UNIVERSIDADE
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FACULTY OF ENGINEERING

MASTER’S IN HEALTH, SAFETY AND ENVIRONMENT ENGINEERING

MASTER'S THESIS

RISK ANALYSIS METHODS OF WATER SUPPLY SYSTEM CONSTRUCTION WORK: CASE OF STUDY – CONSTRUTORA DO MESSALO, LDA.

A Dissertation by

Nicole Lord Conjo

Maputo, April 2023

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Supervised by:

Prof. Doutor João Chidamoio, Engº

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The undersigned certify that they have read and recommend to the Faculty of Engineering a thesis entitled “**RISK ANALYSIS METHODS OF WATER SUPPLY SYSTEM CONSTRUCTION WORK: CASE OF STUDY – CONSTRUTORA DO MESSALO, LDA´´** submitted by, **NICOLE LORD CONJO** in partial fulfillment of the requirements for the degree of Master Program in **HEALTH, SAFETY AND ENVIRONMENT ENGINEERING.**

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Prof. Doutor João Chidamoio, Engº

Supervisor

____

Doutor Marcelino Januário Rodrigues, Arq.to

Course Coodinator

DECLARATION OF DOCUMENT ORIGINALITY

"I declare that this dissertation has never been submitted to obtain any degree or in any other contextand is the result of my own individual work. This dissertation is presented in partial fulfilment of the requirements for the award of Master’s in Health, Safety and Environment Engineering, from the Universiade Eduardo Mondlane".

Submitted by:

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Nicole Lord Conjo

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ABSTRACT

The civil construction sector is considered one of the most dangerous sectors in the world. Thus, there is a need for consistent risk management to understand the risks and present control plans with effective measures to minimize them. To achieve these results, it is essential to carry out a risk assessment and consistently understand the risks and hazards present in each task performed by workers. This work will carry out a risk assessment based on the risks and hazards of each task and study its results. After understanding the construction process, all hazards and risks were identified through field observations and interviews with workers and site managers. Then, the Preliminary Risk Analysis methodologies were applied, Failure, Mode and Effects Analysis and Fault Tree Analysis. Where the FMEA and FTA methodologies present parameters for calculating the level of risk that were duly simulated and tabulated for a better interpretation of the risks. The sub-processes, execution of the slab, walls, pillars, and beams, were divided into 6 tasks, where 96 risks of 35 hazards were identified. The PRA methodology did not analytically define the concentration and the maximum and minimum risks but presents in detail each of the 96 risks observed in the work. For FMEA, risk ranking showed that falls from height risks are maximum value of criticality, and median risks are material drop, crushing and, trapping. For the FTA, the results responded to the simulation of the assumptions within the risk levels, tending as a probability of occurrence with a high percentage for falls from heights, perforation and effective ergonomics, fire and electrification, as well as material falls and burns in 23%, 23%, 28%, 49%, 49%, 50% and 50%, respectively. The divergence in the results of the three methods applied in this study can be justified by means of behaviours guided by the matrix of possibilities that each risk presents showing a correlation of 0.75 and not being homogeneous, being distributed in 3 groups of extreme risk. Another justification is the fact that all methods have different parameters and application forms, despite having the same purpose.

Keywords: risk analysis; construction work; fault tree analysis; failure modes and effects analysis; preliminary risk analysis; safety at work.

RESUMO
O sector da construção civil é considerado um dos sectores mais perigosos do mundo. Assim, há necessidade de uma gestão consistente dos riscos para compreender os riscos e apresentar planos de controlo com medidas eficazes para os minimizar. Para alcançar estes resultados, é essencial realizar uma avaliação dos riscos e compreender consistentemente os riscos e perigos presentes em cada tarefa desempenhada pelos trabalhadores. Este trabalho realizará uma avaliação de riscos baseada nos riscos e perigos de cada tarefa e estudará os seus resultados. Após a compreensão do processo de construção, todos os perigos e riscos foram identificados através de observações de campo e entrevistas com trabalhadores e gestores de obra. Depois, foram aplicadas as metodologias de Análise Preliminar de Riscos, Análise de Falhas, Modos e Efeitos e Análise de Árvore de Falhas. Onde as metodologias FMEA e FTA apresentam parâmetros para o cálculo do nível de risco que foram devidamente simulados e tabelados para uma melhor interpretação dos riscos. Os subprocessos, execução da laje, paredes, pilares e vigas, foram divididos em 6 tarefas, onde foram identificados 96 riscos de 35 perigos. A metodologia PRA não definiu analiticamente a concentração e os riscos máximos e mínimos, mas apresenta em detalhe cada um dos 96 riscos observados no trabalho. Para a FMEA, a classificação dos riscos mostrou que os riscos de queda de altura são os máximos críticos, e os riscos medianos são queda de material, esmagamento e, armadilhagem. Para o FTA, os resultados responderam à simulação dos pressupostos dentro dos níveis de risco, tendendo como uma probabilidade de ocorrência com uma elevada percentagem para quedas de altura, perfuração e ergonomia eficaz, fogo e eletrificação, bem como quedas e queimaduras materiais em 23%, 23%, 28%, 49%, 49%, 50% e 50%, respectivamente. A divergência nos resultados dos três métodos aplicados neste estudo pode ser justificada através de comportamentos guiados pela matriz de possibilidades que cada risco apresenta mostrando uma correlação de 0,75 e não sendo homogéneo, estando distribuído em 3 grupos de risco extremo. Outra justificação é o facto de todos os métodos terem parâmetros e formas de aplicação diferentes, apesar de terem o mesmo objectivo.

Palavras-chave: análise de risco; trabalho de construção; Análise de árvore de falhas; modos de falha e análise de efeitos; análise preliminar de risco; segurança no trabalho.

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LIST OF SYMBOLS AND ABBREVIATIONS

ax - Gamma Law shape parameter

Cr - Criticality

D - Detectability

FE - Feared event

FMEA - Failure Modes and Effects Assessment

FTA - Fault Tree Analysis

ISO - International Standardization Organization

mp - Most likely probability value in Beta 1 law

mx - Gamma Law scaling parameter

my - Minimum value that probability can assume in Beta Law 1

O - Occurrence

PRA – Preliminary Risk Analysis

P – Probability

PPE – Personal Protective Equipment

pinf – Minimum value that probability can assume in Beta Law 1

psup - Maximum value that probability can assume in Beta Law 1

R – Risk

R^2 – Coefficient correlation

S or **G** - Severity

vp inf –Lower bound of the probability in Beta Law 1

vp sup - Upper bound of the probability in Beta Law 1

vx – Gamma Law variance parameter

Threshold - Parameter describing the minimum level of damage that must occur before the failure event occurs

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CHAPTER 1: INTRODUCTION

1.1. Context

The sharp growth of civil construction, verified in recent years across the country, has been accompanied by an increase in the number of work accidents and worker deaths, mainly due to burial, fall or electric shock, which demands systematic planning of all processes and resources of a work, from the qualification of the worker to the maintenance of the equipment.

The rate of reported accidents that occur is extremely high showing that care for the protection of the health and well-being of the worker. Mozambique is not excluded from this statistic having had more serious accidents at work that were recorded in the Civil Construction Sector, totaling 1,136 cases, out of a universe of 4,084 across the country according to the 2016 annual report of the Ministry of Labor in Mozambique.

As much as it is a source of employment and income, the construction sector is still highlighted about accidents and occupational diseases the great variety of activities and materials present in a work, allied to an unsafe work environment, together with the low qualification of professionals and the low investment in health and safety at work, confirms the variety of risks present in that sector and consequence the high occurrence of accidents and occupational diseases.

According to Bezerra (2015), the work present on a construction site already defines a risk to the health and safety of the worker, these are intensified by the form of execution by part of the employee, who only follows verbal instructions given by those responsible construction technicians, or in unstable situations, in which they make decisions to carry out self-authored activities.

In the construction sector, work can be considered high risk, considering the exposure of workers in activities of constant danger. To maintain a normalization of service, the inspection bodies exercise their role in the area constantly, aiming at the execution of the work to guarantee the safety of the worker (Silva Junior & Cambrais, 2013).

The risks faced by workers in this branch of construction civil society, the importance of applying systems, methodologies and learning relating to work safety, so that it can guarantee the integrity of the employee and the employer. In addition, it is necessary to raise awareness and education of these, being of great importance of risk management and training in security techniques. Risk management must be a central element, as it is a process that analyzes the specific risks to the respective activities, to have a good risk management fundamental is in the identification and treatment of them. Therefore, it must be guaranteed reduction to the danger of workers and third parties, all dangers being identified, evaluated, and taken thenecessary preventive measures (Guilherme, 2015).

