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A BIM-based tool to support time risk management in construction projects

(Extended abstract)

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1. Introduction

The architecture, engineering, and construction (AEC) industry requires a high level of collaboration between different parties involved in construction projects and encompasses domains that make diverse use of building information [1]. Building Information Modeling (BIM) can help achieving these requirements. BIM contributes in a better owners' engagement and understanding of the project, helps with a better documentation and constructability, creates a better understanding of the design for contractors and contributes in the reduction of unplanned changes during construction [2].

In the last four decades, the research about risk management in the construction industry has grown considerably [3]. During time the risks increased due to the involvement of many contracting parties such as owners, designers, contractors [4]. Analyzing risks can be time consuming and therefore expensive, hence, it is important that the parties involved quickly understand the risk framework. Furthermore, risk analysis information is often presented based on complicated numerical analysis, which reduce its usability in practical work [6].

This presented research work studies the possibility of implementing a Failure Mode Effect Analysis (FMEA) process based on a BIM model by creating a tool that can be used by risk managers to have a better overview of the risks. It can improve the communication between different stakeholders and help determining adequate risk measurements. With FMEA, time and cost related risks can be analyzed and prioritized by level of importance where after the risks will be linked to the elements in the BIM model to which they are related. Each risk level will then be assigned with a risk color and BIM will visualize these risk colors in a 3D and 4D design. This will provide the user an overview which can be easily analyzed, documented and discussed with all the relevant stakeholders involved.

This summary is divided into three parts. The first part presents a literature review which explores the different aspects of BIM and Risk management. The second part describes the development of the BIM-based risk management tool in a 3D and 4D environment and in the third part the tool is tested in a pilot case and the results are discussed.

2. Literature review

2.1. Building Information Model (BIM)

With BIM technology, virtual models of a structure are digitally build. It supports design through its entire lifetime, allowing better analysis and control compared to manual processes. This provides the basis for new design and construction capabilities and changes the roles and relationships in a project team. With BIM, several possibilities arise such as, visualization of the design, manufacturing of fabrication drawings, cost estimating and construction sequencing, collision detection and forensic analysis. BIM also provides a higher quality of work performance and improves coordination between design and engineering disciplines [6][7]. BIM is all about the cooperation between different disciplines and several parties must work together to fully implement the BIM methodology. It enables that anyone involved can process information immediately into the model, making the sharing faster and more efficient [1].

2.2. Risk management

All types and sizes of organization face internal and external influences that make it uncertain whether and when their objectives will be achieved. The effect this uncertainty has on an organization their objectives is called 'risk'. All activities of an organization involve risks and they try to manage this by identifying, analyzing and evaluating whether the risk should be modified by risk treatment to satisfy their risk criteria. Throughout this process, they communicate and consult with stakeholders and monitor and review the risk to ensure that no further risk treatment is required [8].

2.3. Failure Mode Effect Analysis (FMEA)

A tool to analyze risks is the FMEA, it is developed to identify and prioritize risks in a construction project. When applied properly, FMEA can anticipate and prevent problems, reduce costs, shorten product development times, and achieve safe and highly reliable products and processes [9]. The main advantage of FMEA is the fact that it addresses budget, schedule and technical risk together where as other techniques are usually limited to addressing these risks individually [10]. In a FMEA there are three main objectives; identifying and evaluating the risks, and determine possible actions to eliminate or reduce the effect and impact of failure. When the analysis is completed, the risks will be prioritized based on a Risk Priority Number (RPN). Generally, the RPN is ranges from 1 to 1.000, calculated as the product of the severity (S), occurrence (O), and detection level (D) of a failure mode, where each of the three parts is evaluated on a scale from 1 to 10. Thus, elements that are assessed to have a high RPN are assumed more critical than those with lower values.

2.4. BIM and Risk management

BIM could not only be used to support the project development process as a risk management tool, but it could also serve as a platform to allow other BIM-based tools to perform further risk analysis [11]. BIM has some advantages specifically related to risks. The risk of wrong measurement or inaccurate generation of cost can be minimized due to the elimination of manual extraction of drawing through data exchange platform. Another advantage is, when BIM is made accessible to all stake holders it will improve communication and cooperation and thereby decreasing the risk of defragmentation among project actors [12]. This is important because stakeholders can have a significant impact on the decisions made. It is important that their perceptions of risk, as well as their perceptions of benefits, be identified and documented and the underlying reasons for them understood and addressed [13].

