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Proposal for the Integration of Health and Safety into the Design of Road Projects with BIM

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Abstract: The high number of accidents in the construction sector makes the concept of prevention through design (PtD), which starts with the integration of an occupational risk assessment in this phase, increasingly important. To this end, BIM (building information modelling) is a methodology that provides benefits related to the management of health and safety in the design phase. Its application in linear work projects is less developed than its application in building, even more so with regard to health and safety in BIM. This research proposes a methodology for integrating risk assessment into the design phase of BIM road projects, structuring the information, establishing the information integration processes, its analysis and risk management, and automating its integration into the model through zones. As a result, the research enables risk assessment in the BIM model through zones, differentiating risk values and allowing for the analysis of interferences between certain activities and the study of other specific activities in the design. As a result of the structure and organisation of the data, it is possible to export the data to IFC for coordination with other stakeholders. Thus, the final contribution of the research is the introduction of health and safety into road projects conducted with BIM, in compliance with legal requirements.

Keywords: safety and health; BIM; road; risk assessment; automation

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1. Introduction

The high number of accidents and mortality make the construction sector one of the most dangerous in the world [1]. Despite the efforts of professionals and the great legal production regarding occupational health and safety, there has been no significant reduction in the number of deaths, injuries or illnesses in the construction sector [2]. The abovementioned factors show the importance of safety in this industry. Additionally, the specific hazard particularities of this industry contribute to the existence of many unidentified hazards and make the hazard identification process more difficult than it is in other production industries [3]. In this sense, research in the field of safety and health contributes to achieving the United Nations' 2030 Sustainable Development Goals (DSG), in particular SDG3 [4].

For these reasons, this topic studied by numerous organizations, as in the case of International Labor Organization [5], internationally, or the U.S. Bureau of Labor Statistics [6] in the United States. Furthermore, statistics from the Social Security Organization (SOCSO) indicate, in a study carried out in Malaysia, that between 2011 and 2016, the number of accidents increased by 69.47% [7]. The Malaysian Department of Occupational Safety and Health Records (DOSH) reported that from 2015 to 2016, the death toll in the construction sector increased by 18%.

It is possible that there are many hazardous aspects of road construction, with workers exposed to more risks than in other construction sectors [8]. In fact, between 2017 and

2019, a study carried out in Indonesia confirmed the increase in the number of occupational accidents, with 54% stemming from road construction. These accidents result in increased costs, as well as the loss of time and lives [9].

The organization of road construction safety is very important, as it is affected by topography, geography and climate [10]. Most occupational accidents are caused by the poor organization of work and ineffective management of preventive activities [11]. Figure 2 of this study shows that 68.1% of accidents in the execution of roads stem from poor risk management, a number that exceeds its counterpart in the construction sector in general, which is 50.2%. This leads to the need for effective health and safety integration into the design phase [12–15].

Due to the number of accidents, the concept of prevention through design (hereinafter PtD) is becoming increasingly important. The PtD aims to address the safety of workers throughout the project in the design phase [16], since decisions made during the design stage in construction works can significantly reduce the risk of accidents occurring during work, as well as injuries and illnesses [17]. The analysis of 224 accidents showed that 40% of accidents were due to design and confirmed the relationship between design and accidents [18].

Along these lines, Behm discovered that PtD could eliminate about one-third of the potential security risks, of which 50% were related to an insecure design [19]. For this reason, the assessment of risks during the design stage is essential for ensuring a reduction in occupational accidents in construction [20]. This requires integrating the knowledge of the construction process into the design [21].

In the last decade, the construction industry has been transforming with the use of digital technologies, particularly with building information modeling (BIM) [22]. BIM is a technology that is changing the ways in which works are conceived, designed, built and exploited [23,24].

The implementation of BIM can be defined as a process that converts the information from data associated with three dimensions to an information model with data relating to many dimensions [25]. A comprehensive application of BIM has been conducted, highlighting seven dimensions of BIM application. The incorporation of the health and safety BIM discipline is beginning to be considered as the eighth dimension (8D) [21]. However, integration methodologies still need to be developed in order to transform BIM into an ideal tool for health and safety management [26–30]. Authors such as Kumar and Aziz [31,32] highlight the benefits of BIM adoption in infrastructure construction, among other aspects of safety and health.

In addition, the BIM methodology is becoming a legal requirement, included in mandatory European Parliament directives, such as 2014/24/EU [33], which are implemented at the national level [34] through specific actions for their integration into road projects, as in the case of Germany [35]. Different studies on the application of BIM are being carried out in other countries. In particular, the study carried out by Mayer et al. [36] analyzes the automation of hazard detection processes in BIM in Slovakia. It shows that 93% of the respondents believe that risk detection would be more effectively ensured by applying BIM. Additionally, 80% of them states that they would use a risk detection tool if it existed. They also stated that the transmission of information between project participants is of fundamental importance.

On the other hand, health and safety in construction is a legal requirement in most countries, just as it is at the level of the European Union [33,37]. At the national level in Spain, it is obligatory to include a document called the Health and Safety Study, or Basic Study, in all projects, depending on the characteristics of the project [38].

For consistency within the BIM methodology itself, and for a complete integration of this methodology into road projects, it is necessary to integrate, in addition to the other disciplines, health and safety. This integration must meet the legal requirements of health and safety regulations. In addition, in order to carry out the design, the health and safety technician must be in the BIM environment, having all the design information available to ensure a better analysis of the risks, providing very important benefits of BIM to health and safety, as the authors of [26–30] have investigated. In this way, the coordination required by the PtD can be ensured. Otherwise, risk situations not detected in the design phase could arise, with the consequences indicated by Gambatese et al. [18].

The integration of safety and health into BIM, as in the case of other disciplines, requires the structuring of information, which, in this case, is information for the development of 8D, as well as the defining of the processes required to perform safety management from the risk assessment to the implementation of preventive measures.

Therefore, the objective of this research is to propose a methodology in order to integrate safety and health into the design phase of road projects designed with BIM methodology by establishing the data structure and the work processes of analysis and management and by automating the introduction of risks through zones in such a way that it allows users to meet the legal requirements of safety and health and to obtain the benefits that the BIM methodology can provide.

2. Literature Review

BIM has helped in the analysis of design requirements and the verification of regulations, contributing to the quality of the design, resolution of conflicts, planning and cost evaluation in the design phase of a road [39].

Road construction is fundamentally different from building construction in terms of its products, types of work, operations, processes and the resources used, as well as its BIM modelling, as shown in Table 1, reproduced from Dikbas et al. [39]. In addition, the same author analyzes how the structure of information development for linear infrastructures is much less advanced than it is in the construction of buildings, which implies a difficulty related to interoperability in the development of the methodology workflow. This causes the application of BIM in transport infrastructure to be more limited and applied more slowly than it is in buildings [40–43]. In the same vein, Collinge et al. [44] conducted very interesting work, creating a risk library by structuring their data in order to perform a risk assessment with the PtD approach, creating scenarios based on seven stages. It brought together explicit and tacit health and safety knowledge in a holistic way. The research focused on building construction, and the risks were associated with the elements of the model but did not indicate how to address them spatially.

Despite the abovementioned considerations, BIM is widely used for road design [44]. Indeed, China has taken an interest in the design of municipal roads, combining traditional CAD 2D drawings with the BIM model in order to share digital design information [45]. Other authors, such as Lou, Omoregie and Turnbull, have studied the application of BIM in complex urban environments [46] and to the design of highway infrastructure [47], as well as the different aspects of the adoption of BIM in public client organizations, taking the German road infrastructure sector as a case study.

For the integration of safety and health into construction projects, some authors have described the conceptual framework, detailing the trends, benefits and challenges, without actually indicating their integration with the methodology, and focusing primarily on building construction [48–50].

As mentioned before, BIM also offers the possibility of creating a four-dimensional model, including the time variable. Sulankivi and Zhang studied the relationship of health and safety discipline with 4D analysis. This represents a significant improvement in occupational safety, since it connects safety problems with the work plan in a more intimate way, and in such a way that it enables the simulation of falls or accidents and the corresponding collective protections [51,52].

The first steps were taken by Sulankivi et al. [53] in a partial manner, because he offered a generic proposal without detailing the safety assessment itself using BIM. In other cases [54,55], the study focuses on the creation and standardization of BIM objectives for safety and health. Other authors, such as the authors of [53], have developed systems for the identification of risks in tunnels, obtaining preventive measure sheets, but without carrying out the evaluation and re-evaluation process within the model.

The work developed by Lee [56] adds more value, since it not only identifies the risks but also assesses them according to their probability and severity, obtaining risk output parameters. However, it does not carry out the assessment graphically within the model, nor does it carry out the risk reassessment or its implementation in a road project. Shen's case [57] is a slightly more particular, because this work does describe the link between a risk and accident database and a color-coded BIM model that specifies the severity of the risk, but the author did not perform the analytical process, re-evaluation and risk management within the model. Another step was taken by Cortés-Pérez [58], who did carry out said evaluation and re-evaluation work. However, this took place within the context of a building construction project.

An important advance in risk assessment research is the work carried out by Lu et al. [59]. In addition to the likelihood and consequence parameters of the accident, they examined the exposure, which takes into account the working hours required to carry out the unit of work. However, they did not indicate how to carry out risk management based on these data and how to integrate this assessment into the BIM methodology. The research of Torrecilla-García et al. [60] is more general, but it represents a step towards integration by proposing a framework for connecting the information flows between the BIM model and the safety management processes. More detailed is the risk assessment procedure for building construction proposed by Tran et al. [61] through a spatio-temporal exposure analysis. This enables the detailed study of space and type by discretizing the space in a rectangular and horizontal way and analyzing the interconnection between up to two activities.

In the literature search carried out in our study, no study was found that solves the problem of the integration of health and safety in BIM road projects into the design phase. The following searches were carried out: topic (BIM + project + Health and Safety + Risk evaluation), topic (BIM + project + Health and Safety + Road) and topic (BIM + Health and Safety + Road design). Only one study [62] has some bearing on the objective of the present research, and it was incorporated into the literature review.

The work carried out by Zou et al. [62] focuses on establishing a communication system for health and safety management in road construction projects, but it is focused on the construction phase and does not address the process of evaluation, the incorporation of preventive measures, risk re-evaluation within the BIM model, information output from this model to the health and safety study, the risk information output and its coordination with the rest of the project agents [63].

The only regulation in Europe that regulates the integration of safety and health into the BIM methodology is PAS 1192-6:2018 [64], but it is very much oriented to the construction of buildings and is used in the building construction environment without specifying the creation of a single database that integrates the evaluation, preventive measures and reassessment. Spanish regulations, due to the implementation of the regulations of the European Union [33,37], require that a document called the Health and Safety Study, or Basic Study, be included in all projects, depending on the characteristics of the project [38].

For example, in Spain, the public administration is legally empowered to demand the inclusion of BIM requirements in the public procurement processes for the design, construction and/or maintenance and exploitation of assets [38], which relates to the European directive on public procurement [37]. Despite this fact, it is currently not being implemented in the sector [65], and there is no regulatory document or guide in Spain or other countries that defines the criteria for integrating Safety and Health into the BIM methodology in road projects using a single database, which is necessary in order to comply with the requirements of safety and health regulations [38,65] in this incipient phase of the implementation of the BIM Methodology.

Table 1. Quantitative matrix of risk assessment in the BIM, adapted [66], and actions according to the risk level.