Managers, in turn, must ensure the health of their workers, in addition to making them aware of safety in the processes and alert about the importance of their lacking the productive area, interfering in the socioeconomic life of the worker, and causing negative effects on the company's corporate image. Risk analysis is a methodology that can be used for work safety, is responsible for identifying the risks present in the environment, so that they can be analyzed and, according to the results, measures are adopted that can guarantee safety and prevent future accidents (Nascimento & Nunes, 2018).

In this sense, the present project aims to analyze three potential risk methods and their suitability and application to the construction industry, namely and Preliminary Risk Analysis (PRA), Failure Modes and Effects Analysis (FMEA) and, Fault Tree Analysis (FTA), as Risk analysis, at the company in the company Constutora do Messalo, Lda, the construction site located in Possulane neighborhood, Marracuene district, Maputo Province.

1.2. Problem Identification

Bearing in mind that the correct and effective implementation of adequate methods of Health and Safety risk analysis in a medium-sized company is necessary to reduce the number of accidents, proposing prevention measures consistent with the reality of the civil construction industry, to this is essential to minimize accidents and consequently to preserve the integrity of workers' health, and thus reduce the number of expenses resulting from accidents, resulting in productivity gains by providing a safer environment for its employees.

With this investigation project, it is intended to study the risks involved in carrying out works during the construction of the water supply system of the case under study and to propose preventive measures for them, which is fundamental to minimize accidents and consequently for the preservation of the integrity of the workers' health.

The accident risk assessment becomes efficient for the reduction of risks and dangers of each task/activity employed in the company Constutora do Messalo, Lda. Therefore, the following research questions arise:

1. What and how are the risks, risks levels and consequences that can be assessed at the construction in case of study?
2. How to control in case these risks occur during the construction process?
3. Why are the measures being necessary to mitigate the consequences of these deficiencies after they occur?

1.3. Project Justification

Performing good adverse event analysis makes it possible to understand risks, solve problems and protect people. Thus, investigating the risks involved during the construction under study and proposing preventive measures for these is fundamental for the minimization of accidents and consequently for the preservation of the health integrity of workers.

The analysis and risk assessment in the industry today play a key role in companies allowing a better performance of their workers, as it detects the risks and manages to prevent and protect these workers from accidents and illnesses, as well as to promote equipment efficiency. When passing from one developed country to a developing country, such as Mozambique, there is a big difference in this matter.

The project focuses on the medium construction industry, with the particularity of constraints and natural difficulties of companies operating in African countries, which substantiated the need to develop this work. The study, carried out at the company Contrutora do Messalo, Lda concerns the analysis and risk assessment in the construction of a water supply system, in Possulane neighborhood, Province of Maputo.

This project also has a social interest in promoting water distribution, ensuring 24/7 unrestricted water supply in the neighborhood.

1.4. Objective of the project:

1.4.1. Main objective:

Analyze the risks using the PRA, FMEA and FTA methods, covering all the tasks involved in the execution of the construction work of the water supply system, of the case of study belonging to the company Construtora do Messalo, Lda.

1.4.2. Specific objectives:

- Characterize the activities and tasks in construction.
- Identify critical components and trigger events associated with the identified tasks.
- Propose an adequate risk analysis tool for the work under study, together with preventive and protective measures will be indicated to establish safety in activities in this sector.

CHAPTER 2: LITERATURE REVIEW

2.1. Risk Management

Organizations in any industry face a variety of risks in achieving business goals. These goals can be related from strategic initiatives to its operations, that is, all activities of an organization present risks that must be managed (ISO 3100, 2009).

Risk assessment is an important tool used to assess an organization's occupational risks so that appropriate decisions can be made to prevent or mitigate and effectively manage the risks to an acceptable level. Using a consistent assessment process allows an organization to understand risk levels, compare those risks, and address those at greatest risk first (Popov et al., 2016).

As shown in Figure 1, the risk assessment or risk assessment is composed of 3 steps, namely:

- Risk identification: Finding, recognizing and recording risk;
- Risk analysis: Perception of consequences and probabilities and existing controls;
- Risk evaluation: Confront risk levels and consider additional controls.

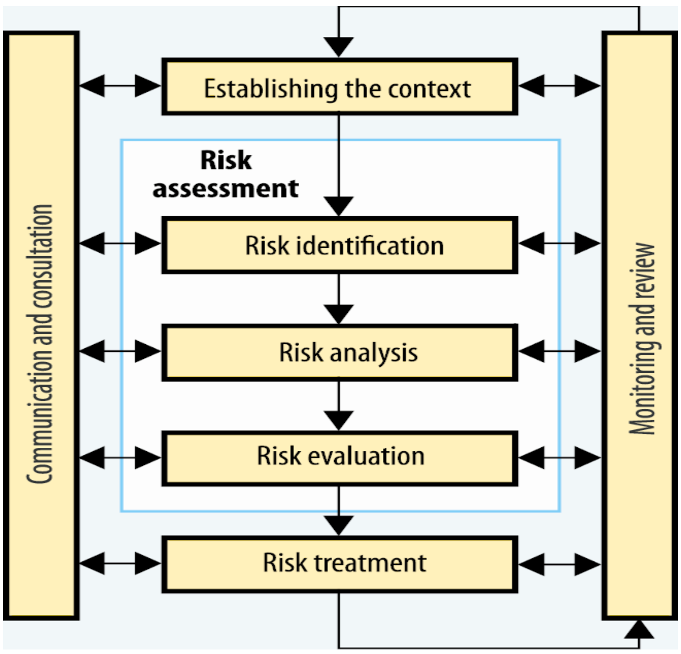


Figure 1. Risk management process Adapted from ISO 31000 (2009)

2.1.1. Risk identification

The hazard is the source of the risk, so if the risk is to be assessed the hazard must be identified first. The purpose of risk identification is to find, recognize and record the risk. The key component of this step is the identification of the causes and source of risk events, situations or circumstances, which may affect the achievement of the organization's objectives. Once identified, it must be verified that controls exist for the risk (ISO 31000, 2009).

There are numerous techniques for identifying hazards, but a systematic approach is likely to be complete and more reliable (Popov et al., 2016). Some of the most common methods and sources for identifying hazards are listed below:

- Brainstorming;
- Check list;
- Regulations (OSHA, EPA, DOT, etc.);
- Job Hazard Analysis (JHA) / Job Safety Analysis (JSA);
- Accident/incident investigation.

Identification of exposed persons

The risk estimation (subsequent phase) provides knowledge, objective or subjective, of the Severity or Severity that a certain damage can assume, as well as the Probability of its occurrence.

This probability of occurrence will depend on:

- The type of people exposed, i.e., depending on the level of training, awareness, experience, individual susceptibility, etc., the probability of suffering a certain level of harm will differ;
- Frequency of exposure.

When the assessment is aimed at social risk, the severity or severity will depend on the number of people who may suffer a certain level of harm.

It is always important to consider all people who may be exposed, that is, not only workers directly assigned to the job in question, but also all other workers in the workspace. Importantly, it is also important to consider those that may not always be present.

2.1.2. Risk analysis

After the hazards have been identified, this is the step for the assessment of potential risks where risk understanding is required. The analysis for each risk/hazard found includes:

- Determining the severity of consequences;
- Estimation of the probability of occurrence;
- Assessment of the efficiency of existing controls;

• Estimation of the level of risk.

The estimation of risk consists of quantifying the magnitude of the risk, that is, its criticality.

Roxo, 2003 stated that the magnitude of the risk is a function of the probability of occurrence of a given damage and the severity associated with it, represented by the equation (Eq.1):

$$Risk\ (R) = \ Probability\ (P) x\ Severity\ (G) \qquad (1)$$

In estimating each of the variables (P) and (G), the safety measures already implemented must be considered (e.g., fire detection and fighting systems, safety protection in certain equipment, safety procedures associated with carrying out of a certain task, among others), since these will interfere in the magnitude of the risk.

2.2.Risk Analysis Methods

Over time, numerous methods have been created, developed, and improved with the capacity to identify the hazards existing in the workplace and carry out a rational analysis of the consequences of the associated risks, as well as the possible reductions of the damages, through the adoption of different measures of control.