2.5. Opportunities BIM- based risk management tool

Communication of construction project risk is usually poor, incomplete and inconsistent throughout the construction process. Also, project participants usually do not have a shared understanding of the project risk and therefore are unable to implement effective measures and mitigating strategies. That is why different stakeholders with different backgrounds and knowledge about construction need to communicate in a clear and efficient way [14]. This study aims to develop a tool that can be implemented in every BIM-based construction project whereby the risks can be easily identified and made visible for all the people involved. This helps risk managers to respond to risk in a more efficient way and helps the stakeholders to better understand which actions need to be taken and what the underlying reasoning of the actions is. It also helps to make the risk management activities easier traceable, which is important to provide the foundation for improvement in methods and tools, as well as in the overall process [8].

3. Development of BIM-based risk management tool

The objective of this study is to create a BIM-based risk management tool to support construction managers by visualizing, in the design, the different time and cost related risks and the degree to which they affect the project. First, a conceptual model is developed presenting the different actors involved and how the tool will be used. Secondly, an FMEA interface is created in Excel where all the relevant data can be inserted and the risk analysis can be performed. In the FMEA interface the outcome of the analysis will automatically be converted into a Risk Evaluation Number (REN) where each number will be represented by a color. These colors will, along with information about critical tasks and some additional information which can be filled in per task in the FMEA interface, be converted to a 3D BIM model. To make this possible, a Dynamo programming code is developed to establish a connection between the FMEA interface and the BIM software. Dynamo is a visual programming add-in of Autodesk Revit that enables to automate several operations based on the BIM model. In this case it is used to overwrite colors in the 3D BIM model in Revit and to create a pop-up screen that will show additional information about the risks involved. Since an element can only have one color and multiple tasks can relate to the same element, some information will be lost. Therefore, a 4D model is developed that allow to visualize the risks over time. The 4D model will be created in Navisworks and will directly import the necessary information from the FMEA interface. The disadvantage of the 4D model is that it is not able to show the pop-up screen with extra information.

3.1. Conceptual model

The process starts with a construction schedule and a 3D BIM model. The construction schedule will be linked to the interface where the FMEA can be performed. Using Dynamo, the information obtained will be exported to the 3D BIM model. For the elements to receive the correct information a link will be established in Revit between the tasks and their corresponding elements. In Navisworks, the BIM model containing the link between tasks and elements will be combined with the information from the FMEA interface to create the 4D model. The different steps and data flow are presented in figure 1. In the top right corner, the proposed software is presented. Although different software can be used, this is the software that is advised for an optimal use of the tool.

