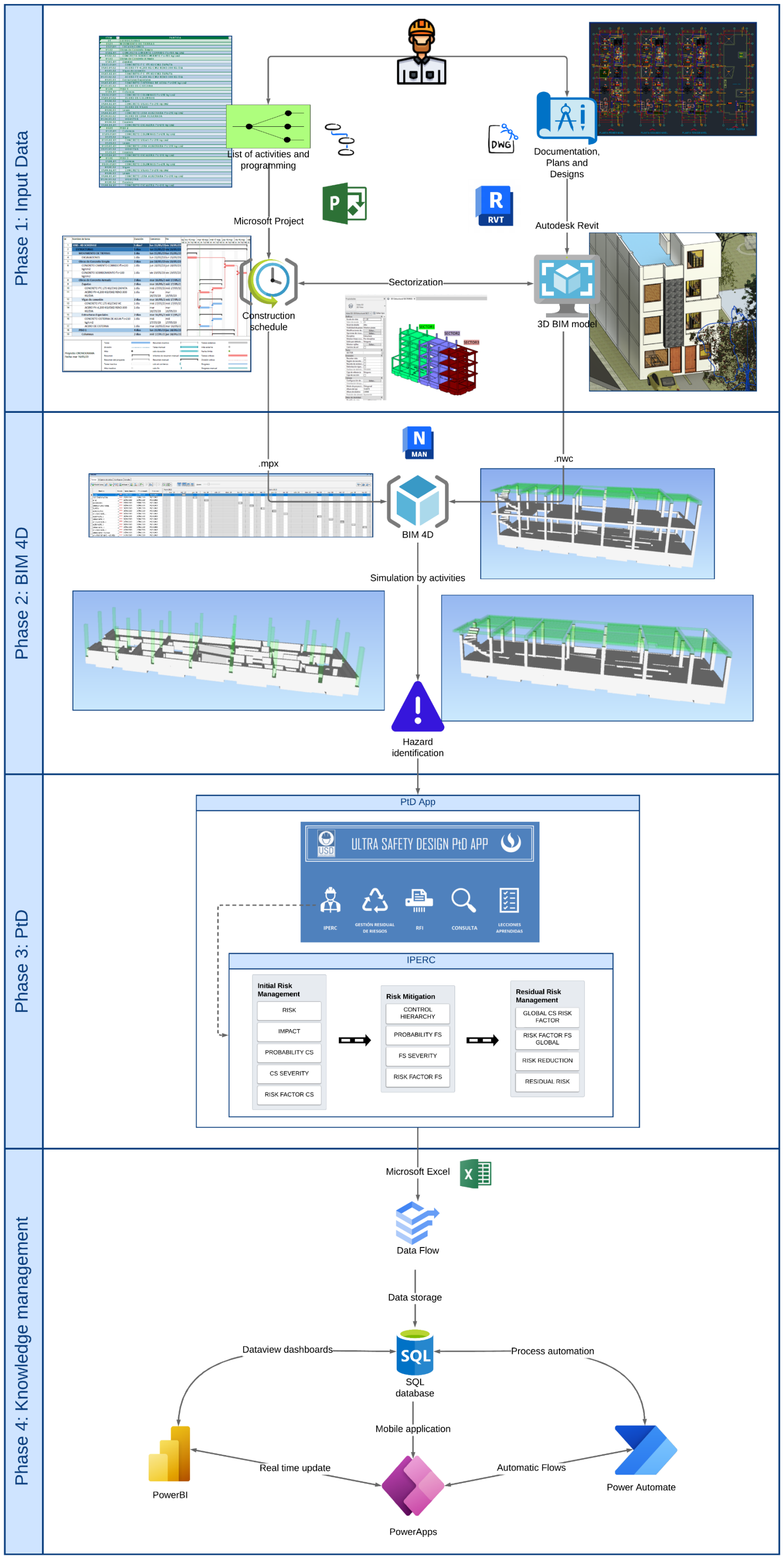


Fig. 2: USD Methodology Flowchart

Fig. 3: Interface of the application developed in PowerApps

The complete methodology, as can be seen in Fig. 2, links the 4 processes. Representing digitally in a three-dimensional modelling the case study, adding the time dimension and simulating by activities to identify risks; followed by entering the PtD App with those hazards to perform risk management and that the information of this feeds and is stored in a SQL server, to later visualize it as required through mobile devices through an app or through dashboards.