<table>
<tr><th></th><th></th><th colspan="5">SEVERITY (Sev_R0i)</th></tr>
<tr><th></th><th></th><th colspan="2">1</th><th colspan="2">2</th><th>3</th></tr>
<tr><td rowspan="3">PROBABILITY (Prob_R0i)</td><td>1</td><td colspan="2">1</td><td colspan="2">2</td><td>3</td></tr>
<tr><td>2</td><td colspan="2">2</td><td colspan="2">4</td><td>6</td></tr>
<tr><td>3</td><td colspan="2">3</td><td colspan="2">6</td><td>9</td></tr>
<tr><td rowspan="3">ACTIONS ACCORDING TO THE RISK LEVEL</td><td>Level</td><td>1</td><td>2</td><td>3–4</td><td>6</td><td>9</td></tr>
<tr><td>Risk assessment</td><td>Trivial risk-T</td><td>Tolerable risk-TO</td><td>Moderate risk-MO</td><td>Significant risk-I</td><td>Intolerable risk-IN</td></tr>
<tr><td>Action</td><td>No specific action is required</td><td>There is no need to improve the preventive action.</td><td>It is necessary to reduce the risk and identify appropriate actions to do so.</td><td>Work should not commence until the risk has been reduced.</td><td>You must not carry out the work until the risk is reduced.</td></tr>
</table>

The discussion of the state of the literature highlights the need to bridge the gap between the legal requirements for health and safety and the application of the BIM methodology in road projects, as well as the lack of methodologies for the integration of health and safety into this type of project, which is the objective of this study.

3. Methodology

3.1. General Description of the Research Methodology

The research methodology follows the process of safety assessments and, as a working framework, is based on the requirements established by European and Spanish Health and Safety regulations in the analysis stage, and it is carried out in the design stage.

Thus, based on the topographical data of the area (Figure 1A), the process begins with the creation of the 3D model for the conceptual design of the road in InfraWorks 2020 (Figure 1B), a specific tool for this type of design. For the construction design, the model is exported to Civil 3D 2020 (Figure 1C) to develop the road in 3D detail. From this point onwards, the process produces a bifurcation of the models, one of which is used for the design of the rest of the construction project in Civil 3D 2020 (Figure 1D). The other is exported from Civil 3D 2020 to Revit 2020 in order to analyze the health and safety details (Figure 1E), and this is where the risk analysis of this research is carried out. This step is essential for carrying out a 3D analysis of the risks.

In the Revit 3D model, the geometric discretization of the space where the construction will take place is carried out (Figure 1F). In this stage, the parameters for the specific risk analysis are created and associated with each zone and phase according to the activities to be carried out in the execution (Figure 2). This stage makes it possible to create the minimum number of parameters using the identified risks, optimizing the process and the volume of data. Part of this stage is automated in order to reduce possible errors, specifically in the identification of risks associated with each activity, starting with an Excel file and progressing towards their subsequent evaluation within the model (Figure 3).

In each zone and construction phase of the 3D model, the risk assessment is carried out by applying the National Institute for Occupational Safety and Health (hereinafter NIOSH) guidelines [67], carrying out the assessment of the parameters in the model according to the 3D analysis of the zone (Table 1). This enables an analysis of the risks according to the zones and construction phases, which helps to improve their management using color filters and data tables and facilitates, for example, the analysis of risks due to interference between activities. This enables the re-evaluation, which is essential for establishing the traceability of the entire process in a single model. It also ensures the ability to respond to the legal requirements by generating the plans and the specifications of the preventive measures, using the 3D model.

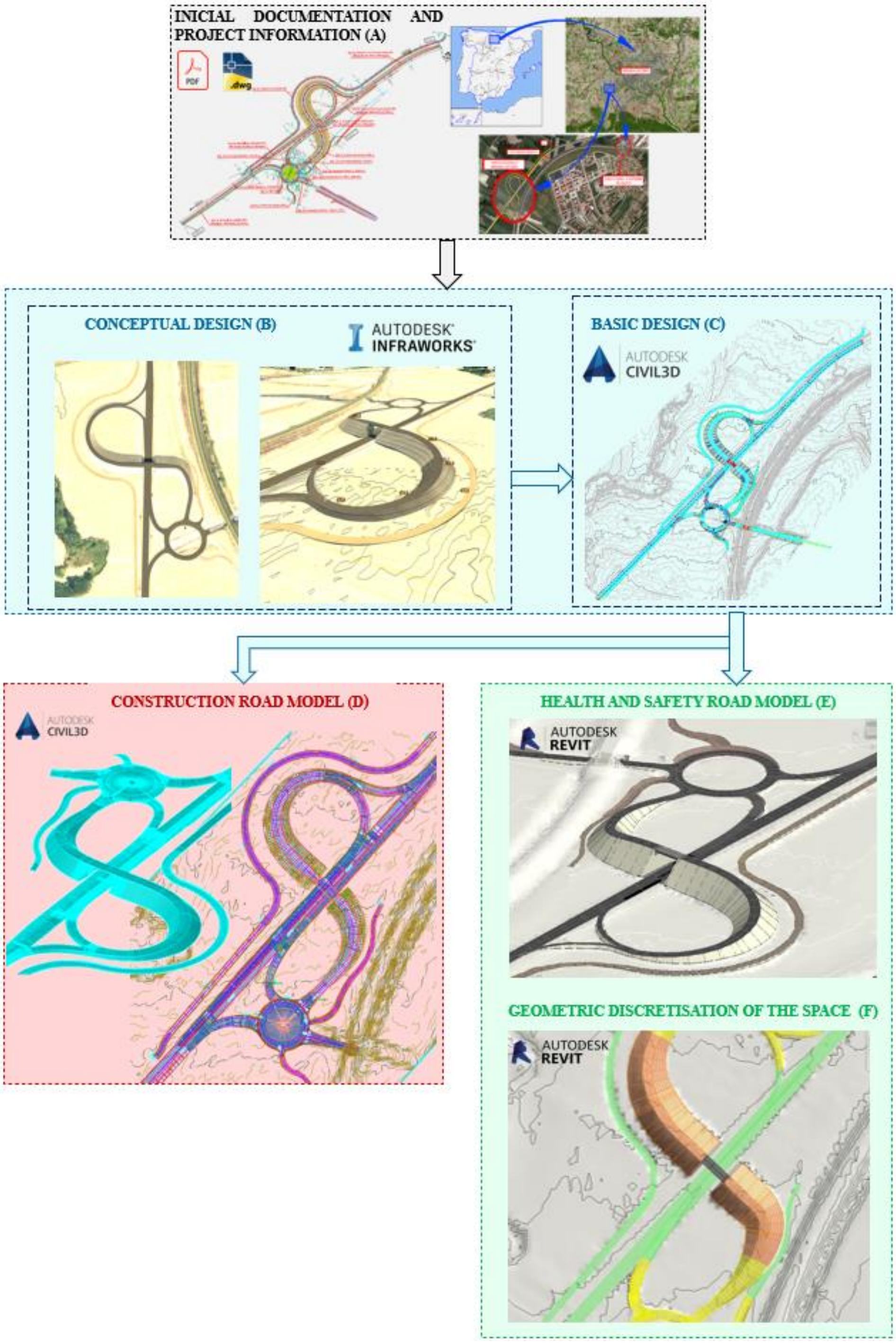

Figure 1. Conceptual diagram of the workflow used to create the health and safety road model ((**A**) Background information on the project, (**B**) Conceptual design of the project in InfraWorks 2020, (**C**) Design model with a low level of detail associated with a basic project, (**D**) Design model with a high level of detail associated with a construction project in Civil 3D 2020, (**E**) Low level of detail design model associated with a basic project in Revit 2020, (**F**) Model with information on the result of the implemented risk assessment).

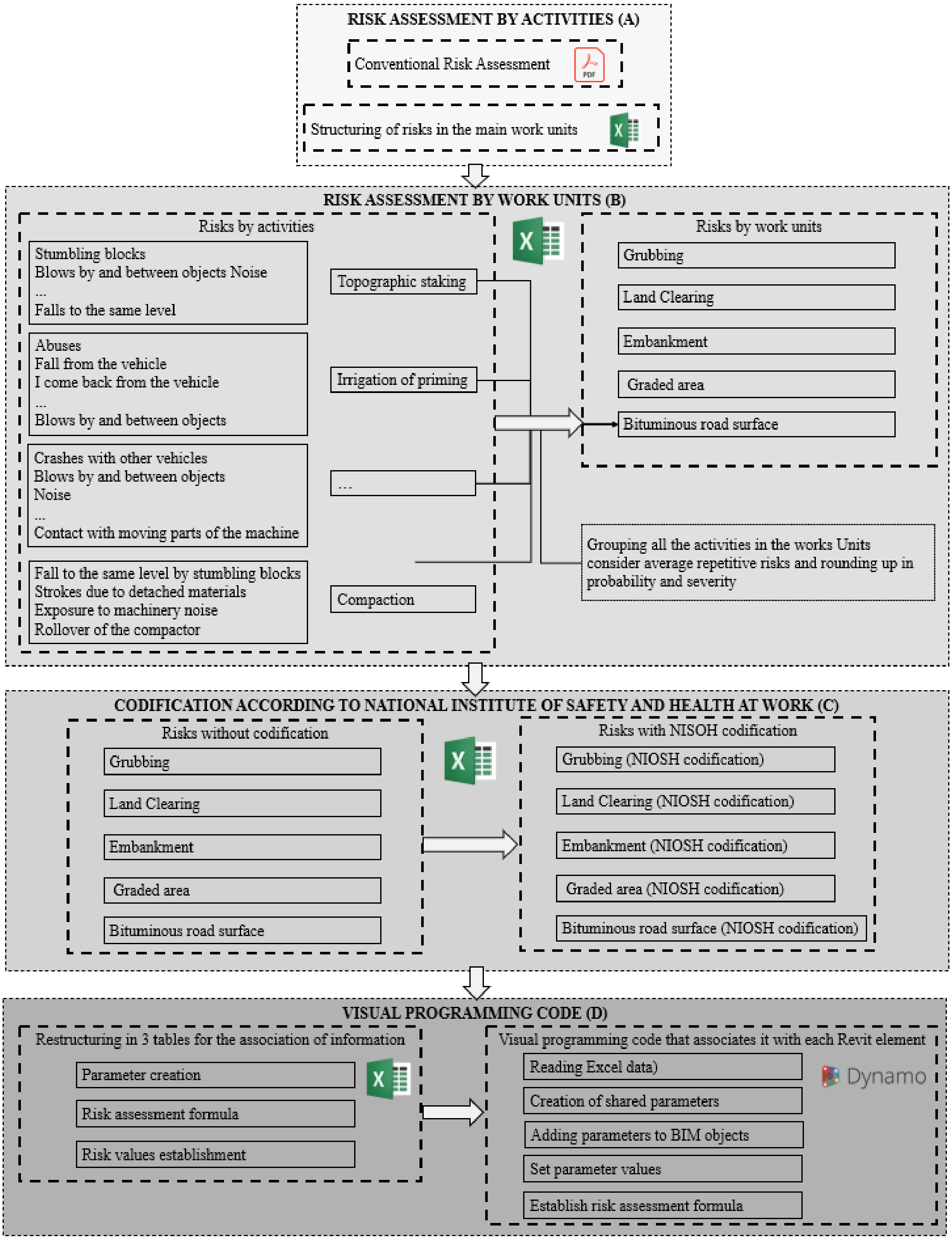

Figure 2. Workflow to link the risk assessment results to the BIM objects ((**A**) Risk assessment information by activities, (**B**) Risks assessed by activity are then assessed for each work unit, (**C**) These risks are coded according to the National Institute for Occupational Safety and Health, (**D**) The risk assessment information is structured in Excel and entered with Dynamo 2.3 to each of the elements in Revit 2020. The background color is not relevant.