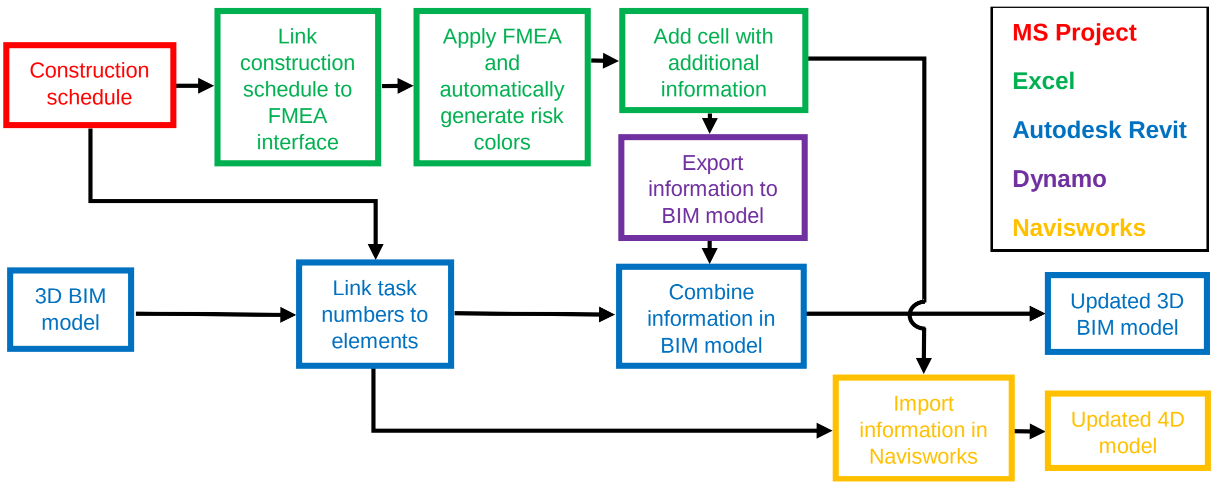


Figure 1 - Data flow conceptual model

3.2. FMEA interface

The FMEA interface will perform as the center of the tool and contains the construction schedule, the FMEA and the results of the FMEA. An extra column is added where additional information can be filled in such as what the specific risk involves, the risk owner, risk source and the risk recipient. This information will pop-up in the 3D BIM model when a specific element is selected. An example of the FMEA interface is shown in annex I.

The construction schedule contains columns with Task_ID, Name, Duration, Start date, Finish date, Predecessors and if a task is part of the critical path. Next to the construction schedule, the FMEA will be performed which will be divided in a cost analysis and a time analysis. Each analysis is divided in columns for the assessment of occurrence, severity and detection. In each of the columns the risk will be rated with a value between 1 and 10. These 3 values multiplied with each other form the RPN. In the next column, the RPN will automatically be evaluated in terms of 'low' (RPN<27), 'medium' (27<RPN<216) and 'high' (RPN>216). Next to the cost and time analysis the evaluations will be automatically combined into a REN ranging from 1 to 9 where each value will be represented by a risk color (see table 1). These colors will be applied to the 3D BIM model and the 4D model to show the degree of the involved risks. The tool involves an extra feature in which the elements that have tasks that are not on the critical path will receive a transparency. This will improve the overview of the time related risks, since the risks that are on the critical path will become clearer compared to the risks that are not on the critical path and therefore can be assumed to be less critical.

Table 1 - Assigned risk colors

Risk Cost	Risk Time	REN	Risk Color
Not evaluated	Not evaluated	"null"	White
Low	Low	1	
Low	Medium	2	
Low	High	3	
Medium	Low	4	
Medium	Medium	5	
Medium	High	6	
High	Low	7	
High	Medium	8	
High	High	9	

3.3. Linking tasks to elements

In MS Project the construction schedule will be converted in a format with main task and subtasks with each a unique Task ID number. The main tasks will refer to an element or a set of elements because it will allow an easy use of the FMEA since risks related to the costs are evaluated per element and the risks related to time per task. An example of the desired construction schedule format is shown below:

1. Constructing footing (main task)
1.1 Placing formwork (sub task)
1.2 Placing reinforcement (sub task)
1.3 Etc. (sub task)

In Revit, it is possible to add parameters to the elements to describe the specific element which later can be filled in. For this method, it is necessary to add the parameter Task_ID to each element. The link will be established by manually filling the task numbers to the 4d_Task_ID parameter of the corresponding element. With this additional parameter, the elements can be selected and modified by searching for the task ID number in the model. This method is straightforward, easy to understand and easy to use. Task numbers can easily be attributed to specific elements and when selecting an element in Revit the related task number is immediately shown in the properties menu. The user can, when necessary, consult the FMEA interface to see which tasks are related to this specific element

3.4. Connection between FMEA interface and Revit

To translate the information from the FMEA interface to the 3D BIM model a visual programming software (Dynamo) is used that can be interpreted much faster and easier by non-programmers which includes most of the stakeholders in a construction project. Dynamo is a Revit plug-in and works as a visual programming extension that allows to manipulate data, sculpt geometry, explore design options, automate processes, and create links between multiple applications [15]. It can link the colors generated based on the risks list, the tasks on the critical path and additional information to the Revit software in an automatic way.