4 Results

4.1 Design Phase

According to ANSI/ASSP Z590.3 (Prevention Trough Design standard), an effective PtD management one that has an overall residual risk indicator of less than 30%.

From the simulations, 25 additional risks were identified, which were effectively mitigated. All were reduced to below the residual risk threshold of 30%. Fig. 4 presents a 3D histogram of the comparison between pre-control and post-control risk levels.

An analysis was also performed from a global perspective, accounting for all risks. Equations (1), (2), (3) and (4) were used to find global indexes.

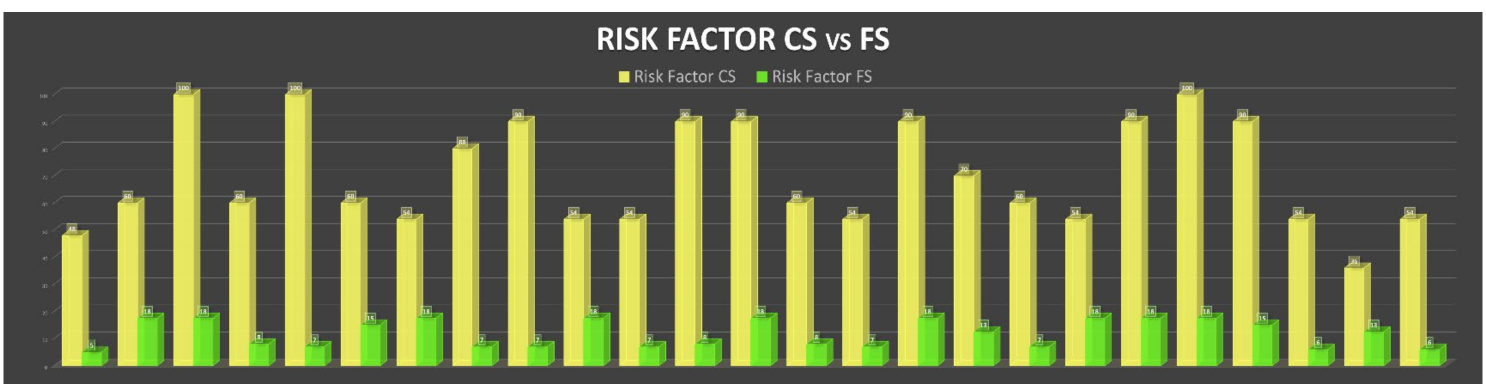


Fig. 4: Comparative 3D Histogram. Risk Factor Current Situation (CS) vs Future Situation (FS)

Therefore, an individual and global comparison of the PtD indicators was realized using the RR tool of the spreadsheet developed in phase 3, obtaining the following results (Table 2).

$$RF\ CS_{GLOBAL} = \sum RF\ CS_{individual} \tag{1}$$

$$RF\ FS_{GLOBAL} = \sum RF\ FS_{individual} \tag{2}$$

$$IR = 100\% - RR \tag{3}$$

$$RR = \frac{RRF\ FS_{GLOBAL} \times 100\%}{RRF\ CS_{GLOBAL}} \tag{4}$$

Table 2: Summary table of Indicators

Indicator	Residual Management
RF-CS (Eq. 1)	**1752**
RF-FS (Eq. 2)	**286**
IR (Eq. 3)	**83.68%**
RR (Eq. 4)	**16.32%** < 30% (OK)

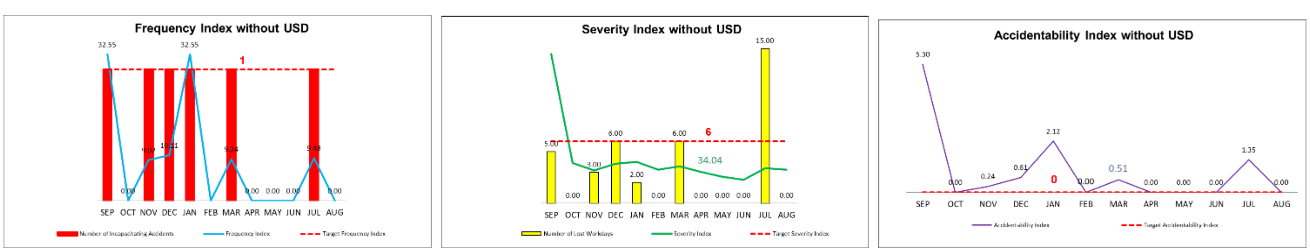
4.2 Construction Phase

During the construction phase, monitoring occupational health and safety (OHS) with the USD app was crucial in reducing G.050 indexes compared to expected ratios. The indexes were calculated using equations (5), (6), and (7), and then compared to the actual ratios achieved with the application of USD (as shown in Fig. 5).