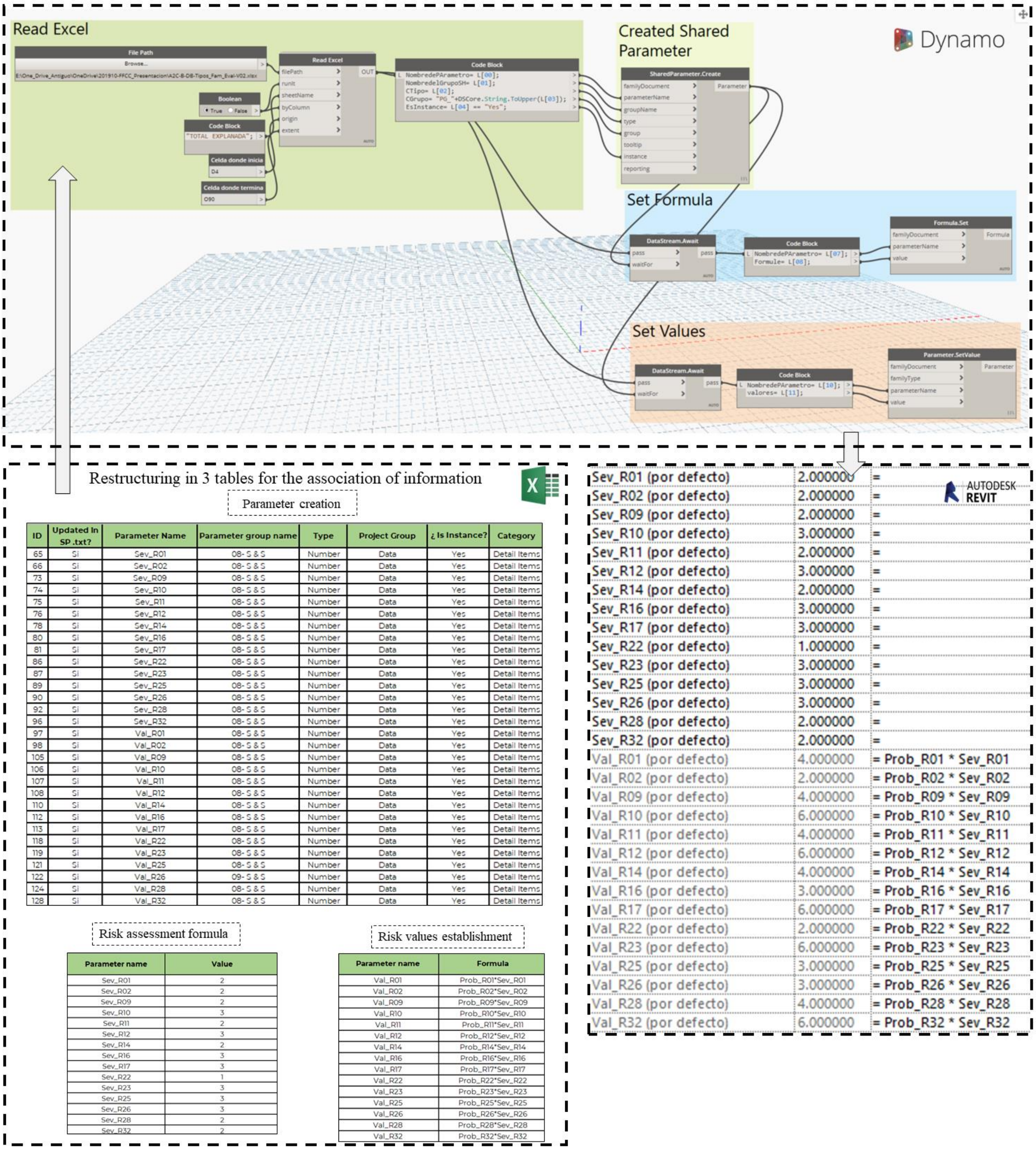

Figure 3. Automation of the introduction of risk information to BIM objects using Dynamo 2.3. The asterisk in the Revit 2020 table is used as the multiplication symbol.

3.2. Legal Framework Considered in the Study for the Health and Safety Integration into BIM

For the development of the proposed methodology, the legal requirements established by the health and safety regulations were considered. In this case, the Spanish legal framework was used [38,66], in accordance with the regulations of the European Union [33,37], which is mandatory to consider in the design of any construction work. This regulation requires the inclusion of a study, the Basic Health and Safety Study [38], in all construction projects, with specific contents considered [58]:

- The definition of the methods, equipment and auxiliary resources necessary to carry out a specific task.
- The determination of the conditions, applying the corresponding regulations, as well as the specifications for the machines, tools and other preventive resources.
- The drawings, with the correct definition of the preventive measures and the required technical specifications.
- Measurement of the health and safety work units.
- Estimation of the costs required to carry out the health and safety analysis.

3.3. Generation of the BIM Model

The process begins with the road design model in InfraWorks 2020. In this software, a conceptual design of the project is carried out. This model is passed on to Civil 3D 2020, where the accurate design of the project is created. In the early stages, this model is passed on to Revit 2020, the most frequently used BIM software among BIM users [68], where the risk integration is carried out. This results in two BIM models, one for the road's design and the other for the design of health and safety (Figure 1). This allows the user to perform the risk assessment and continue the road design process at the same time.

Using this software, the road model is composed of certain BIM objects (road divisions) that act as the carriers of the health and safety information. In this case, a BIM object is developed that groups the tasks of each of the main work units: embankments, land clearing, bituminous mixture extension, etc. These BIM objects, which are linked to each work area, are associated with the results of the risk assessment for the purpose of the execution of each work unit in that specific work area.

This process is related to the amount of information associated with the BIM models. It should be noted that the amount of information involved in a project developed with BIM grows from the conceptual phase to the construction phase. The level of information development is defined by the acronym LOD (level of development). This concept is associated with the BIM objects integrated into the model, ranging from the lowest level (LOD 100) to the highest (LOD 500), the latter being the one with the most information regarding manufacturing or installation needs [68].

3.4. Safety and Health BIM Objects and Their LODs

The health and safety integration stage in projects developed with BIM require a methodology for the risk assessment. There are different methodologies, such as the NAIWC method of the National Agency for the Improvement of Working Conditions [69], the RFM method of Renault Factory Management [70], the FINE method of William T. Fine [71] and NIOSH [67]. The latter was used in this study as it is the most widely used in Spain, facilitating its implementation.

The risk assessment process starts with the identification of the specific risks involved in the site activities (transport to landfill, excavation work, teamwork, etc.). The first step in the risk assessment is to identify the risks. This work of the technician is based on guidelines or internal engineering documents and, in this research, was used to generalize the results, applying the guide described in [72] using an Excel sheet (Figure 2A). This guide is based on the study carried out by the Navarra Institute of Occupational Health and the Association of Public Works Construction Companies of Navarra and establishes a methodology for carrying out a general risk assessment of all the work units related to road construction. It determines the probability, consequences and magnitude of the associated risks for each activity of the work units, as well as the preventive measures to be adopted in order to reduce them, based on the criteria of the technicians who comprise this organization.

From this preliminary identification, a grouping of the specific risks in the main work units is carried out. The risks that resulted from the above operation were coded according to the 32 general risks of the NIOSH assessment method, in order to be consistent with the legal specifications [67].

This methodology was adapted in the same way as described in [58]. The adapted methodology consists of the assessment of each identified risk by assigning the following numerical values related to the probability of occurrence (Prob_R0i) and the severity of consequence (Sev_R0i). Prob_R0i is assigned a score of 1, 2 or 3 for a low, medium or high probability, respectively, and Sev_R0i is assigned a score of 1, 2 or 3 for slightly damaging, damaging or extremely damaging, respectively. Thus, the risk level was calculated as the multiplication of its probability by its severity, i.e., Val_R0i = Prob_R0i × Sev_R0i. Finally, a quantitative matrix for the risk rating and color grading was proposed, with a color code associated with each numerical value (Table 1) [66].

Risk assessment methodologies are based on the identification of risks associated with tasks. These tasks can be related to BIM objects, and their geometric definition and the information associated with them depends on the LOD defined in the project. Therefore, the risk assessment depends on this LOD, so that the health and safety technician must indicate the LOD with which the project is evaluated to meet the standardization requirements [73]. This study aimed to integrate risk assessment into the design phase. This involved adopting an LOD of 300 [74], so that the risk assessment in the model could be carried out per unit of work.

To make s comparison between the proposed methodology and the current method of carrying out the risk assessment, the assessment values described by the authors of [73] were introduced into the 3D model. To perform this stage, based on the initial risk identification and assessment carried out in Excel (Figure 2A), the risks are grouped according to the main work units: grubbing, land clearing, embankment, esplanade and bituminous mixture extension. If a risk relates to more than one activity, according to the initial evaluation, its assessment will involve the multiplication of the average value of the probability by the average value of the severity, rounding the result up to the upper integer in order to remain on the side of safety. This process is programmed and structured in Excel in the initial phase (Figure 2B).

3.5. Integration of Risk Assessment into the BIM Model

Initially, the risks of each of the work units are coded according to [67] (Figure 2C), ordering them in order to facilitate the automation with Dynamo 2.3 (Figure 2D). To perform this step, the information is structured in Excel, determining:

- The name of the information Revit parameter: Prob_Ri, Sev_R0i, Val_R0i, etc.
- The name of the shared parameter group, which is the name of the file that contains the parameter information.
- Type of parameter: text, integer, number, etc.
- Whether it is information of type (same value for the same object BIM type) or instance (different value for the same object BIM type).
- The category, which is a classification of the parameters in Revit.
- The risk assessments formula: Val_R0I = Prob_Ri x Sev_Ri.
- The value of Risk 0i, for example, falls of people at different levels.
- The value of Prob_R0i, for example, 2.
- The value of Sev_R0i, for example, 3.

The integration of the preliminary evaluation into the model is accomplished through an application called Dynamo, a visual programming tool that enables programming actions on Revit 2020. For Dynamo to link the results of the risk assessment, one must indicate the characteristics of each type of parameter that it is going to be introduced into the BIM model. The process followed is described below, as follows.

The information contained in the table above is associated with each of the BIM objects that form the discretized geometry of the road model in Revit 2020. The association is carried out through a visual programming code using the Dynamo plugin (Figure 2D). The code selects the BIM elements of the corresponding road according to the work area and work unit they represent (land clearance, embankment, road, etc.) and associates the results of the risk assessment corresponding to that work unit.

Once this is accomplished, the BIM safety and health objects associated with each area of the BIM model of the road are retained with the information from the preliminary risk assessment: the identification, probability, severity and evaluation of the corresponding work unit, which is fully integrated into the BIM model.

3.6. Analysis and Risk Management in the BIM Model

After this previous phase, the final risk assessment of each work unit is carried out for each area within the model, considering the specific conditions of the area, as well as its interaction with the work environment.

For the management of the actions, filters are created that materialize the color code, as shown in the level and risk assessment table, according to the NIOSH evaluation method [58]. These filters are created using the Dynamo plugin. In this way, the BIM objects acquires different colors depending on the probability and severity defined for them, and these are applicable to both the assessment and the probability and severity. This enables the user to visually verify whether the risk assessment is correct and consistent and whether or not preventive measures should be applied.