A Dynamo code is built by connecting nodes with wires in a workspace to specify a logical flow of the resulting visual program. The inputs and outputs for nodes are called ports and act as the receptors for the wires. Data comes into the node through ports on the left and flows out of the node, after it has executed its operation, on the right. Wires connect the output port from one node to the input port of another node. This establishes a flow of data in the visual program. An example is shown in figure 2.

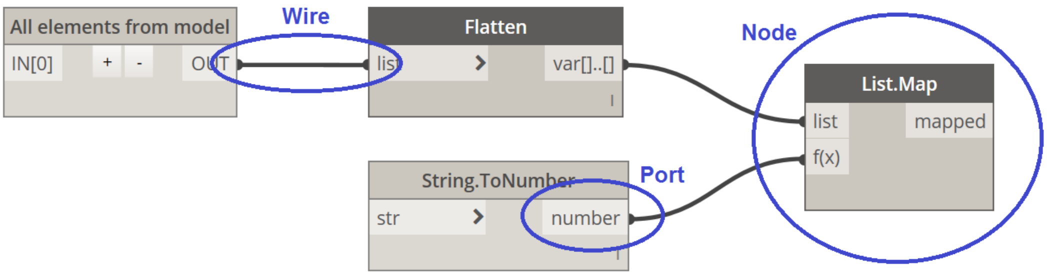


Figure 2 - Example of data flow in Dynamo

Dynamo has a built-in library where various node packages are available. Because Dynamo is an open software, nodes that are created by other users can be downloaded and used freely. However, if a node cannot be downloaded or is not available in the library, it is possible to create custom nodes with the Python programming language and add them to the Dynamo code.

The role of Dynamo in the BIM-based risk management tool is to extract the data from the FMEA and convert this to specific elements in the 3D BIM model. Dynamo will also provide a function that, when an element is selected, this element will be shown in a separate window with a pop-up message which contains the additional information entered in the FMEA interface. The main advantage of this is that the user will still get the full information that is needed, even from small/ embedded elements. For example, lighting fixtures which are not very visible in the complete 3D BIM model. Table 2 describes how the Dynamo code is used in the BIM- based risk management tool.

Table 2 – Elaboration Dynamo code

Function	Main nodes	Description
1. Extract information from Revit	"Custom node"	Selects all the elements in the BIM model
	"Code Block"	Selects the Task ID numbers
	"Element.GetParameter ValueByName"	Filters the list of elements to get all the elements that contain a Task ID number
2. Extract information from FMEA interface	"Excel.readFromFile"	Reads information from an Excel file
	"Code Block"	Selects information about Task ID, Critical Path, REN and the column additional information
	"List.GetItemAtIndex"	Filters the information from Excel and provides a list with the input from the "Code block"
3. Compare information from Interface and Revit	"Springs.Dictionary. ByKeysValues"	Compares the information from Excel and Revit and creates a list with all the elements in the Revit model with their corresponding REN
4. Filter elements	"=="	Filter the list of elements into 10 different groups (0 to 9) based on their REN
	"List.FilterByBoolMask"	
5. Update 3D BIM model with colors and transparency	"SetIntersection"	Compares each group of elements (with the same REN) with a list of critical tasks
	"Element.Override ColorInView"	Overrides the elements in the BIM model with a color (table 1) corresponding to its REN, elements without tasks on the critical path will be attributed with a transparency
6. Isolate element in separate window	"Select Model Element"	Enables to select a specific element in the BIM model
	"Element.Temporarily IsolateInView"	Opens the selected element in a temporary view within the BIM model.
7. Adding a pop-up message with additional information	"Springs.Dictionary. ByKeysValues"	Compares the information from a selected element with the information from the Excel-column additional information.
	"Dialog	Opens a dialog screen with the 'additional information' from Excel

3.5. Connection between FMEA interface and Revit

Within Navisworks, a 4D model can be created by linking a construction schedule with a 3D BIM model using the Timeliner option. The construction schedule is imported by Excel using a .CSV file. In Navisworks the different columns of the FMEA interface can be linked to the default columns in Navisworks. Linking the tasks with the elements need to be done again manually. In Navisworks it is possible to search elements based on their parameters. By selecting all the elements with the same parameter 'Task ID number', search sets can be created. These search sets can then be linked to the corresponding tasks in the construction schedule where search set '2' will be linked to for tasks 2.1, 2.2, 2.3 and so forth. To change the color of the element the column 'REN' (in the FMEA interface) is linked with the column 'Task type' (in Navisworks). In the Timeliner option "configure" in Navisworks the different task types can be assigned to the same evaluation colors as proposed in table 1. All the tasks with this 'Task type' (REN) will then change to the color as evaluated in the FMEA interface.