These methods can be integrated into different categories according to their specific characteristics, the objectives for which they were developed, the means used and the factors they relate to. As an example, depending on the relative importance of each of its risk “identification” and “quantification” components, it is customary to distinguish them as qualitative methods, quantitative methods, and semi-quantitative methods. We move on to a brief description of each of these categories.

Qualitative methods

They describe or outline, without reaching a quantification of the risks, the dangerous points of a workstation or installation, as well as the available safety measures, whether preventive or corrective. They also identify which events are capable and likely to generate dangerous situations, as well as trigger measures to ensure that they do not occur. The level of security is normally determined based on the compliance of the installation processes and procedures with applicable safety standards and regulations.

Quantitative methods

Quantitative assessments involve objective quantification of the different elements of risk, namely the Probability and Severity of consequences.

These are methods that aim to obtain a numerical answer on the magnitude of the risk, so the probability calculation makes use of sophisticated calculation techniques that integrate data on the behavior of the variables under analysis. They allow determining a pattern of regularity in the frequency of certain events. The quantification of gravity uses mathematical models of consequences, to simulate the field of action of a given aggressive agent and the calculation of the aggressive capacity in each of the points of that field of action, then estimating the expected damages (Roxo, 2003).

2.2.1. Preliminary Risk Analysis - PRA

It is a tool of qualitative risk assessment that precedes the performance of a task. The objective is to identify hazards, analyze risks and establish control measures in order to avoid possible accidents. The PRA can be used in the evaluation and general review of the security in systems that are already in operation, revealing aspects that may not have been considered during the design phase, which can bring large budget losses for companies and organizations. (Maia, 2014).

For the development of an PRA, the following steps must be performed (Decicco and Fantazinni, 2003; Lima, 2019):

– The search for analogies or similarities with other systems to apply in the project being developed;
– Pay attention to objectives, performance requirements, main functions and procedures and demarcation of the operating environment;
– Indicate risks with the potential to cause immediate direct injury, loss of of function, damage to equipment and loss of materials;
– Research possible means of eliminating and controlling risks, in order to establish the best options compatible with the system requirements;
– Find the most efficient possible methods for limiting damage generated by the loss of control over the risks;
– Indicate those responsible for carrying out preventive and/or corrective actions, as well as designating the activities to be developed.

PRA's are mainly developed using tables and charts that do not have a specific standard. The development of an PRA usually follows tables or tables, using the causes and effects of each risk corresponding to a specific service of the construction site, so that the later can report the measures of protection and categorization of risks so that actions are prioritized. After identification of the degree of risk in each situation in the preliminary analysis, they can be categorized and define the severity and frequency of occurrence of these risks to the worker (Maia, 2014).

2.2.2. Failure Mode and Effects Analysis - FMEA

Consists of an inductive tool with the objective of identifying and analyzing potential failures that may occur in a certain equipment, product or process and determining their causes and their effects on its operation (Sobral et al, 2013). This methodology can be used to define the best actions to take to identify, prevent and correct potential failures, problems and errors of a system, project, or product before it reaches the consumer (Stamatis, 2003).

Defects during initial production and in global volume:

- Complaints from users/consumers.
- Line failures.
- Problems during the warranty period.

The FMEA can present four typologies: System; of Product or Project; of Process and Service. On the other hand, other authors divide the FMEA into only three types: System, Product and Process. Despite this, with the development of FMEA applications, the number of classifications of the same was basically restricted to two types: Product and Process (Stamatis, 2003).

The FMEA product, or sometimes also called Project, seeks to analyze a product before its production begins, or also sometimes analyze it throughout its useful life, as is the case of specific machines, tools, or components. This focuses on product/design failure modes that are caused by poor material selection, inadequate specifications, or other types of design deficiencies that can lead to problems in the final product.

While it is up to the FMEA process to focus on the process, be it manufacturing, assembly or other purpose. Analyzing the process as a whole or just certain tasks/steps, it seeks to identify possible failure modes that result from, for example, defects arising from assembly or fluctuations during production.

2.2.3. Fault Tree Analysis – FTA

In Mannan (2005) it is possible to note that a Fault Tree is used to know the causes of an event. It begins with the event to be studied, which could be a dangerous situation or an equipment failure, for example. From there, the event develops from the top of the tree down. The Fault Tree is a technique both qualitatively and quantitatively. It is used qualitatively to identify possible paths that can lead to the top event. Its use quantitatively is through the possibility of estimating the frequency, or probability of the top event occuring.

The Fault Tree method can be used as a complement to other methods that aim to identify hazards. Furthermore, it can be used in project development that require high reliability - nuclear power plants, for example - as multiple layers of protection are required to be built into its construction.

The choice of the FTA tool is because it provides professionals and researchers with a means to determine or give access to the risk of the process or product and to know in detail how the system under study works.

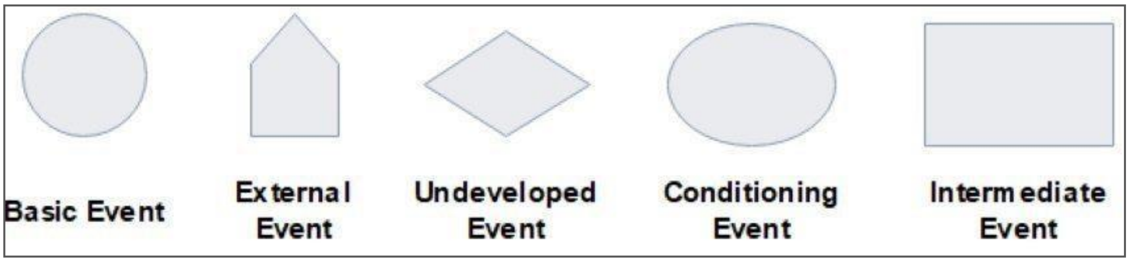


Figure 2. Symbols used in Fault Tree

CHAPTER 3: METHODOLOGY

3.1. Research Materials and Methods

The research methodology followed in this study, in terms of technical procedure, was extensive direct observation, which involved a survey of data, through interviews, applied to a sample of workers at the service of the organization studied and distributed by different functions and hierarchical levels.

The use of the questionnaire allows a quantitative approach, through the quantification of the opinions of the individuals that make up the sample. As to its nature, this investigation can be classified as an applied investigation, as it is a case study, with academics. It is also cross-sectional research as the data collection was limited to a short and given space of time (Stake, 2007).

To meet the objectives of this work, direct methods of exploratory were used. For the development, photographic records and bibliographic references were used to provide foundation to the object of study, in addition to the main study tools, namely PRA, FMEA, and FTA. The methodology for carrying out the risk assessment is summarized in the flowchart presented by Figure 3:

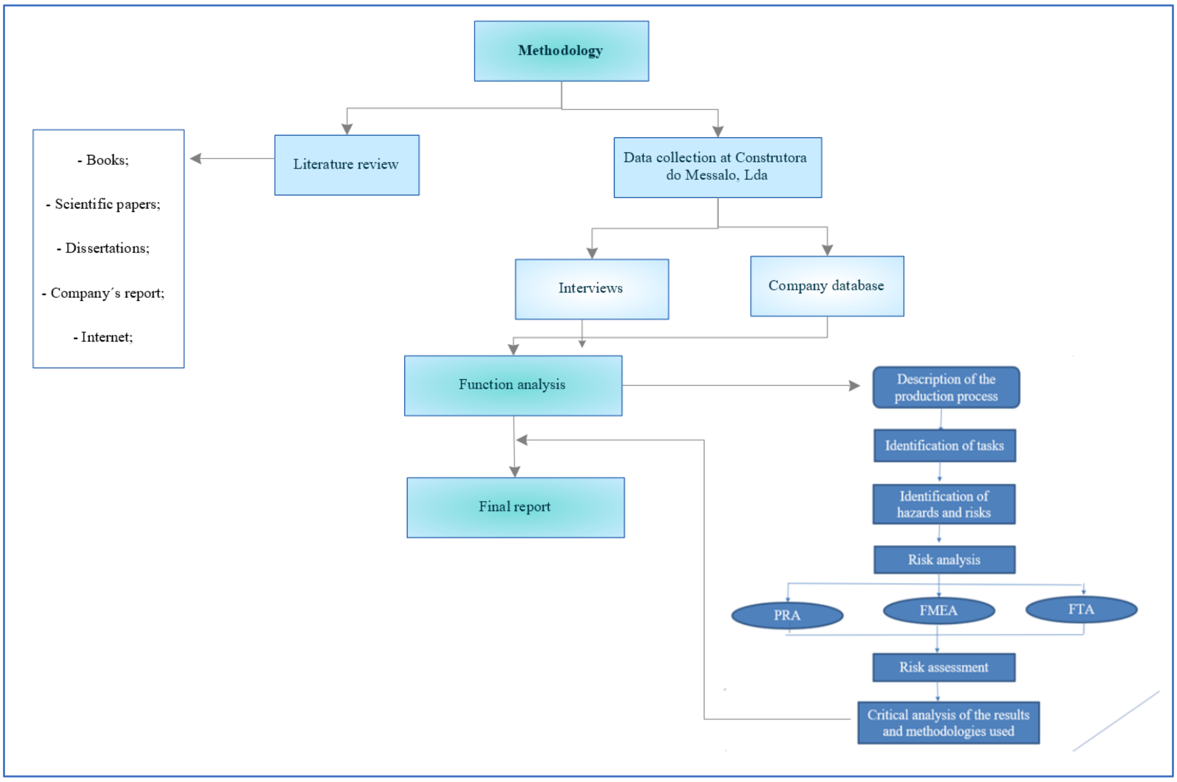


Figure 3. Flowchart of the methodology used

3.2. Literature review

In search of literary information, bibliographical and documental research was carried out, through books, dissertations, scientific papers, and reports from the company itself, on standards, concepts and data of probability and frequency of the feared events, bibliographic review was part of the process in all steps until the compilation of the final report.

3.3. Description of the production process

The area under study is a civil construction work for a water supply system (see Figure 4). The work is in Possulane neighborhood, Marracuene district, Maputo Province. The construction has a wide structure for the high deposit, with height average total of 18 meters and about 20 professionals directly connected with construction activities, regular concreting and at different heights (tower) and scaffolding for the execution of coverings for the manager's house, semi buried deposit and tower.

Figure 4. Construction of the case under study

Source: Own Authorship, 2022

Based on observations and work instructions in a traditional and recoverable way, the constructive methodology used for the execution of pillars, beams, walls, and slabs will be described.

Execution of Slabs

The construction of the floor slab for the manager's house, raised storage and semi-underground storage starts with the formwork. The system used to formwork the slab consists of plywood-coated wooden sheets for the water reservoir in the tower, as well as for the semi-underground storage (see Figure 5) and plywood-coated aluminum sheets for the administrator's house (see Figure 6).

The assembly of the plates which are operated by 4 workers. One of the workers must position himself at the top to receive the loading of the sheets, pick up and fit the lower part, while the others must position themselves at the bottom floor and 1 worker holds the panel with the aid of an open wooden frame support.

Figure 6 also shows the finished slab formwork with its plates and struts in place, the last stage of the formwork is the application of a release oil so that the concrete does not stick strongly to the surface of the formwork with the aid of a squeegee.

Figure 5. Water tower box and manager house slab formwork

Figure 6. Bottom view of the assembled slab formwork

Next, the in-situ assembly of the frames is carried out, as shown in Figure 7. As shown in Figure 8, the blocks are placed to guarantee the minimum distance between the frame and the formwork face. The frame is placed above the blocks, and the connections are made to the beams, walls, and pillars, complying with the stability plans to the letter which these are interconnected with the aid of an iron wire. After the slab frame finished then it needed to carry out the concreting.

Figure 7. Elevated deposit box slab frame

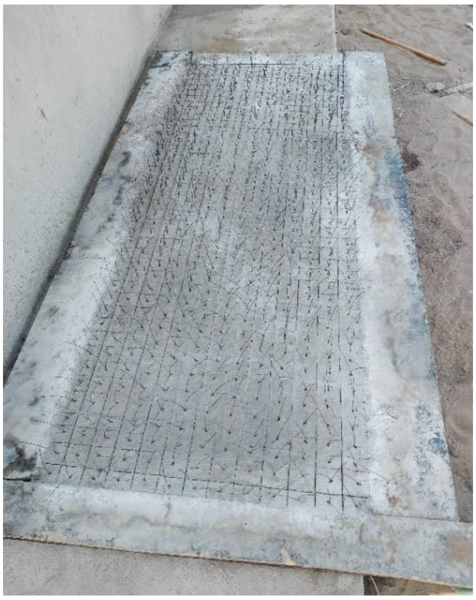


Figure 8. Blocks used as formwork spacers

The concreting starts with the reception and transfer of rotating buckets loaded by the workers with the concrete. Then the concrete is cast onto the slab. The task of concreting is carried out by approximately 15 workers. The one responsible for placing and controlling the material is released on the slab, the other for keeping the vibrator in contact with the concrete to avoid bubbles and the third for levelling the concrete with the aid of a ruler. Figure 9 shows the partially concreted slab in a front and top view, respectively.

Figure 9. Top view of partial concreting of the slab of the manager's house

Execution of Walls

The execution of the walls of the water tank (where the water will be stored) essentially begins with the assembly of its armature, which begins to be prepared in the shipyard reserved for its assembly. However, normally its execution always ends in the area where it will be concreted and where the connection with the adjacent elements must be made.

With the aid of a fixed pulley, the reinforcement is positioned against one of the faces of the formwork assembled and anchored to the slab, as shown in Figure 10.

Figure 10. Frame and positioning of the mesh of the semi-buried deposit

Concreting of the walls is carried out with the aid of a bucket for discharging concrete, as shown in Figure 10. After concreting and its rest time, about 15 days, the formwork is removed. All parts of the formwork are removed by the workers (always wearing a safety belt) and the result of the wall is shown in Figure 11.

Figure 11. Concreting of the water tower box with the aid of buckets

Figure 82. Unformed water tower box

Execution of Pillars

The execution of the pillars begins with the preparation of the reinforcement around the shipyard reserved for its prefabrication. This task is carried out by two workers as shown in Figure 13. Next, it is necessary to draw the alignments where the pillar will be implemented. In the implantation area, with the aid of the fixed pulley, the loading is carried out to the foreseen place and the union is made with the stars. It should check that the spacers (a piece that prevents the reinforcement from encountering the formwork and which guarantees a minimum covering of concrete between the steel and the formwork) have already been applied.

Figure 13. Junction between frame and iron wire, and formwork of water tower pillars

Concreting is carried out using the bucket for discharging concrete, which is loaded by the workers, as shown in Figure 14. This is lifted and held, and a worker must help with the concreting on top of the work platform.

Figure 14. Concreting carried out by the bucket for discharging concrete

Execution Beams

The execution of the reinforcement of the beam is normally carried out in a similar way to that of the column around the site reserved for its assembly. However, this must be connected to the other elements (pillars, slab, and adjacent beams) in the place where it will be concreted, as shown in Figure 15.

Figure 15. Water tower beam frame and formwork

At some points in the construction, it is necessary to make cuts in the wooden panels to shape the lower formwork of the beam and guarantee the continuity of the concrete between it and the adjacent vertical elements, usually pillars.

The concreting of the beams is carried out after the concreting of the pillars and subsequently the pillar after that and so on, so the process described above is the same. Finishing the execution with the formwork phase by phase, leaving it to dry before proceeding to the next concreting.

3.4. Identification of parameters for risk analysis

The following step shows the description and understanding of the subprocesses divided into tasks to facilitate carrying out a risk analysis. The criteria used for this separation was the work cycle and accidents that can occur in any task, that is, general. So, the subprocesses were divided as:

- Frame
- Concreting
- Formwork
- Formwork removal
- General
- Cargo handling (ergonomics)

Then, the risk situations were verified through observations at the construction site and dialogue with workers and site managers. All the knowledge acquired in this step was placed in a table in the Excel tool for its detailing, it is presented in the Appendix B.

Note that the triggering event field is the area responsible for describing the factors that, if they occur simultaneously, result in the occurrence of the accident. In the observation field, all the details relevant to the event were filled in, such as the duration of the task.

Furthermore, all the necessary parameters for carrying out the risk analyzes were defined.

3.5. Data collection and evaluation

3.5.1. Preliminary Risk Analysis (PRA)

During the execution of the work, the data collected and photographed in loco were organized using the 3 tools of this study. First, it prepares the PRA using according to the model shown in Table 1 and analyzing the images of the construction site and using collected data, a PRA's was developed for the structural phase.