For a better analysis and risk management, planning tables are created in Revit 2020, which contain the information regarding the evaluation parameters. As the model is parametric, from these tables it is possible to review and change any parameter of the probability, severity or risk assessment.

Preventive measures are introduced into the model using BIM objects with the corresponding characteristics so as to comply with health and safety regulations. It should be noted that, although they are not the object of this research, specific categories of safety and health have been developed, such as those for fences, barriers and railings, as well as specific road signs, both standard and construction, according to the current regulations [75]. The foregoing procedure complies with the provisions of article 5 of the regulations [38], which establishes that, in the Health and Safety Study, preventive measures must be specified using images and plans.

In addition, the same regulations entail the re-evaluation of risks once the preventive measures have been implemented so as to measure the degree of effectiveness with respect to the safety and health of workers. This degree of effectiveness must be determined by the corresponding health and safety technician. In addition, cost information is incorporated into the measures in order to complete the cost–benefit analysis. This process is carried out using the risk re-evaluation parameters, which have the same nomenclature as the evaluation parameters, starting with "Re_", and are integrated into the model gaps, for example "Re_Prob_R01". The parameters must be assessed based on the reduction in probability and severity provided by the applied measure. The result is visually verified using the color filters.

The technical characteristics, legal and regulatory requirements and the installation and supplier information must be incorporated into the model with a URL parameter for the BIM objects of the collective protections. Through this, the corresponding BIM object is linked with the documents, enabling their classification, as well as their consultation, in an agile and fast manner. Finally, these objects are exported to IFC for their coordination within the project, leaving a traceable record of the decision making.

4. Results

The theoretical development of the proposed methodology contrasts with its application in a real project, which, in this case, is that of a road located in Miranda de Ebro, Burgos (Spain). The purpose of the project is to define and calculate all the works required for the removal of the level crossing of the PK 456+727 section of the Madrid–Hendaya railway line. To comply with the abovementioned guidelines, a distribution roundabout, a bridge over the N-1, a section connecting the underpass to the roundabout, a section connecting the roundabout to the bridge, two sections connecting the roundabout to paths and, as a replacement for these, four access or exit branches to the N-1, as well as a service road parallel to the N-1, were projected.

In the assessment of risks at the road design level, the starting point is the identification of risks based on previous studies related to each activity, associated with ANECOP [72], and the experience of the technician or company carrying out the analysis. In order to automate the integration of this risk identification of all the BIM objects in each risk area of the project, a structure of the information in Excel (Figure 2) is proposed, grouping the types of risks that can occur in the execution of each unit of work a priori. Figure 2B shows the grouping of the risks associated with each activity. Specifically, in this case, four risks associated with each activity were collected, and the figure shows the case of the bituminous road surface work unit, which involves, among other activities, compaction. However, this activity is carried out in different work units, and in this example it is associated with the execution of the pavement work unit (Figure 2C). This enables the information to be transferred to any road model. In addition, if, during the evaluation, new risks are identified in any construction unit, or new construction units are added, the Excel sheet can be updated.

The introduction of this information to the BIM objects was programmed by means of a routine in Dynamo 2.3, which collects the information from each Excel cell and associates it with each element of the model according to the BIM object of the corresponding work unit. The workflow schematic and explanation of the code are shown in Figures 2D and 3.

The result is an LOD 300 model for road health and safety information, which is applied to the BIM objects and discretizes their geometry into the space occupied by the road construction, as shown in Figure 4. In this figure, it can be seen that the same space may be associated with different work units, with different BIM objects and, therefore, with different risks, establishing the relationships with the work area. Figure 4 also shows how the script optimizes the generation of risks by automating the loading of risk information to the BIM objects. In addition, it should be noted that specific risk information is introduced to each area through different BIM objects depending on the task being performed. For example, Figure 4 shows the pavement BIM object (bottom figure), which has different risks than the embankment BIM object (top figure), with both being in the same area.

After loading the initial data from Excel for the preliminary risk assessment, we proceed to the detailed assessment of each work zone by means of the specific analysis of the risk according to the zone, work unit and phase of execution. Thus, Figure 5 shows how, when loading the initial assessment of the risk of falling to a different level during the earthwork unit, it is the same in all the activities and throughout the spatial distribution of the project, demonstrating the immobility of the conventional risk assessment. This is because it does not consider the severity of the damage according to the area where it occurs.

Therefore, it is necessary to carry out the evaluation within the BIM model, considering its 3D analytical capabilities and the discrimination of the areas that allow for a detailed assessment of the severity for the execution of activities in each work unit. To this end, it is essential to create display filters that enables the better management of health and safety and facilitate the assessment and revaluation of each risk according to the colors of the NIOSH. Thus, Figure 6 shows an example demonstrating how the filters are applied to the risk of entrapment by overturning (risk R12) in the execution of the bituminous road surface work unit. The probability of the risk is shown at the top, with light cyan blue for the low probability and a darker color for the high probability. The lower part of Figure 6 shows the severity parameter value, ranging from light magenta for slightly harmful to dark magenta for a highly harmful risk. This shows the different assessments of the probability and severity depending on the area (BIM object) for which the risk is analyzed, visually indicated by means of color. This procedure is the same for each risk that is assessed.

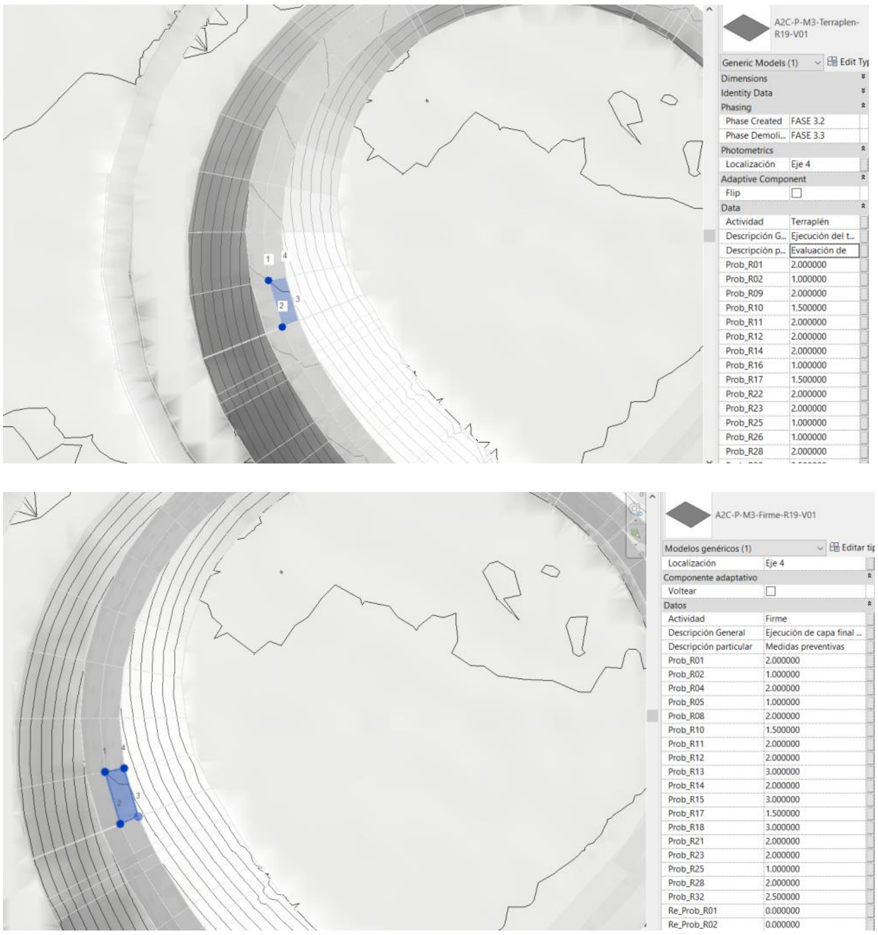

Figure 4. Revit road model with associated risk assessment information. In the image (**above**) are the risks associated with the execution of the earthworks. In the (**lower**) image are the risks associated with the execution of the pavement in the same area.

Figure 5. BIM model of the risk of falling to different levels during the execution of the earthworks work unit with the conventional risk assessment.

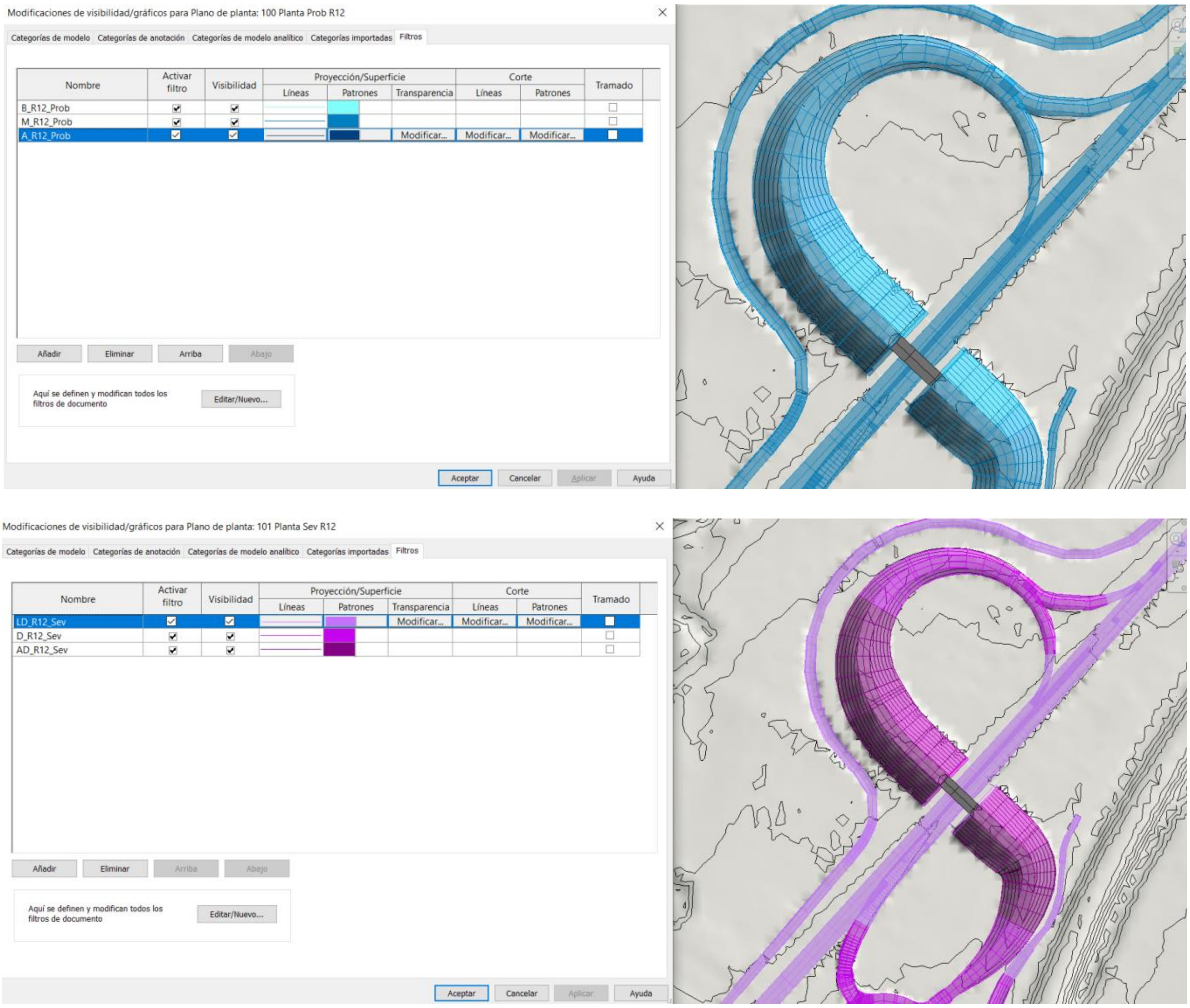

Figure 6. Execution of filters in the analysis of the risk of entrapment due to overturning in the bituminous road surface work unit (risk R12). Probability in (**upper**) figure and gravity in the (**lower**) figure.