4. Results

The prototype of the tool has been tested on an experimental Revit model of a large T3 residential house with two floors and an area of 325 m2 and a corresponding construction schedule. In figure 3, the 3D BIM model is shown with the risk evaluation colors. The internal walls, doors/ windows, stairs railing and the kitchen received, besides their risk color, a transparency of 50% since they exist of tasks that are not critical. The model shows that the Dynamo code is functioning and that all the elements have their correct risk color and transparency. The established color code system proved to be efficient since it reflected "hot" areas where severe risks can occur that need some extra attention of the stakeholders. Images of specific parts or sections of the model can be taken and shared among stakeholders that have not the necessary software to see the model in Revit.

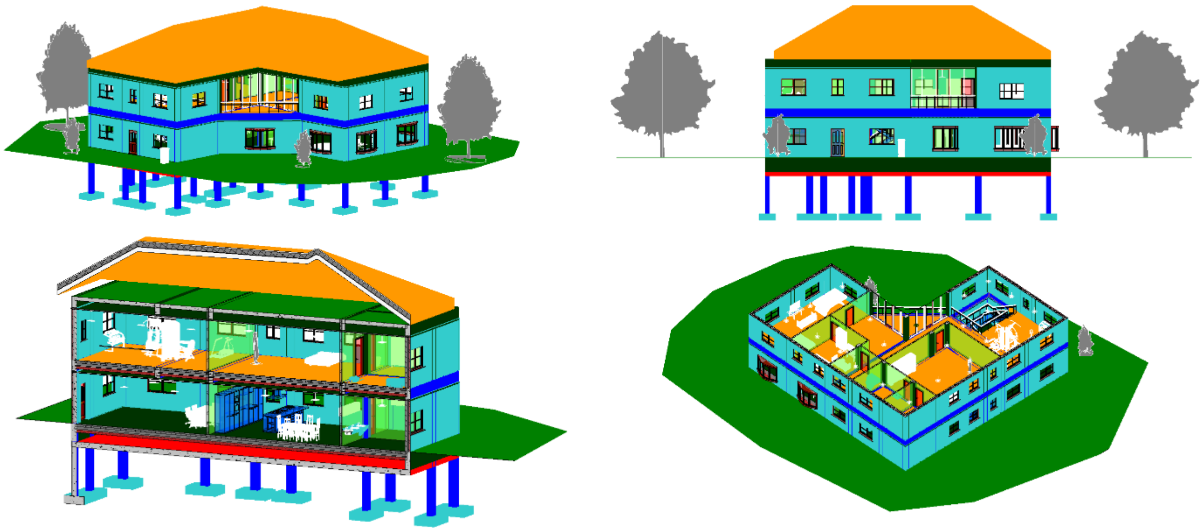
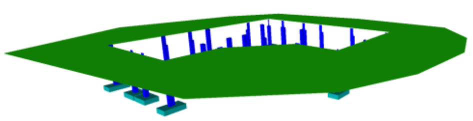
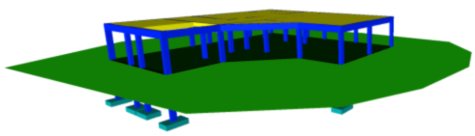
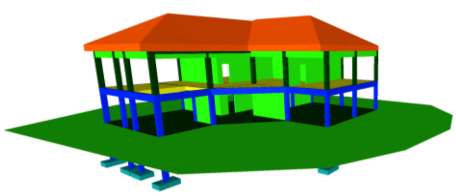
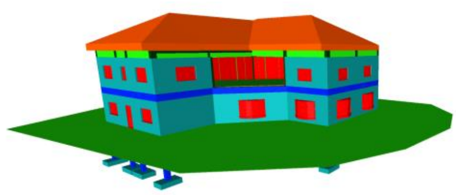