According the pre-survey of activities in the PRA's, a survey of hazards according to the rating of risk for each situation encountered.

Subsequently, some corrective and preventive measures were proposed so that it coul minimize the possible risks of accidents encountered, providing improvements in health and protection to the employee, avoiding occupational diseases and significantly reducing the probability of work accidents.

Table 1. Standard PRA Worksheet

Reference	Subprocess	Tasks	hazard	Triggering Event	Comments	Risks	Consequence	Control measures (to be implemented)

Source: Own Authorship, 2022

In the first column of Table 1, has the objective of identify which phase of the work's development the PRA is being applied. In the column "Subprocess" and "Tasks" is detailed what activities are being performed. The "Triggering Event" and "Hazard" shows what are the collaborators that are exposed during this phase of the work.

In the category "Risks" it is based on the intensity of risks to which workers are exposed. The order of risks represents the severity and probability of the risk, that is, the higher the degree, the more serious the consequences, for example, grade is the classification for more dangerous activities, that can cause accidents and serious illnesses and even death of the worker.

The "Control measures" highlights the acts and practices carried out to combat the risks present in the activity in question, describing a set of tasks which aims to reduce or eliminate the rich and the possible accidents and illnesses occupational hazards generated by this activity.

3.5.2. Failure, Mode, Effects Analysis (FMEA)

The FMEA methodology is important to verify the potential failures, effects, and processes to determine actions that tend to reduce or eliminate each risk added to each failure (Puente et al., 2002).

From the situations observed in the place under study, five processes were listed within the execution of the work for the application of the FMEA: use of the concrete mixer; use of scaffolding; execution of slabs; use of PPE and organization of the construction site.

The Risk Rating is based on a numerical scale from 1 to up 5 to assess the intensity of risks to which workers are exposed, as can be seen in Table 2.

Table 2. Risk Rating Table

Total Score	Risk Rating
0	Without risk
1	Low risk
2-4	Medium risk
5	High risk

Source: Adopted from Puente et al., 2001

In the FMEA model applied is in Table 3 (bellow), with 5 processes that were studied in relation to the causes of failure, effects, means of detection and corrective actions; and each failure recommended actions, at the end.

Table 3. FMEA model worksheet

Process	Function	Failure Mode	Failure Causes	Failure Effects	Severity (S)	Occurence (O)	Detectability (D)	Criticality S*O*D	Recommended Action(s)

Source: asq.org, 2022

During the execution of the work, the data collected and photographed in loco were organized using the 3 tools of this study.

After the survey of the identification of the failure modes and definition of the severity (S), occurrence (O) and detectability (D), the criticality (Cr) was calculated using Equation 2 bellow:

$$Criticality = Severity\ x\ Occurrence\ x\ Detectability \qquad (2)$$

The tables of the severity, occurrence, and detectability classification levels used to categorize the case study and conduct the FMEA can be found below:

Table 4. Severity Level

Severity (S)		
Level	**Signification**	**Contextualized explanation**
1	Without consequence	No impact in any equipment or man who uses
2	Low severity	Noticeable impact in the operator/ equipment
3	Medium severity	Permanent effects of accident
4	High severity	Several accident
5	Catastrophic	Risk of death

Table 5. Occurrence Level

Occurrence (O)		
Level	**Signification**	**Contextualized explanation**
1	Exceptional	Failure was never noted
2	Very rare	Failure seen only once or twice relevantly on the operate conditions
3	Rare	The potential for failure has been noted during the construction on several operator/equipment
4	Frequent	Several process of construction (20%) present Failures
5	Very frequent	The potential for failure was noted during the constructions (45%)

Table 6. Detectability Level

Detectability (D)		
Level	**Signification**	**Contextualized explanation**
1	Total	Detectable failure
2	High	Low detectable failure
3	Low	Ability to detect the failure
4	None	No ability to detect the failure

3.5.3. Fault Tree Analysis (FTA)

The FTA approach will bring an approach in relation to work at height and occupational risks to which the employee is subject depending on each activity, always considering the bibliography referenced in the theoretical explanation. The simulation was develop using Microsoft Excel.

The worksheet will show all the root causes previously determined of the feared event (FE). Thus, allowing to have a global view of all the variables, which are used in the calculations for the Beta 1 Law and Gamma Law following the assumption of the study (*ax, bx, mx, vx, vpinf, vpsup, psinf, psup, threshold*).

Then, a table was created to simulate the probability of each primary cause (Level 4) toensure the quality of statistical results with 1000 simulations that was performed.

Beta 1 Law

The standard form of the probability distribution is expressed as follows:

$$fx\ (X) = \frac{\gamma(p+q)}{\gamma(p)p\gamma(q)} + x^{p-1}\ (1 - X)X^{q-1} \quad (3)$$

$$\text{With } X \geq 0, \quad \gamma(a) = \int_0^\infty e^{-u}u^{a-1}du \quad (4)$$

The mathematical function in this law is defined between two limits a_X and b_X and which depends on two form factors p and q. With $a_X < b_X$, p and q between higher than *0*, $a_X < m_X < b_X$.

The parameters p and q are related to the main identifiers of the random variable X (m_X; σ_X; β1; β2).

Gamma Law

For this law, the probability distribution is:

$$fx\ (X) = \frac{\alpha}{\gamma} x^{p-1}\ e^{-ax}$$

(5)

$$\gamma(a) = \int_0^\infty e^{-u}u^{a-1}du \quad (6)$$

It had a confidence level of 90%.

CHAPTER 4: RESULTS AND DISCUSSION

4.1.The system: Water supply construction work

The system for water supply construction work must be considered and be designed to ensure the proper execution of infrastructures (execution of slabs, walls, pillars, and beams), while adhering to construction standards and the project design. It is critical in this system to select the proper analysis methods to evaluate risks and control the quality of the data used and the methodology used in this construction.

Failure can occur because of the execution of the above-mentioned tasks or as a failure in the methodology of field monitoring and quality reports of the risks identified. Failure in this system can have an impact on the environment, which is made up of the government, society, and ecosystem, and each of those elements of the environment, if not related as well as possible, can have a negative impact on the process and the achievement of the goal. The diagram of the defined system is shown in the Figure 16 below.