Due to the parameterization, the risk assessment in the model is automatic, based on probability and severity values of the area being analyzed. Thus, the assessment of the level of the risk of entrapment due to overturning (risk R12), as mentioned above, is greater in areas where the fall height is greater (Figure 7Left). This facilitates the precise location of preventive measures.

If, when carrying out the execution phases, there were any areas with a trivial risk, a trench was created for the placement of a drainage pipe. This could be observed in the 3D model, and the areas close to the trench had a higher severity assessment. Consequently, the level of risk in that area was not trivial and required preventive measures, such as the cutting off of traffic (Figure 7Right).

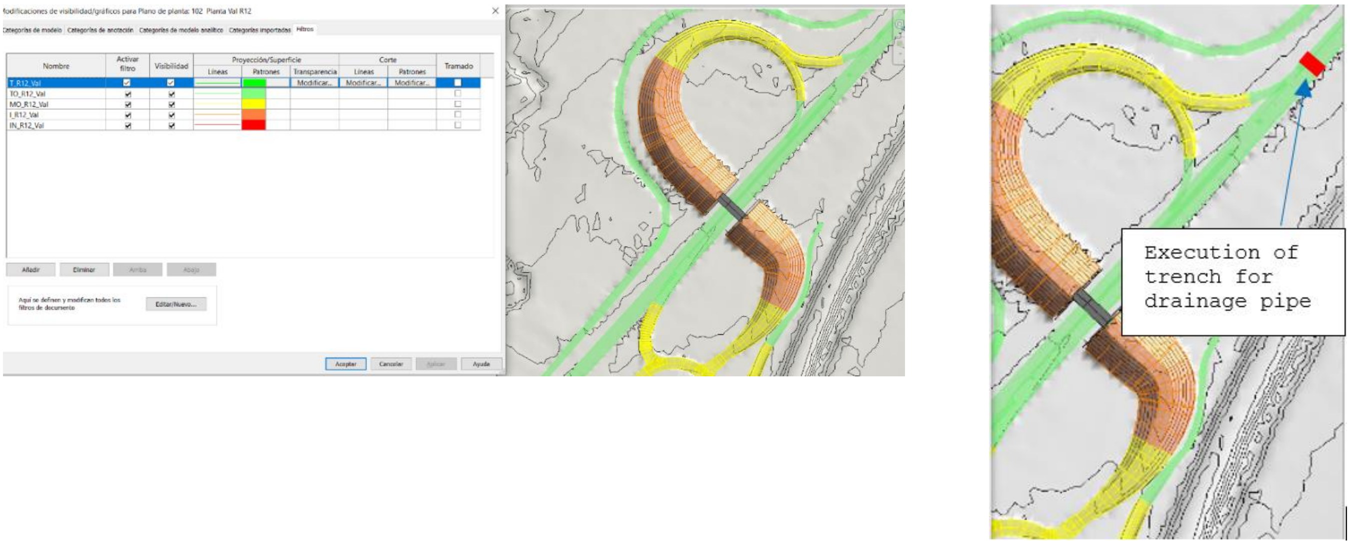

Figure 7. (**Left**): Execution of filters in the risk assessment of the risk of falling to different levels during the execution of the bituminous road surface work unit. (**Right**): execution of a trench for the placement of a drainage pipe.

The information entered into the model can be managed using dynamic tables (Figure 8), with which the evaluation can be managed while working with the 3D visualization of the model. This allows for greater versatility in the risk assessment.

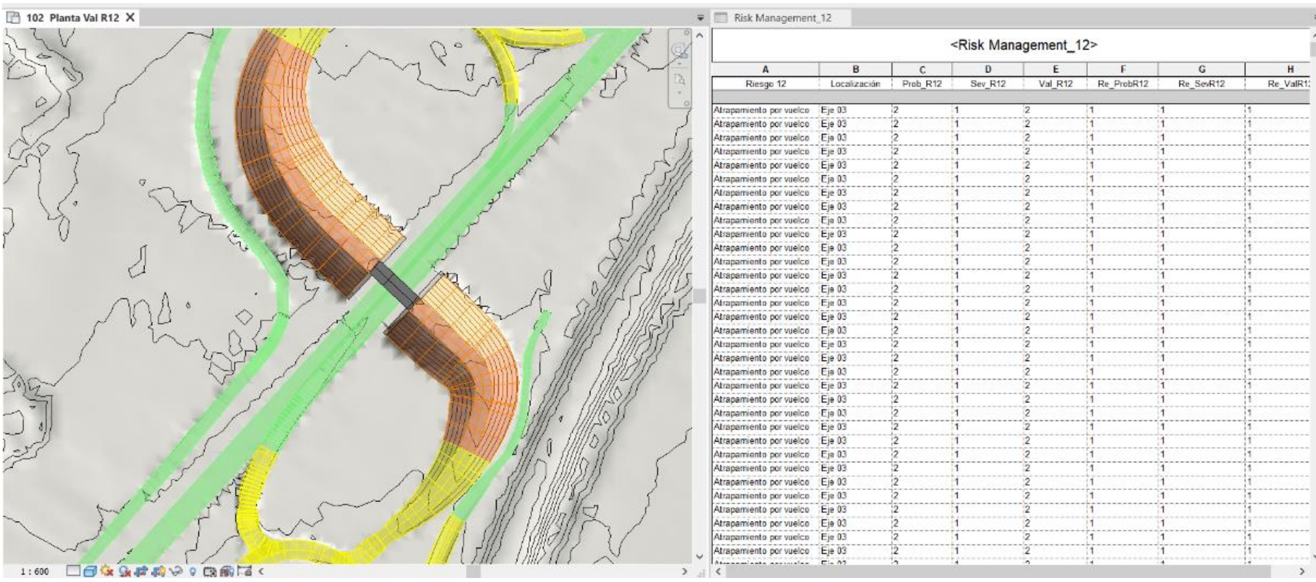

Figure 8. Risk assessment management.

With the proposed methodology, it is possible to study the interferences between the risks of different work units in the design phase, providing a 4D risk analysis in the design phase. For example, if, according to the work schedule, the bituminous paving work unit on the main trunk of the road and the construction of the access slopes to the bridge are being carried out at the same time, when the data are loaded into the model, it will be observed in the 3D view (Figure 9). When carrying out the risk assessment, the technician defines the radius of action of the machine (marked with vertical cylinders in the figure) and obtains moderate (MO) and significant (I) risks, and the same process is carried out for the areas of the slopes and in areas of the main trunk. Given that other work units are being executed in the main trunk, the interference of risks makes it necessary to apply the preventive measures required to reduce or eliminate the risk (Figure 10), such as the delimitation of the area of the main trunk, which is affected by risks due to the slope execution work unit. Therefore, it is possible to detect interferences between activities and manage the risks added to those existing risks due to the activities in the area.

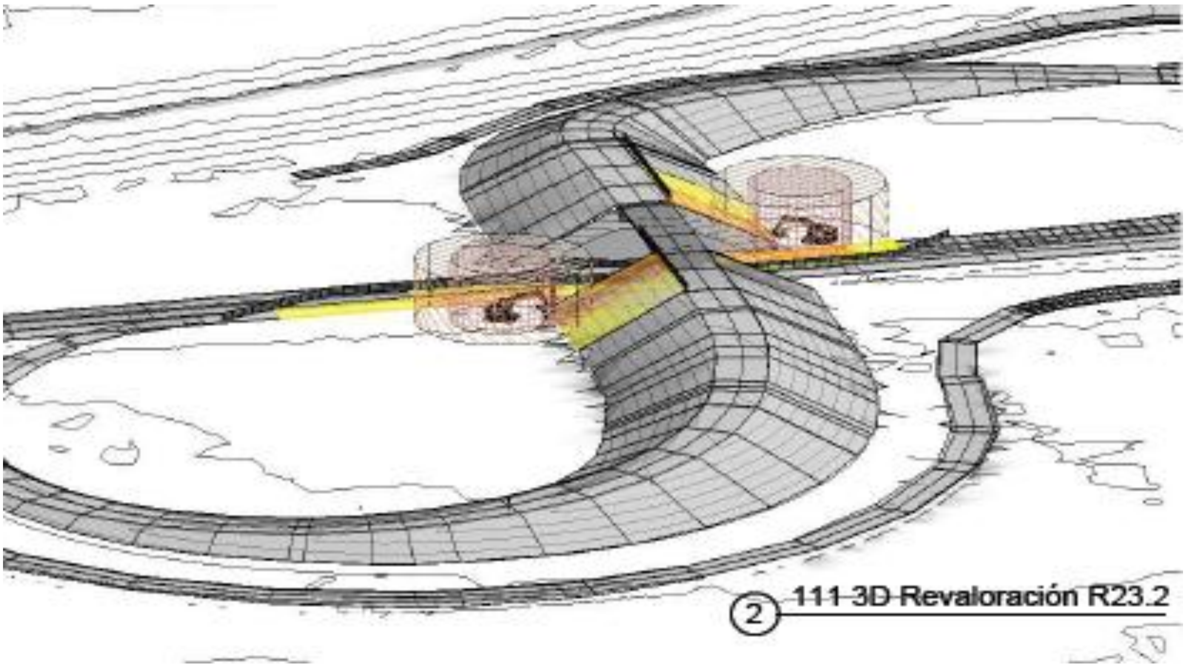

Figure 9. Analysis of specific works. This figure shows the interference between the execution of the refining task of the slopes and the bituminous mixture extension.

The assessment proposal also allows for the analysis of risks outside the model, such as those involving workers who are carrying out activities outside the execution of the road, where risks can be generated using the activities which take place on the road itself. Figure 11 shows an example where the construction activity of earthworks using a backhoe on the main trunk of the road and on the secondary road can cause risks to workers who move between the two areas.

Once the risk assessment has been carried out, the implementation of the necessary preventive measures is studied using the BIM objects created according to the specifications of the regulations, technical documentation, installation requirements, supplier information, etc. In this way, the information is registered, classified and centralized in the BIM model. Based on this, the necessary preventive measures are incorporated, and the risk is re-evaluated (Figure 10). In addition, the BIM objects of the preventive measures must include both the legal and technical requirements to be considered for their execution, in order to comply with the legal requirements (Figure 12). In the final BIM model, you will have all the information necessary to produce Health and Safety plans, with collective, individual measures, measurements, costs, etc. (Figure 11).

Finally, associating the cost variable with the element, the costs of the preventive measures can be obtained (Figure 12), in such a way that it is possible to carry out a cost-benefit analysis of the implemented measures.