Figure 3 - 3D views of the updated 3D BIM model

In Navisworks the 4D simulation shows all the necessary elements, in the right order and with the correct color. The biggest advantage of the 4D part of the tool is that the user can address the risk for any specific day or even hour see table 3. The simulation can be stopped and the Timeliner will show the date, the tasks that are performed, how far the task is completed in percentages and the model will show the specific risk colors for that moment. During the simulation in Navisworks it is possible to look around the model, zoom in on specific elements and create sections for better visibility.

Table 3 – Screenshots of the 4D model in Navisworks

1. 	2. 
3. 	4. 

A video can be made from the model in a .AVI format and shared among the stakeholders that do not have the necessary software to view the simulation in Navisworks. A screenshot of a video from the pilot case is shown in figure 4. The exact date and time are shown in the top left corner.

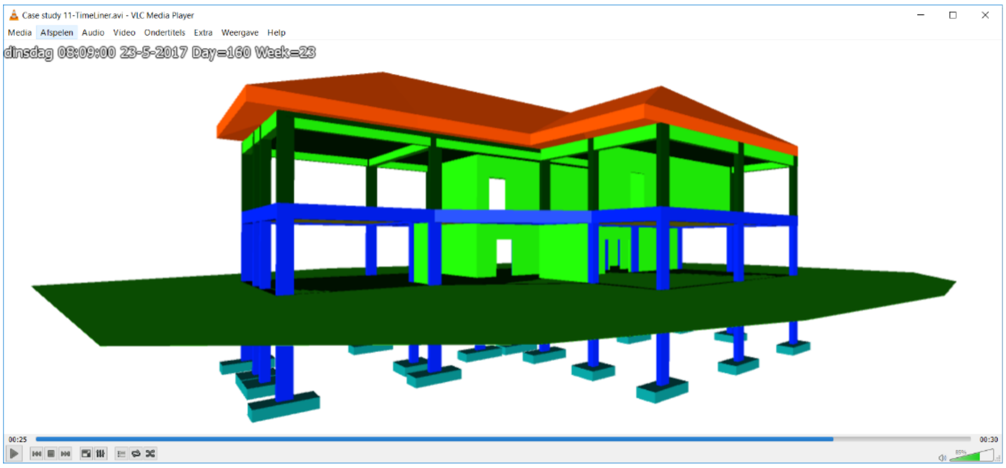


Figure 4 - Screen shot of a video from the 4D model

5. Conclusions

The tool was tested in a pilot case and has shown that it effectively allows visualizing the risk degrees of specific elements of the construction using a color code system. During the pilot case, all the analyzed risks were shown in the 3D BIM model and a video could be produced of the construction phase with the involved risks shown at any time during the construction of the building. To study the actual contributions this tool could make, it is important that it will be applied on a real case study.

In a thesis with a comparable structure of using different colors to visualize information from an Excel sheet in a BIM model, three challenges were identified; the manually linking of tasks and elements, the loss of information while linking multiple tasks to one elements, and the non-automated selection of elements in the Dynamo code [16]. The automatic linking of the tasks with the elements remains unsolved, mainly because information is not fully organized yet which makes it difficult to link different types of information. By using Task ID numbers, an acceptable method is applied which is easy to use although the user still must fill in the parameters manually. Another challenge was the loss of information while linking multiple tasks to one element. By creating a 4D model this problem was tackled because different tasks can be visualized in the same element over time. The challenge of selecting all the Revit elements at ones in the Dynamo code was addressed by creating a custom node with the python script which could select all the elements at once.

One of the limitations of the tool is the poor visibility of small or embedded elements. An interesting study could be to apply this BIM-based risk management tool to more robust structures such as bridges and road overpasses which often have less small elements which will them more suited for a risk visualization tool as proposed in this research work. Since the proposed tool is just a prototype, it is not user friendly yet. The user needs to perform many tasks to get an outcome which compromises the value of the tool. There is a big open area that can be developed, mainly by programmers, to reduce the amount of steps the user must take. Also, the creation of one single 4D model in which all the information is stored would be a great improvement in terms of user friendliness.