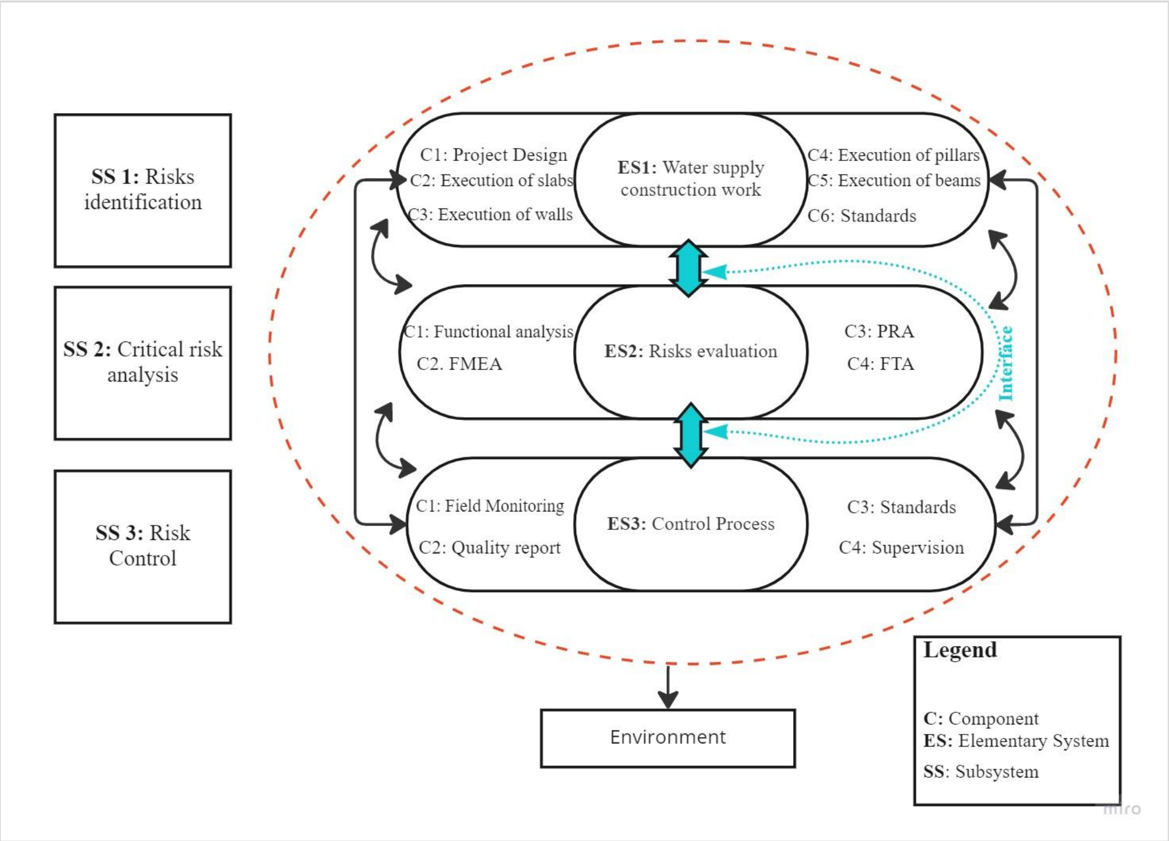


Figure 16. Water supply construction work system

4.2.Functional analysis

A functional analysis is a method for analysing and prioritizing a product's functions. They will then be analysed to determine how best to respond to the production and commercialization cycles. The procedure is usually carried out as a project and can be used to create or improve a product or process.

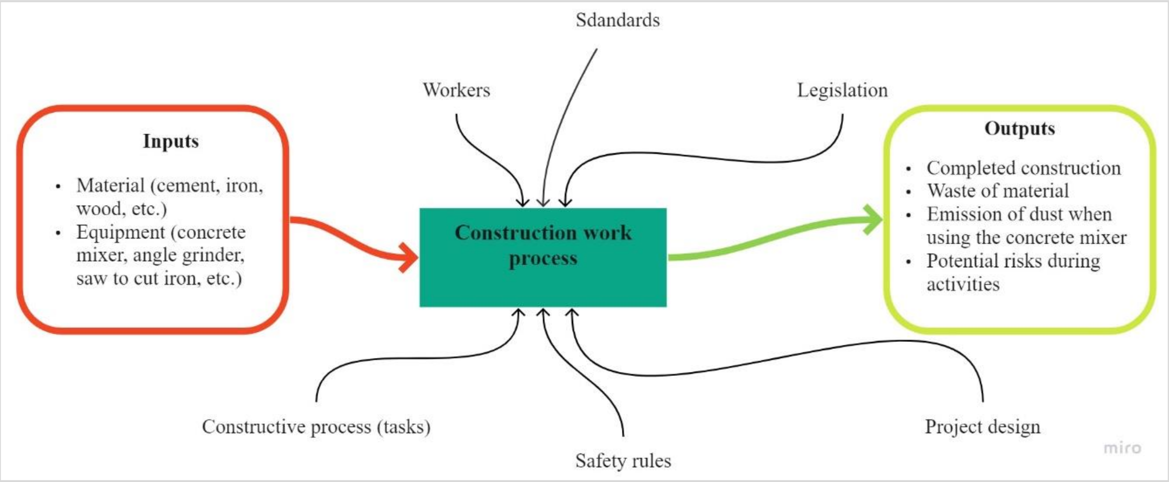


Figure 17. Functional analysis diagram of the construction process of the water supply under study

The inputs are the materials and equipment used to complete the work. These are required for the water supply system's construction and correspond to the basic tools transformed during the construction process. They represent both the means of implementation and the constraints to which entrants must adhere.

The outputs of the construction process, and thus of the action of the factors described above, represent the completion of the construction and potential public opening of the service, as well as the various emissions generated by the concreting process of the cement used in its construction.

4.3. Identified risks and hazards

There were 13 types of risks identified from 35 hazards. A complete list of all risks and hazards is available in Appendix A. The Figure 18 depicts all the risks discovered and their numbers within each sub-process.

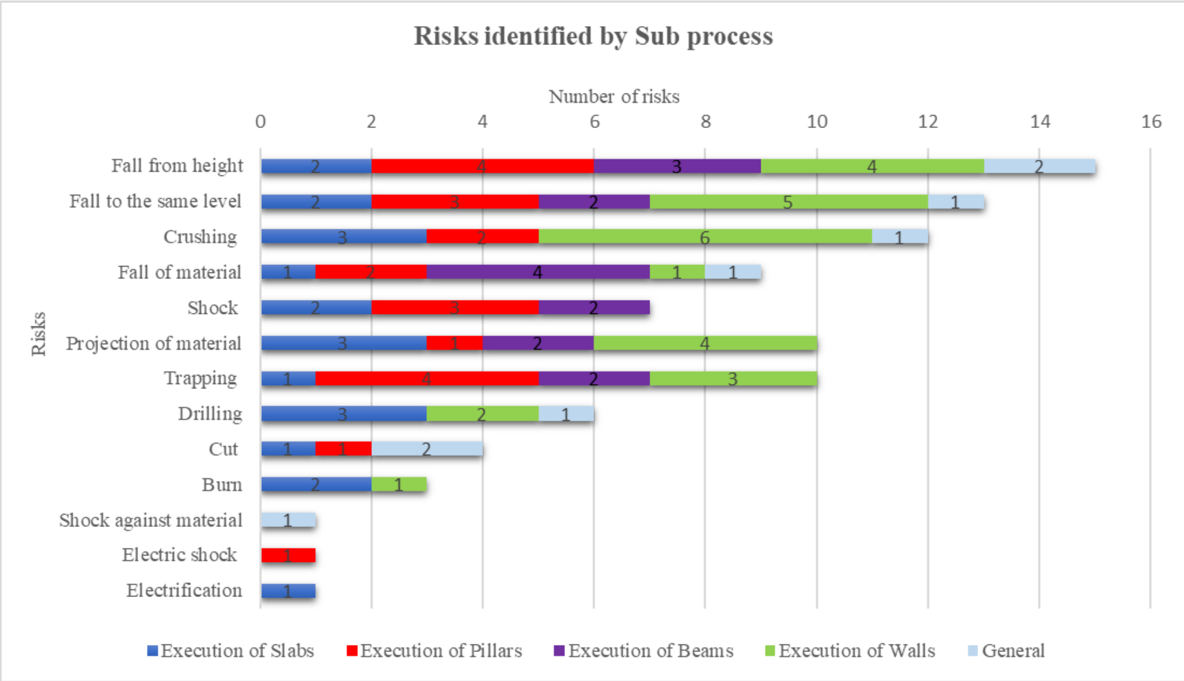


Figure 18. Types of risks and their quantity by Sub-process

The most common risks were noted to be falling from a height, falling at the same level, and crushing. Because the work involves the construction of a residential tower, the risk of falling from great heights was expected to have the greatest impact in terms of numbers.

The second risk, falling to the same level on the construction site, demonstrated the significance of workers' attention and work organization.

4.4. Risk analysis

4.4.1. Preliminary risk analysis (PRA)

The preliminary risk analysis is a technique for detecting and assessing hazards, as well as their causes, effects, and severity. The aim of this analysis is to determine the methods and appropriate responses to prevent or reduce risky situations.

Hazards from crushing, falling objects, and shock were also anticipated in significant numbers. Since many jobs require working at heights, there is a high scaffolding on the tower for the transfer of materials and support for employees, therefore there is a considerable risk of a fall or impact from a load when workers are present.

Another crucial circumstance involving the fall of material is that the structure lacks complete lateral protection and merely has guardrails, which greatly increases the risk of falling pieces of solidified concrete, wood, materials, etc.

Table 7 presents this situation where it is possible to observe fragments of materials on the

Table 7. Example of objects falling from the scaffolding

Ref.	Subprocess	Task	Hazard	Triggering Event	Comments	Risks	Consequences	Control Measures
92	General	General	Objects	Objects fall on workers who are at a lower level	Task duration: 9h with a 1h break * Length: 1 employee	Material drop	Excoriation	*Placement of protection; *Delimitation of a safety zone of 5m around the work;

floor, in the passage area and next to the building facade.

It is also noted that all these risks, which were identified in notable amounts, appear in practically all sub-processes, showing that they must be carefully evaluated to be able to implement adequate controls to mitigate or minimize them.

There is also the importance of making a thorough study to identify risks and dangers through the description of tasks. It can be seen from the preliminary risk assessment of the case under study, in Appendix B, that the assessment is generalized and does not specify equipment, substances or objects that are assessed as a risk in the tasks presented. Furthermore, it was possible to identify the events triggering the risk, what are the consequences for each risk presented, the number of workers exposed, resulting in a subjective assessment.