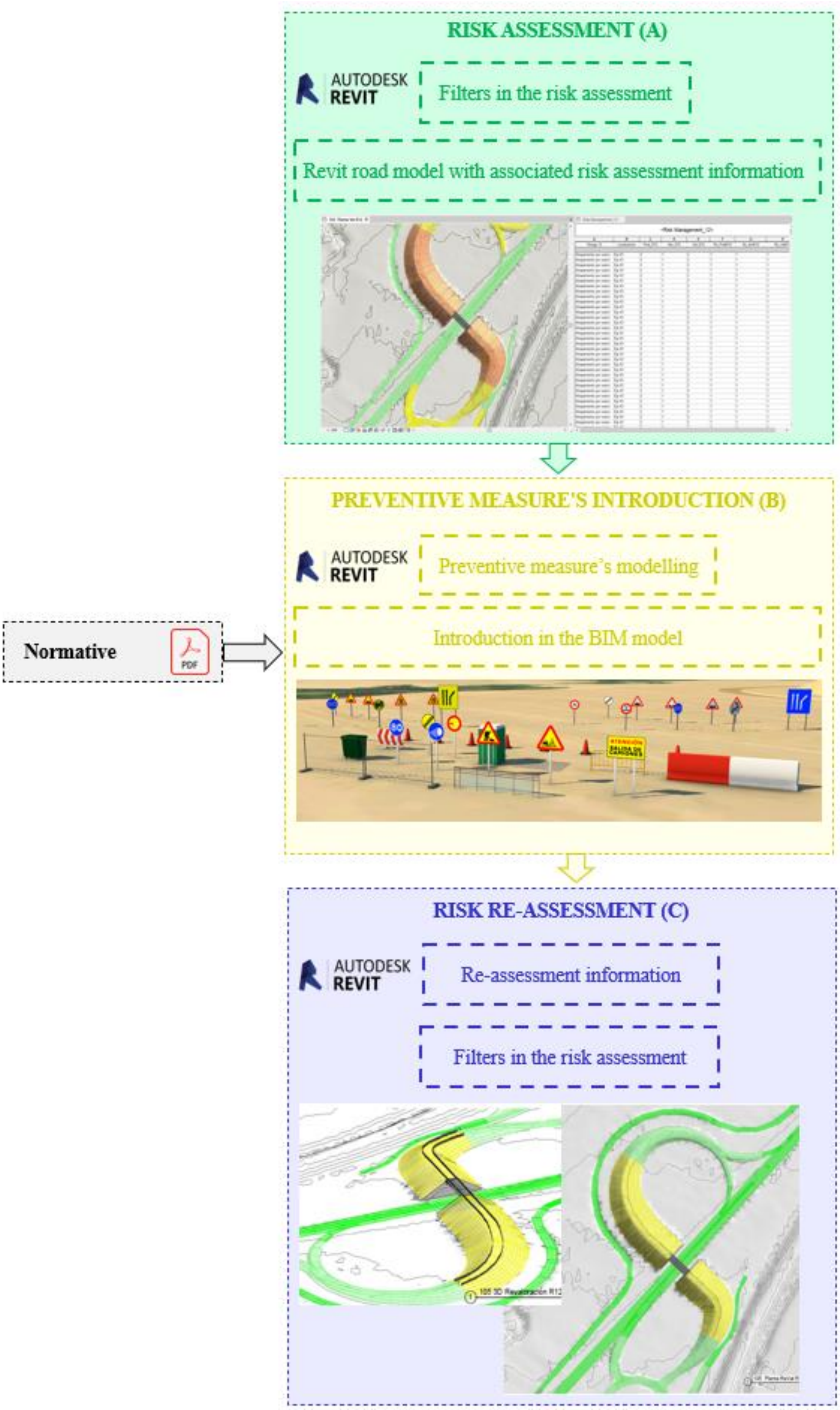

Figure 10. Introduction of preventive measures and risk reassessment.

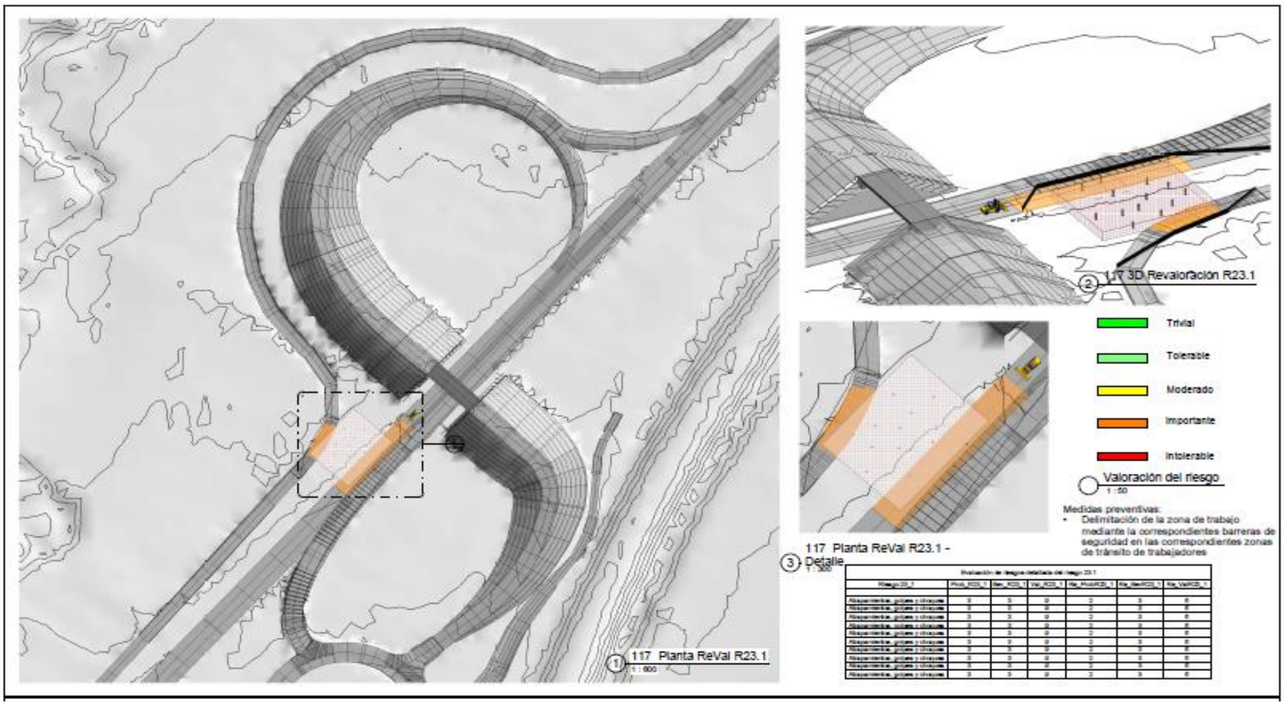

Figure 11. Plan with information on the risk areas, evaluation and collective protection measures.

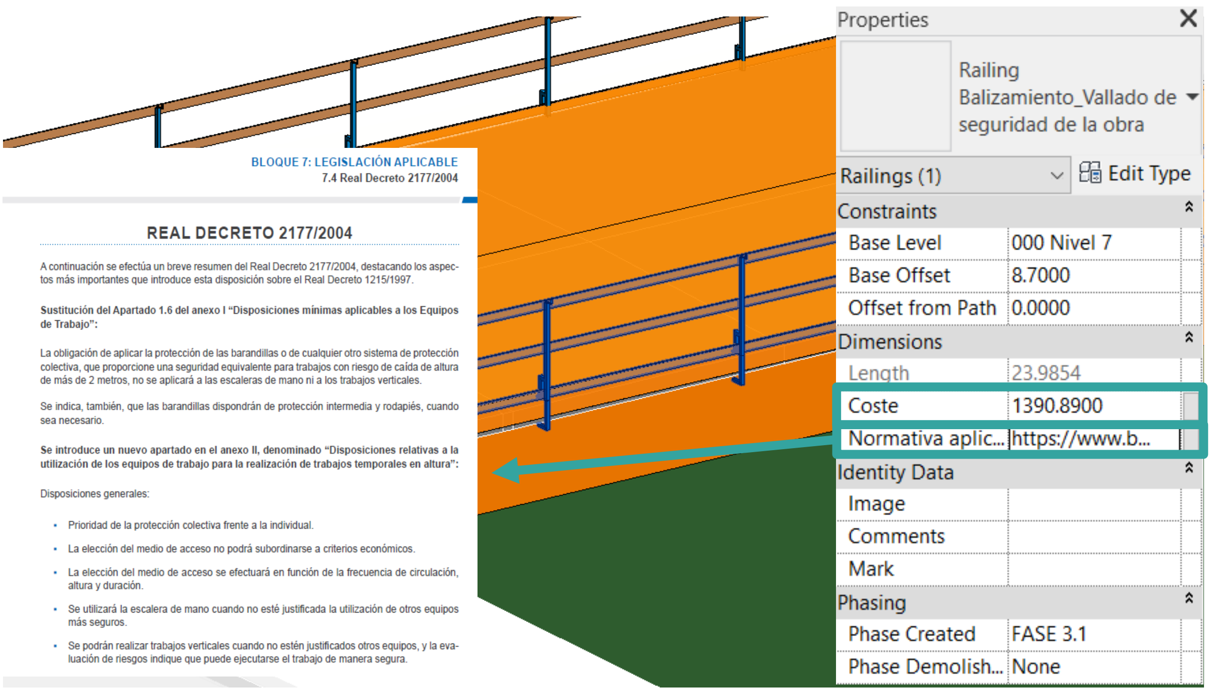

Figure 12. Association of auxiliary information with preventive measures.

5. Discussion

From the above results, it can be seen that the integration of safety and health into BIM was carried out using a general approach, as proposed by Zhang et al. [52]. Thus, Figures 1 and 2 show the general processes of safety and health integration in road BIM projects, resulting from the application of the methodology to a specific project. In this work, unlike that of Sulankivi et al. [53], there is a general working methodology that addresses the entire design phase. Furthermore, the proposed methodology represents a step forward because, although there were precedents of the integration of the methodology with BIM, such as the work of Shen et al. [57], who performed the evaluation and re-evaluation, this work took shape in the context of a building construction project rather than infrastructure. In this research, the evaluation and re-evaluation were extended to road infrastructure, with all that this entails in terms of the differences in the operations, processes and resources used, as well as the BIM modelling, as indicated by Dikbas et al. [39].

This research also goes further than Zou et al. [62] because although it applies its research to roads, it focuses on the construction phase, when prevention should start from the design phase as indicated by Yuan et al. [16]. Furthermore, Zou et al. [62] does not address the evaluation process, the incorporation of preventive measures or the re-evaluation of risks within the BIM model, as this methodology allows, as shown in the results of the output of information from this to the health and safety study, the output of risk information and its coordination with the rest of the project agents, as shown in Figure 1, Figure 11 or Figure 12. This is a step forward compared to Zou, Ganah or Musa [48–50], as they describe the conceptual framework, detailing trends, benefits and challenges, but do not describe precisely the methodology and its application to road BIM projects. In this case, the benefits derived from the use of the methodology have been shown in a concrete way, reinforcing those described by Zou, Ganah or Musa [48–50], and demonstrating that BIM is an ideal tool for the management of Safety and Health [26–30], as shown in Figure 8.

The identification of risks proposed in this research allows, based on prior knowledge of the risks, to group them according to the tasks to be carried out, assigning to each area only the risks that will exist, this fact will reduce inconsistencies and errors in the design phase of road projects, which will provide a safe design with the consequent reduction of accidents at work. This automation will be a benefit for the application of BIM for risk prevention as required by the technicians surveyed in Slovakia by Mayer et al. [36].