$$IFa = \frac{Lost\ time\ accidents\ during\ the\ year \times 200000}{Year\ to\ date\ hours\ worked} \tag{4}$$

$$IGa = \frac{Lost\ workdays\ during\ the\ year \times 200000}{Year\ to\ date\ hours\ worked} \tag{5}$$

$$IA = \frac{IFa\ \times IGa}{200} \tag{6}$$



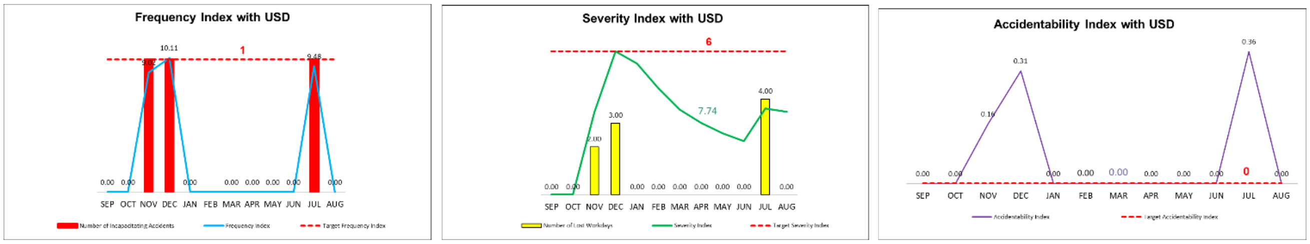


Fig. 5: Comparative Graphics. G.50 Indexes without USD vs Indexes with USD

5 Conclusions

The results demonstrate the incredible effectiveness of the USD methodology reducing OHS risks. As evidenced by the significant reduction of risk percentage, it's clear that the efforts made during the construction phase were truly paying off. Furthermore, the notable OHS indicators decline has led to a reduction in the incidence of accidents.

Moreover, the lessons learned tool of Phase 3 and the preservation of information through the database and applications of Phase 4 promote continuous improvement because the data collected can be used in future projects, reducing the time required for risk management and increasing its efficiency. This improves the two PMBOK management areas that the research focused on: OHS and Knowledge.

In conclusion, the USD methodology is not only effective, but it also contributes significantly to improving OHS management and knowledge in construction. This leads to improved safety, quality, and productivity of the project. As a result, delays and over costs are reduced, leading to increased profits and prestige for the company.

References

[1] N. De Silva, U. Rathnayake y K. M. Kulasekera, Under-reporting of construction accidents in Sri Lanka, vol. 16, Emerald Group Holdings Ltd., 2018, pp. 850-868.

[2] Estadísticas Accidentes de Trabajo | Ministerio de Trabajo y Promoción del Empleo.

[3] M. Gangolells, M. Casals, N. Forcada, X. Roca y A. Fuertes, Mitigating construction safety risks using prevention through design, vol. 41, Elsevier Ltd, 2010, pp. 107-122.

[4] Cómo gestionar la seguridad y salud en el trabajo? (Administración e inspección del trabajo).

[5] Y. Feng y M. T. Trinh, Developing Resilient Safety Culture for Construction Projects, vol. 145, American Society of Civil Engineers (ASCE), 2019.

[6] J. P. Cortés-Pérez, A. Cortés-Pérez y P. Prieto-Muriel, BIM-integrated management of occupational hazards in building construction and maintenance, vol. 113, Elsevier B.V., 2020.

[7] Y. Lu, P. Gong, Y. Tang, S. Sun y Q. Li, BIM-integrated construction safety risk assessment at the design stage of building projects, vol. 124, Elsevier B.V., 2021.

[8] N. S. Samsudin, M. Z. Mohammad, N. Khalil, N. D. Nadzri y C. K. Izam Che Ibrahim, A thematic review on Prevention through design (PtD) concept application in the construction industry of developing countries, vol. 148, Elsevier B.V., 2022.

[9] N. Umeokafor, A. O. Windapo, P. Manu, I. Diugwu y H. Haroglu, Critical barriers to prevention through design in construction in Developing Countries: a qualitative inquiry, Emerald Group Holdings Ltd., 2022.

[11] Notificaciones de accidentes de trabajo, incidentes peligrosos y enfermedades ocupacionales BOLETÍN ESTADÍSTICO MENSUAL ENERO 2023.