4.4.2. Failure, mode, effect analysis (FMEA)

Five procedures within the execution of the work for the use of FMEA were mentioned within the conditions noticed after the identification of risks and dangers during the tasks: execution of slabs, execution of pillars, execution of beams, execution of walls, and general. while carrying out the subsequent tasks: frame, concreting, formwork, formwork removal and cargo handling.

The processes were examined in connection to the reasons of the failure, effects, severity, occurrence, detectability, and corrective actions; each cause of the failure ultimately received criticality. This was done in the FMEA applied in the table of appendix C. The debate that was had at the table is as follows.

For execution of slabs, the chosen failure mode was frame, concreting, formwork, formwork removal and cargo handling. Based on these elements, all causes will have to be solved, however the projection of material in the movement of charges in the frame failure mode deserves immediate attention due to the average risk index criticality obtained of 45.

In the execution of the walls, there is a medium risk, crushing during the formwork removal, which is 48 as criticality, and may present as failure effects, leg fracture.

This happens because of when storing the panels in the yard, the worker does not stack them correctly, causing them to fall on another worker.

The execution of the pillars has a criticality of 64 for the formwork removal task, this in response to the worker positions himself in the wrong way to perform the Removal of formwork and has his hand wedged between the wall and formwork causing trapping, material projection, fall at the same level and having as failure effect shoulder injury, bruise and excoriation.

For execution of the beams, where it finds the highest risk rate, which reaches 100 criticalities if this danger occurs, which is during the implementation of the framework, with the risk of falling from a height, especially on work platforms, resulting in death as a failure effect. Others eminent risks are considered during the execution of concreting and formwork removal activities, with the risk of material projection. They present 60 and 48 of Cr, where they can be presented as failure effects partial visibility loss and bruise, respectively.

In general, crushing have the highest rate with 40 Criticality index, when the worker when using table saw does not remove his gloves, this catches the saw and breaks his finger.

All these observations can be seen in the table in Appendix C.

4.4.3. Fault tree analysis (FTA)

After defining the dreaded event using PRA, it was necessary determine the various events that could cause the main event to happen, looking for sub-events until concrete causes are obtained. In total, it determined 4 different levels, ranging from 0 to 4 (0 being the feared event and 4 being the level of main causes) for one Feared event nominated Accident during the construction of the water supply system (E0).

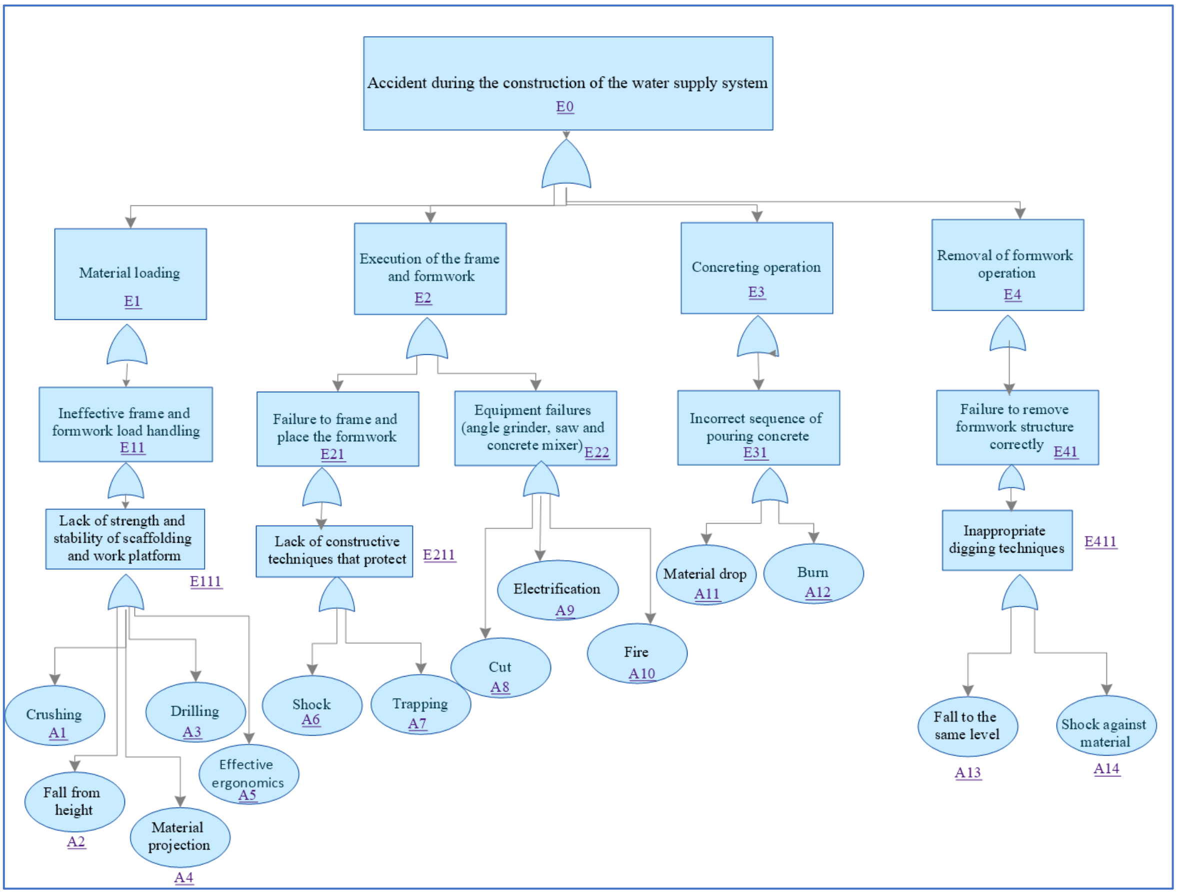


Figure 19. Fault tree analysis of the system

According to the identification of risks in the case under study, 35 hazards of 13 risks were found, which were analyzed and studied the 13 root causes of fault tree, having added fire of the 13 risks identified based on the case study. The latter, numbered from A1 to A14.

Below (Table 8) the assumed assumption for the causes with respective questions for the root cause factor and probability law.

Table 8. Assumption of the 14 root causes

Ref.	Root cause	Root cause factor	Probability law	Question
A1	Crushing	Human error	Beta 1	The probability of crushing by material drop is around 10%
A2	Fall from height	Human error	Beta 1	The average probability offall from height is 15%
A3	Drilling	Human error	Beta 1	The probability of drilling risks be less than 12% in 15 days
A4	Material projection	Human error	Beta 1	What is the probability of the material projection? is more than 10%
A5	Effective ergonomics	Human factor	Gamma	The probability that 1 operator loads wire mesh from a batch of 2 batches knowing that the average 2%
A6	Shock	Human error	Beta 1	The probability of shock with the operators during the activcities is around 15% in 20 days
A7	Trapping	Human error	Beta 1	What is the probability of the trapping in formwork and frame? is more than 4.5% with average of 5% per year
A8	Cut	Human error	Beta 1	The probability of cut during bending of iron meshes is less than 6% in 30 days of activities
A9	Electrification	Mechanical stress	Gamma	The probability of the fire damaged in less than 5 years of use of the equipements is 3%
A10	Fire	Human factor	Gamma	The probability of the fire damaged is less than 3% in 5 weeks
A11	Material drop	Human error	Beta 1	The probability of material drop is more than 4.5% in 5 days
A12	Burn	Human error	Beta 1	The probability of the operator burn is be less than 5%
A13	Fall to the same level	Human error	Beta 1	The probability of fall to the same level is around 15%
A14	Shock agaist the material	Human error	Beta 1	The probability of the shock agaist the material be more than 8%

For level 3 and 4, in the Tables below, shows the root causes that were used to calculate the probability about the question simulated i Table 9.