In addition, the combination of the discretization of the zones and the automation enables the flexible and precise management of the risks associated with the LOD of the project (Figures 3 and 4), as proposed by Yu, Khan and Arezes [27,29,30]. This discretization, conceptually, has the same basis as that used by Tran et al. [61] for buildings, with the difference lying in the geometric complexity of a road compared to a building plane, where the majority of the space constitutes horizontal planes (see, for example, Figure 9). In addition, the results of this research show that more than two activities can be combined in the same area, overcoming the limitation described by Trans et al. The growing importance of PtD makes risk assessment during the design phase essential for reducing the number of construction fatalities [20]. It is a significant improvement on the current design phase methodology, which, as shown in Figure 5, provides a rigid and ineffective risk assessment. This work not only describes the integration of safety and health into the design stage but also enables 3D risk management, enabling the advantages of BIM as a tool for safety and health management to be realized, as previous research has shown [26–30].

Regarding the ways in which risks are assessed and managed, the above results constitute an improvement on those of Zhang and Shen et al. [52,57], as they described the linking of the risk and accident database to a color-coded BIM model but did not carry out the process analysis, reassessment and risk management in the model, as we demonstrated in this research (Figures 6–8). In these figures, it can be seen that risk assessment can be integrated into a BIM model as an alternative to conventional risk assessment.

BIM offers the possibility of creating a four-dimensional model integrating the construction phases in such a way that the problems related to safety are connected in a more intimate way with the work plan [51,52], contributing towards the safe design proposed by Kamardeen and Durán [20,21]. The Figure 9 shows how the proposed methodology allows a connection to be created between the BIM health and safety model and the work plan, enabling the analysis of interferences between activities and the planning of preventive activities in the design phase. Thus, work phases that involve interference between zones can be analyzed, addressing problems involving operating machines that are working in that zone and affect another. For this purpose, the machine BIM object is introduced, and the operating range is analyzed by generating risk cylinders and assessing their interference with other work units carried out in the machine's radius of action (Figure 9). This is in line with what was proposed by Tran et al. [61] in the case of buildings, without the automation of the interference detection process, which these authors carried out.

Other authors, such as Getuli [55], focus their studies on the creation and standardization of BIM objects for health and safety. The present investigation, although it is not concerned with the same main object of research, also carried out the development of preventive measures according to the health and safety regulations [33]. The advance lies in the fact that, in this case, the BIM object that represents the preventive measure is used to perform a risk re-assessment (Figure 11). Thus, this work overcomes the gap in the procedure developed by Lee et al. [56], since the consistency of the preventive measures adopted as a consequence of a given level of risk can be verified, leaving the traceability of this decision graphically within the model itself.

Once this process is completed, in order to comply with the national and international health and safety regulations of the European Union [33,37] and Spanish regulations [38,65], the final BIM model contains all the information necessary to create health and safety plans, with collective and individual measures, measurements, costs, etc. (Figure 11). These preventive measures are also carriers of relevant information for the project, such as regulations, installation recommendations, costs, etc., with a data structure that can be exported to an open format (IFC). This allows for the coordination of the information not only with the rest of the agents in the team, but also with third parties, as a complement to the data structure proposed by Collinge et al. [44], which focuses on the risk detection and assessment parts but not the measures and information on the legal requirements that must be met, as shown in Figure 12. Moreover, the developed methodology is in line with the processes of PAS 1192-6:2018 [64], such as risk assessment matrix, risk characterization, use of risk information and risk information representation.

An important goal of future development is to address the integration of the site planning into the risk assessment of a road, automating decision making based on the type of activity and the people and machinery involved. This would improve the process of automation and, therefore, the integration.

Another goal for the future is to develop specific automation processes for risk assessment in regard to the tasks that cause the most accidents, considering the real situations on site: the machinery used, specific planning of the work area, people working in the area, etc. In this way, one could facilitate the integration of health and safety into the BIM of the construction phase.

Finally, the proposed methodology addresses the design phase at an already advanced stage, but it is very important to address health and safety at earlier stages. The difficulty that this entails is the fact that there is less graphic information associated with the model, which means that one must define what this should in order to address the safety assessment in these phases with the sufficient level of detail that the phase requires. To this end, it is necessary to make progress in defining the requirements for graphic and non-graphic health and safety information depending on the degree of development of the project.

6. Conclusions

The research carried out in this study shows that the proposed methodology enables the integration of the risk assessment into the virtual construction model in the design phase of a road project developed with the BIM methodology, allowing for the elimination or minimization of occupational risks, coherence between the different phases of the risk assessment and the traceability of decisions. In this way, it complies with the health and safety regulations that are mandatory in Europe and Spain.

This methodology makes it possible to discriminate between levels of risk in the model itself depending on the area in which a particular unit of work is executed, overcoming the limitations of non-digitized risk assessment, which does not enable differentiation by area of work, characteristics, height, machinery used, personnel, etc.

The automation of the introduction of risk information into the model and its dynamic management within the model represent considerable advances, reducing time, errors and inconsistencies, facilitating the assessment of tasks and avoiding risks on site.

The methodology enables the study of interferences between works according to the project work plan, carrying out a 4D risk assessment, which allows the management of occupational risks and their evolution to be considered in different phases of the planning of road works.

The flexibility of the information introduces facilitates that the proposed methodology can be applied to in different topographic environments and in any country, with the only consideration necessary being the specific requirements of these regulations for the risk assessment or for the creation of BIM objects.

The proposed data structure enables the generation of an export in open format (IFC), with structured information that facilitates the interaction of all the agents involved in the collaborative environment for the purpose of decision making.

All of this can result in improved health and safety management in the design phase through the application of PtD.

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References

1. Guo, H.; Li, H.; Chan, G.; Skitmore, M. Using game technologies to improve the safety of construction plant operations. *Accid. Anal. Prev.* **2012**, *48*, 204–213. [CrossRef] [PubMed]
2. Azhar, S. Role of Visualization Technologies in Safety Planning and Management at Construction Jobsites. *Procedia Eng.* **2017**, *171*, 215–226. [CrossRef]
3. Mihić, M. Classification of Construction Hazards For A Universal Hazard Identification Methodology. *J. Civ. Eng. Manag.* **2020**, *26*, 147–159. [CrossRef]
4. Matsuura, H. Gender mainstreaming in occupational health and safety. In *Gender and the Sustainable Development Goals*; Routledge: London, UK, 2022; pp. 46–60. [CrossRef]
5. International Labour Organization. *Safety in Numbers. Pointers for a Global Safety Culture at Work*; International Labour Organization: Geneva, Switzerland, 2003; p. 39.
6. U.S. Bureau of Labour Statistics. *Census of Fatal Occupational Injuries Summary*; U.S. Bureau of Labour Statistics: Washington, DC, USA, 2017.
7. Hamid, A.A.R.; Azmi, M.R.A.N.; Aminudin, E.; Jaya, R.P.; Zakaria, R.; Zawawi, A.M.M.; Yahya, K.; Haron, Z.; Yunus, R.; Saar, C.C. Causes of fatal construction accidents in Malaysia. *IOP Conf. Series Earth Environ. Sci.* **2019**, *220*, 012044. [CrossRef]
8. Zhang, X.; Huang, S.; Yang, S.; Tu, R.; Jin, L. Safety Assessment in Road Construction Work System Based on Group AHP-PCA. *Math. Probl. Eng.* **2020**, 1–12. [CrossRef]
9. Bernessa, A.R.; Latief, Y. Safety cost component development of risk-based standardized work breakdown structure to determine safety cost on road construction project (Case study: At-grade road works). *IOP Conf. Series Mater. Sci. Eng.* **2021**, *1098*, 022034. [CrossRef]
10. Kim, Y.A.; Ryoo, B.Y.; Kim, Y.-S.; Huh, W.C. Major Accident Factors for Effective Safety Management of Highway Construction Projects. *J. Constr. Eng. Manag.* **2013**, *139*, 628–640. [CrossRef]

11. National Commission for Safety and Health at Work. Prevention in Infrastructure Explotation and Conservation Works; National Commission for Safety and Health at Work. 2016. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014SC0108&qid=1665944672141 (accessed on 25 June 2021).
12. Behm, M. Linking construction fatalities to the design for construction safety concept. *Saf. Sci.* **2005**, *43*, 589–611. [CrossRef]
13. Frijters, A.C.; Swuste, P.H. Safety assessment in design and preparation phase. *Saf. Sci.* **2008**, *46*, 272–281. [CrossRef]
14. Zhang, S.; Teizer, J.; Lee, J.-K.; Eastman, C.M.; Venugopal, M. Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Autom. Constr.* **2013**, *29*, 183–195. [CrossRef]
15. Cortés, A. *Methodology to Manage The Risks Of Falling From Height During The Exploitation Of New Buildings*; Universidad Europea de Madrid: Madrid, Spain, 2015.
16. Yuan, J.; Li, X.; Xiahou, X.; Tymvios, N.; Zhou, Z.; Li, Q. Accident prevention through design (PtD): Integration of building information modeling and PtD knowledge base. *Autom. Constr.* **2019**, *102*, 86–104. [CrossRef]
17. Poghosyan, A.; Manu, P.; Mahdjoubi, L.; Gibb, A.G.F.; Behm, M.; Mahamadu, A.-M. Design for safety implementation factors: A literature review. *J. Eng. Des. Technol.* **2018**, *16*, 783–797. [CrossRef]
18. Gambatese, J.A.; Hinze, J.W.; Haas, C.T. Tool to Design for Construction Worker Safety. *J. Arch. Eng.* **1997**, *3*, 32–41. [CrossRef]
19. Walker, A. Project management in construction (6th Edition 2015). *J. Chem. Inf. Model.* **2013**, *53*, 1689–1699.
20. Durán, F.; Tudela, G.; Valdeolivas, Y. *Report on the Situation of Occupational Risk Prevention in the Construction Sector in Spain*; Edisofer: Madrid, Spain, 2008.
21. Kamardeen, I. 8D BIM Modelling Tool for Accident Prevention Through Design. In Proceedings of the 26th Annual ARCOM Conference, Leeds, UK, 6–8 September 2010; pp. 281–289.
22. Matarneh, R.; Hamed, S. Barriers to the Adoption of Building Information Modeling in the Jordanian Building Industry. *Open J. Civ. Eng.* **2017**, *07*, 325–335. [CrossRef]
23. Eastman, K.; Teicholz, C.; Sacks, P.; Liston, R. *A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, 2nd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2011. [CrossRef]
24. Azhar, S.; Khalfan, M.; Maqsood, T. Building information modelling (BIM): Now and beyond. *Constr. Econ. Build.* **2015**, *12*, 15–28. [CrossRef]
25. Ding, L.; Zhou, Y.; Akinci, B. Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Autom. Constr.* **2014**, *46*, 82–93. [CrossRef]
26. Matarneh, S.T.; Danso-Amoako, M.; Al-Bizri, S.; Gaterell, M.; Matarneh, R. Building information modeling for facilities management: A literature review and future research directions. *J. Build. Eng.* **2019**, *24*, 100755. [CrossRef]
27. Yu, Z.; Peng, H.; Zeng, X.; Sofi, M.; Xing, H.; Zhou, Z. Smarter construction site management using the latest information technology. *Proc. Inst. Civ. Eng. Civ. Eng.* **2019**, *172*, 89–95. [CrossRef]
28. Jin, R.; Zou, P.X.; Piroozfar, P.; Wood, H.; Yang, Y.; Yan, L.; Han, Y. A science mapping approach based review of construction safety research. *Saf. Sci.* **2018**, *113*, 285–297. [CrossRef]
29. Khan, N.; Ali, A.K.; Skibniewski, M.J.; Lee, D.Y.; Park, C. Excavation Safety Modeling Approach Using BIM and VPL. *Adv. Civ. Eng.* **2019**, *2019*, 1–15. [CrossRef]
30. Arezes, P.M.; Baptista, J.S.; Barroso, M.P.; Carneiro, P.; Cordeiro, P.; Costa, N.; Melo, R.B.; Miguel, A.S.; Perestrelo, G. (Eds.) *Occupational Safety and Hygiene VI*; CRC Press/Balkema: Guimarães, Portugal, 2018; pp. 115–152.
31. Kumar, B.; Cai, H.; Hastak, M. An assessment of benefits of using BIM on an infrastructure project. In Proceedings of the International Conference on Sustainable Infrastructure 2017, American Society of Civil Engineers, Reston, VA, USA, 26–28 October 2017; pp. 88–95. [CrossRef]
32. Aziz, Z.; Riaz, Z.; Arslan, M. Leveraging BIM and Big Data to deliver well maintained highways. *Facilities* **2017**, *35*, 818–832. [CrossRef]
33. European Parliament. Directive 2014/24/EU of The European Parliament and of The Council of 26 February 2014 on Public Procurement and repealing Directive 2004/18/EC (Text with EEA Relevance), Brussels Commentary on EU Public Procurement Law 2014. Available online: https://www.bloomsburycollections.com/book/brussels-commentary-on-eu-public-procurement-law/directive-2014-24-eu-of-the-european-parliament-and-of-the-council-of-26-february-2014-on-public-procurement-and-repealing-directive-2004-18-ec-text-w (accessed on 4 September 2022).
34. BOE. Law 9/2017, of November 8, on Public Sector Contracts, which transposes the Directives of the European Parliament and of the Council 2014/23 / EU and 2014/24 / EU, of February 26, to the Spanish legal system 2014. Boletín Of. Del Estado. Available online: https://www.boe.es/buscar/act.php?id=BOE-A-2017-12902 (accessed on 16 July 2022).
35. Wasemann, H.T. *Exploring the BIM Adoption Of Public Client Organisations A Study of The German Road Infrastructure Sector*; University of Twente Enschede: Enschede, The Netherlands, 2020.
36. Mayer, P.; Funtík, T.; Gašparík, J.; Makýš, P. Analysis of the Current State of Automation of Hazard Detection Processes in BIM in Slovakia. *Appl. Sci.* **2021**, *11*, 8130. [CrossRef]
37. European Commission. Directive 92/57 / EEC, of June 24, 1992, on the implementation of minimum safety and health requirements at temporary or mobile construction sites (eight individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC). *Off. J. Eur. Communities* **1992**, *18*, 1–23.