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Annex I

Link with MS project	
Fill in manually	

Risk evaluation	value
'Low' <	27
'High' >	216
'Medium'	

Planning linked with Ms Project

RPN automatically calculated by multiplying Occurence, Severity and Detection number

Risk automatically evaluated by Low, Medium or High depending on RPN. Evaluation is equal to the highest risk of the onderlaying tasks

Color automatically assigned based on the two risk evaluations

Risk evaluation number (REN) automatically assigned based on the two risk evaluations

Planning							Cost					Time							
Task_ID	Name	Duration	Start_Date	Finish_Date	Predec.	Cr. path	O	S	D	RPN	Risk	O	S	D	RPN	Risk	Color	Additional Information	REN
2	**Footings**	**6 days**	**22-12-16**	**29-12-16**		**Yes**	**9**	**1**	**1**	**9**	**Low**				**81**	**Medium**	**LowMedium**	**Weather conditions**	**2**
2.1	Formwork footings	2 days	22-12-16	23-12-16	4	Yes					Low	1	9	9	81	Medium	LowMedium		2
2.2	Reinforcement footing	1 day	26-12-16	26-12-16	7	Yes					Low	1	2	10	20	Low	LowLow		1
2.3	Casting concrete footing	1 day	27-12-16	27-12-16	8	Yes					Low	7	1	1	7	Low	LowLow		1
2.4	Removing Formwork	1 day	29-12-16	29-12-16	9FS+1d	No					Low	2	4	8	64	Medium	LowMedium		2
3	**Foundation pillars**	**8 days**	**29-12-16**	**9-01-17**		**No**	**4**	**1**	**8**	**32**	**Medium**				**432**	**High**	**MediumHigh**	**Weather conditions**	**6**
3.1	Formwork pillars	3 days	29-12-16	2-01-17	9FS+1d	Yes					Medium	7	7	2	98	Medium	MediumMedium		5
3.2	Reinforcement pillars	2 days	3-01-17	4-01-17	12	Yes					Medium	1	6	6	36	Medium	MediumMedium		5
3.3	Casting pillars	1 day	5-01-17	5-01-17	13	Yes					Medium	8	6	9	432	High	MediumHigh		6
3.4	Casting pillars	2 day	5-01-17	5-01-17	14	Yes					Medium	2	5	1	10	Low	MediumLow		4

Risk	Risk color
Cost: low, Time: low	1
Cost: low, Time: medium	2
Cost: low, Time: high	3
Cost: medium, Time: low	4
Cost: medium, Time: medium	5
Cost: medium, Time: high	6
Cost: high, Time: low	7
Cost: high, Time: medium	8
Cost: high, Time: high	9

Rating	Detection	Criteria
10	Impossible	Impossible Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no design control
9	Very remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode
8	Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode
7	Very low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode
6	Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode
5	Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode
4	Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode
3	High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode
2	Very high	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode
1	Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode

Rating	Effect	Severity of effect
10	Extreme	>15% increase of the planned project time/ cost
9	Major	10% increase of the planned project time/ cost
8	Serious	5% increase of the planned project time/ cost
7	Significant	4% increase of the planned project time/ cost
6	Moderate	3% increase of the planned project time/ cost
5	Low	2% increase of the planned project time/ cost
4	Very low	1% increase of the planned project time/ cost
3	Minor	0,5% increase of the planned project time/ cost
2	Very minor	0,1% increase of the planned project time/ cost
1	None	< 0,05% increase of the planned project time/ cost

Rating	Probability of occurrence	Possible failure rate
10	Very high: failure is almost inevitable	≥ 1/2
9		1/3
8	High: repeated failures	1/8
7		1/20
6	Moderate: occasional failures	1/80
5		1/400
4		1/2000
3	Low: relatively few failures	1/15.000
2		1/150.000
1	Remote: failure is unlikely	≤ 1/1.500.000