38. BOE. Royal decree 1627/97 by Laying Down Minimum Health and Safety Provisions in Construction Sites. *Bol. Of. Del Estado.* 1997, pp. 30875–30886. Available online: https://www.boe.es/buscar/doc.php?id=BOE-A-1997-22614 (accessed on 1 September 2022).
39. Costin, A.; Adibfar, A.; Hu, H.; Chen, S.S. Building Information Modeling (BIM) for transportation infrastructure–Literature review, applications, challenges, and recommendations. *Autom. Constr.* **2018**, *94*, 257–281. [CrossRef]
40. Dikbas, A.; Scherer, R. *eWork and eBusiness in Architecture, Engineering and Construction*; CRC Press: Boca Raton, FL, USA, 2004; pp. 257–258. [CrossRef]
41. Chong, H.Y.; Lopez, R.; Wang, J.; Wang, X.; Zhao, Z. Comparative Analysis on the Adoption and Use of BIM in Road Infrastructure Projects. *J. Manag. Eng.* **2016**, *32*, 05016021. [CrossRef]
42. Bae, A.; Lee, D.; Park, B. Building information modeling utilization for optimizing milling quantity and hot mix asphalt pavement overlay quality. *Can. J. Civ. Eng.* **2016**, *43*, 886–896. [CrossRef]
43. Kim, J.-U.; Kim, Y.-J.; Ok, H.; Yang, S.-H. A Study on the Status of Infrastructure BIM and BIM Library Development. In Proceedings of the 2015 International Conference on Computational Science and Computational Intelligence (CSCI), Las Vegas, NV, USA, 7–9 December 2015; pp. 857–858.
44. Collinge, H.; Farghaly, K.; Mosleh, M.H.; Manu, P.; Cheung, C.M.; Osorio-Sandoval, C.A. BIM-based construction safety risk library. *Autom. Constr.* **2022**, *141*. [CrossRef]
45. Biancardo, S.A.; Capano, A.; De Oliveira, S.G.; Tibaut, A. Integration of BIM and Procedural Modeling Tools for Road Design. *Infrastructures* **2020**, *5*, 37. [CrossRef]
46. Liu, B.; Cai, T.; Xiao, S.; Fu, H.; Chu, W. Research on application of BIM technology in municipal road construction. *IOP Conf. Series Earth Environ. Sci.* **2019**, *330*, 022078. [CrossRef]
47. Lou, J.; Xu, J.; Wang, K. Study on Construction Quality Control of Urban Complex Project Based on BIM. *Procedia Eng.* **2017**, *174*, 668–676. [CrossRef]
48. Omoregie, A.; Turnbull, D.E. Highway infrastructure and Building Information Modelling in UK. *Proc. Inst. Civ. Eng.-Munic. Eng.* **2016**, *169*, 220–232. [CrossRef]
49. Ganah, A.; John, G. Integrating Building Information Modeling and Health and Safety for Onsite Construction. *Saf. Health Work* **2014**, *6*, 39–45. [CrossRef] [PubMed]
50. Musa, S.; Marshall-Ponting, A.; Nifa, F.A.A.; Shahron, S.A. Building information modeling (BIM) in Malaysian construction industry: Benefits and future challenges. In *AIP Conference Proceedings*; AIP Publishing LLC: Melville, NY, USA, 2018; pp. 1–10. [CrossRef]
51. Sulankivi, K.; Mäkelä, T.; Kiviniemi, M. BIM-based site layout and safety planning. In Proceedings of the VTT Symposium (Valtion Teknillinen Tutkimuskeskus), Hongkong, July 2009; pp. 125–140.
52. Zhang, S.; Sulankivi, K.; Kiviniemi, M.; Romo, I.; Eastman, C.M.; Teizer, J. BIM-based fall hazard identification and prevention in construction safety planning. *Saf. Sci.* **2015**, *72*, 31–45. [CrossRef]
53. Sulankivi, K.; Kahkonen, K. 4D-BIM for Construction Safety Planning, W099-Special Track 18th CIB World Building Congress. 2010. Available online: http://cibworld.xs4all.nl/dl/publications/w099_pub357.pdf#page=122 (accessed on 8 August 2021).
54. Getuli, V.; Ventura, S.M.; Capone, P.; Ciribini, A.L. BIM-based Code Checking for Construction Health and Safety. *Procedia Eng.* **2017**, *196*, 454–461. [CrossRef]
55. Cassano, M.; Trani, M.L. LOD Standardization for Construction Site Elements. *Procedia Eng.* **2017**, *196*, 1057–1064. [CrossRef]
56. Lee, Y.; Kim, I.; Choi, J. Development of BIM-Based Risk Rating Estimation Automation and a Design-for-Safety Review System. *Appl. Sci.* **2020**, *10*, 3902. [CrossRef]
57. Shen, X.; Marks, E. Near-Miss Information Visualization Tool in BIM for Construction Safety. *J. Constr. Eng. Manag.* **2016**, *142*, 1–10 . [CrossRef]
58. Cortés-Pérez, J.P.; Muriel, P.P.; Pérez, A.C. BIM-integrated management of occupational hazards in building construction and maintenance. *Autom. Constr.* **2020**, *113*, 1–14. [CrossRef]
59. Lu, Y.; Gong, P.; Tang, Y.; Sun, S.; Li, Q. BIM-integrated construction safety risk assessment at the design stage of building projects. *Autom. Constr.* **2021**, *124*, 103553. [CrossRef]
60. Torrecilla-García, J.A.; Pardo-Ferreira, M.C.; Rubio-Romero, J.C. Overall Introduction to the Framework of BIM-based Digital Twinning in Decision-making in Safety Management in Building Construction Industry. *Dir. Org.* **2021**, *76*, 5–12. [CrossRef]
61. Tran, S.; Khan, N.; Lee, D.; Park, C. A Hazard Identification Approach of Integrating 4D BIM and Accident Case Analysis of Spatial–Temporal Exposure. *Sustainability* **2021**, *13*, 2211. [CrossRef]
62. Zou, P.X.; Lun, P.; Cipolla, D.; Mohamed, S. Cloud-based safety information and communication system in infrastructure construction. *Saf. Sci.* **2017**, *98*, 50–69. [CrossRef]
63. *BIM BSI 1192-6:2018*; BSI (British Standards Institute), Specification for Collaborative Sharing and Use of Structured Health and Safety Information Using. BSI Publisher: London, UK, 2018.
64. esBIM. BIM Requirements for Tenders. Available online: https://cbim.mitma.es/observatorio-bim-en-espana/requisitos-bim-en-pliegos (accessed on 9 August 2021).
65. BOE. Law 31/1995, of November 8, on Occupational Risk Prevention. *Boletín Of. Del Estado 1995.* Available online: https://www.boe.es/buscar/act.php?id=BOE-A-1995-24292 (accessed on 3 August 2021).

66. Noor, B.A.; Yi, S.; Kazmi, S.H.A. Revit-based automation modeling for intermediate railway station. In Proceedings of the 2017 2nd International Conference on Cybernetics, Robotics and Control, CRC 2017, Chendu, China, 21–23 July 2017; pp. 162–166. [CrossRef]
67. INSST. *Technical Guide for The Evaluation and Prevention of Risks Related to Construction Works*; INSST: Madrid, Spain, 2019.
68. Uusitalo, P.; Seppänen, O.; Lappalainen, E.; Peltokorpi, A.; Olivieri, H. Applying Level of Detail in a BIM-Based Project: An Overall Process for Lean Design Management. *Buildings* **2019**, *9*, 109. [CrossRef]
69. INSHT. *Good Practice Guide NTP 210: Analysis of Working Conditions: Method of the A.N.A.C.T.*; INSHT: Madrid, Spain, 1989.
70. INSHT. *Guide to good practices NTP 176: Evaluation of Working Conditions: Method of Job Profiles*; INSHT: Madrid, Spain, 1989.
71. Rubio, J.C. *Manual for Higher Level Training In Labor Risk Prevention*; Edigrafos, S.A.: Málaga, Spain, 2005.
72. ANECOP. *Guide to the evaluation of Labor Risks in the Work Units*; Comunidad Foral de Navarra: Navarra, Spain, 2006.
73. BSI. Specification for information management for the capital/delivery phase of construction projects using building information modelling. *BSI Stand. Publ.* **2013**, *1*, 1–44. Available online: https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocId=306448 (accessed on 23 August 2022).
74. Forum, B. LOD Specification 2019 Part I: For Building Information Models and Data. Available online: https://bimforum.org/resource/%EF%BF%BC%EF%BF%BClevel-of-development-specification/ (accessed on 9 May 2021).
75. Ministry of Development. *8.3. I-C. Manual of Examples of Signaling of Fixed Works*; Publications Centre of the General Technical Secretariat of the Ministry of Development: Madrid, Spain, 1989; p. 76.