Table 9. Probability calculation of each root causes

Level 4													
A1		A2		A3		A4		A5		A6		A7	
pinf	0	pinf	0	pinf	0	pinf	0	ax	0	pinf	0	pinf	0
psup	0.5	psup	0.5	psup	0.5	psup	0.5	mx	2	psup	0.9	psup	0.9
mp	0.1	mp	0.15	mp	0.12	mp	0.1	vp inf	0.1	mp	0.15	mp	0.045
vinf	0	vinf	0	vinf	0	vinf	0	vp sup	0.2	vinf	0	vinf	0
vsup	0.1	vsup	0.1	vsup	0.1	vsup	0.1	threshold	2	vsup	0.1	vsup	0.1
my	0.25	my	0.428571	my	0.298701	my	0.25			my	0.2	my	0.052632
				Treshould	0.15					threshold	0.2	threshold	0.05

Level 3										Level 4			
A8		A9		A10		A11		A12		A13		A14	
pinf	0.03	ax	0.001	ax	0	pinf	0	pinf	0	pinf	0	pinf	0.7
psup	0.8	mx	3	mx	3	psup	0.5	psup	0.5	psup	2	psup	1
mp	0.06	vp inf	0.1	vp inf	0.1	mp	0.045	mp	0.045	mp	0.15	mp	0.8
vinf	0	vp sup	0.2	vp sup	0.2	vinf	0	vinf	0	vinf	0	vinf	0
vsup	0.1	vsup	0.1	vsup	0.1	vsup	0.1	vsup	0.1	my	0.081081	my	0.5
my	0.040541	threshold	5	Treshould	5	my	0.098901	my	0.098901				
threshold	30					Treshould	0.05	Treshould	0.05				

It is possible to see exits a correlation between assumptions (questions) and the data used in the formulation.

So, for level 4 causes, we calculate its probability according to the root causes which is composed of link type "AND".

Fall from height — **A2** — **Beta 1**

The average probability offall from height is 15%

pinf	0
psup	0.5
mp	0.15
vinf	0
vsup	0.1
my	0.4286

0.4281
23%

i	p	q	vp	vx*	P(A2)
1	3321.7	4429	0.0131	0.0131	0.4261
2	107.63	143.5	0.073	0.073	0.4322
3	123.58	164.78	0.0681	0.0681	0.4614
4	76.984	102.65	0.0864	0.0864	0.4103
5	637.56	850.08	0.0299	0.0299	0.4057
6	266.6	355.47	0.0463	0.0463	0.4437

Drilling — **A3** — **Beta 1**

The probability of drilling risks be less than 12% in 15 days

pinf	0
psup	0.5
mp	0.12
vinf	0
vsup	0.1
my	0.2987
Treshould	0.15

0.4253
23%

i	p	q	vp	vx*	P(A3)
1	1016.6	2386.9	0.0263	0.0263	0.4323
2	112.4	263.9	0.0791	0.0791	0.4721
3	805.66	1891.6	0.0295	0.0295	0.4392
4	195.55	459.12	0.0599	0.0599	0.4665
5	283.78	666.27	0.0497	0.0497	0.4614
6	277.22	650.87	0.0503	0.0503	0.4618

Figure 20. Root causes with high possibility of risk occurrence.

These two causes up to level 0 feared event probability. It then finds that the probability of accident hazards from falling from a height and drilling is about 23% for each A2 and A3 of level 4, which gives one in four of the workers can fall from height and get drilled during the activities.

Effective ergonomics					**A5**	**Gamma**
The probability that 1 operator loads wire mesh from a batch of 2 l						
ax	0					
mx	2					
vp inf	0.1					
vp sup	0.2					
threshold	2					
					0.5205	
					28%	
	i	**vx**	**vx***	**p**	**a**	**P(A5)**
	1	0.1401	0.1401	50.944	25.472	0.5186
	2	0.1536	0.1536	42.406	21.203	0.5204
	3	0.1235	0.1235	65.539	32.77	0.5164
	4	0.1762	0.1762	32.196	16.098	0.5234
	5	0.1877	0.1877	28.371	14.186	0.525
	6	0.1255	0.1255	63.45	31.725	0.5167

Figure 21. Root causes with high possibility of risk occurrence of effective ergonomics.

For ergonomics risks the probability is 28% where one in five workers can have ergonomics issues during the tasks.

Electrification						**A9**	**Gamma**
The probability of the fire damaged in less than 5 years of use of the equipements is 3%							
ax	0.001						
mx	3						
vp inf	0.1						
vp sup	0.2						
hreshol	5						
						0.99923851	
						49%	
	i	**vx***	**my**	**sy**	**vp**	**P(A9)**	
	1	0.14378578	1.0880471	0.1430508	0.143737851	0.999865468	
	2	0.173952459	1.0833736	0.1726577	0.173894475	0.998839323	
	3	0.199746693	1.0787172	0.1977962	0.19968011	0.996342552	
	4	0.110038358	1.092261	0.1097074	0.110001679	0.999998775	
	5	0.17971807	1.0823849	0.1782918	0.179658164	0.998436678	
	6	0.11552462	1.0916501	0.1151419	0.115486112	0.999996525	

Fire						**A10**	**Gamn**
The probability of the fire damaged is less than 3% in 5 weeks							
ax	0						
mx	3						
vp inf	0.1						
vp sup	0.2						
Treshould	5						
						0.999595259	
						49%	
	i	**vx**	**vx***	**p**	**a**	**P(A10)**	
	1	0.178211849	0.178211849	31.48667831	10.4955594	0.999287136	
	2	0.12473945	0.12473945	64.26763922	21.4225464	0.999996838	
	3	0.131835706	0.131835706	57.53523634	19.1784121	0.999990512	
	4	0.139754118	0.139754118	51.20009599	17.0666987	0.999973184	
	5	0.177932605	0.177932605	31.5855852	10.5285284	0.99929895	
	6	0.131636918	0.131636918	57.70913852	19.2363795	0.999990778	

Figure 22. Root causes with high possibility of risk occurrence of electrification and fire.

The probability of accident hazards from electrification and fire in level 3 is about 49% for each A9 and A10, which is one in nine of the workers who have change to get electrocuted or burned by fire.

Material drop						**A11**	**Beta 1**
The probability of material drop is more than 4.5% in 5 days							
pinf	0						
psup	0.5						
mp	0.045						
vinf	0						
vsup	0.1						
my	0.0989011						
Treshould	0.05					0.352234771	
						50%	
	i	**p**	**q**	**vp**	**vx***	**P(A11)**	
	1	4438.506274	40439.72383	0.014248615	0.014248615	0.217260661	
	2	528.5086296	4815.300848	0.041295319	0.041295319	0.38957003	
	3	2963.179952	26997.86178	0.017438714	0.017438714	0.26100789	
	4	1037.064601	9448.810809	0.029478409	0.029478409	0.350326707	
	5	176.6518752	1609.494863	0.071441195	0.071441195	0.430060184	
	6	105.3604841	959.9510778	0.092523336	0.092523336	0.441505373	

Burn						**A12**	**Beta 1**
The probability of the operator burn is be less than 5%							
pinf	0						
psup	0.5						
mp	0.045						
vinf	0						
vsup	0.1						
my	0.098901						
Treshould	0.05					0.349461204	
						50%	
	i	**p**	**q**	**vp**	**vx***	**P(A12)**	
	1	562.1276248	5121.607248	0.04004119	0.04004119	0.38649448	
	2	131.4583822	1197.731927	0.08282387	0.08282387	0.4371127	
	3	1522.653989	13873.06967	0.024327626	0.024327626	0.321878279	
	4	2283.880983	20808.6934	0.019863643	0.019863643	0.286570042	
	5	77157.04143	702986.3775	0.003417423	0.003417423	0.000594138	
	6	104.8944587	955.7050686	0.092728833	0.092728833	0.441585999	

Figure 23. Root causes with high possibility of risk occurrence of material drop and burn.

In terms of material drop and get burned when not using gloves is 50%, where one in 10 of the workers are susceptible to take this risk.

Table 10. Sample of first numbers of principal causes of the event and feared event.

P(E1)	P(E2)	P(E3)	P(E4)	P(E0)	
0.9376199	0.999999983	0.999999977	0.64847752	4.86E-01	0.543343509
0.9601103	1	1	0.69067851	6.19E-01	
0.9843591	1	1	0.62922137	4.70E-01	
0.7587874	0.99999882	0.999998528	0.28112644	5.09E-01	
0.9642851	0.99999868	0.999998549	0.55421969	4.01E-01	
0.9156547	0.999999933	0.999999932	0.63946867	6.84E-01	

Average(PE1)	Average(PE2)	Average(PE3)	Average(PE4)
9.38E-01	0.99999976	0.999999715	0.579469512
27%	28%	28%	16%

After analysing each of root causes components in excel, it obtained the percentages in Figure 24 below, with the most risks analysed in red trace.

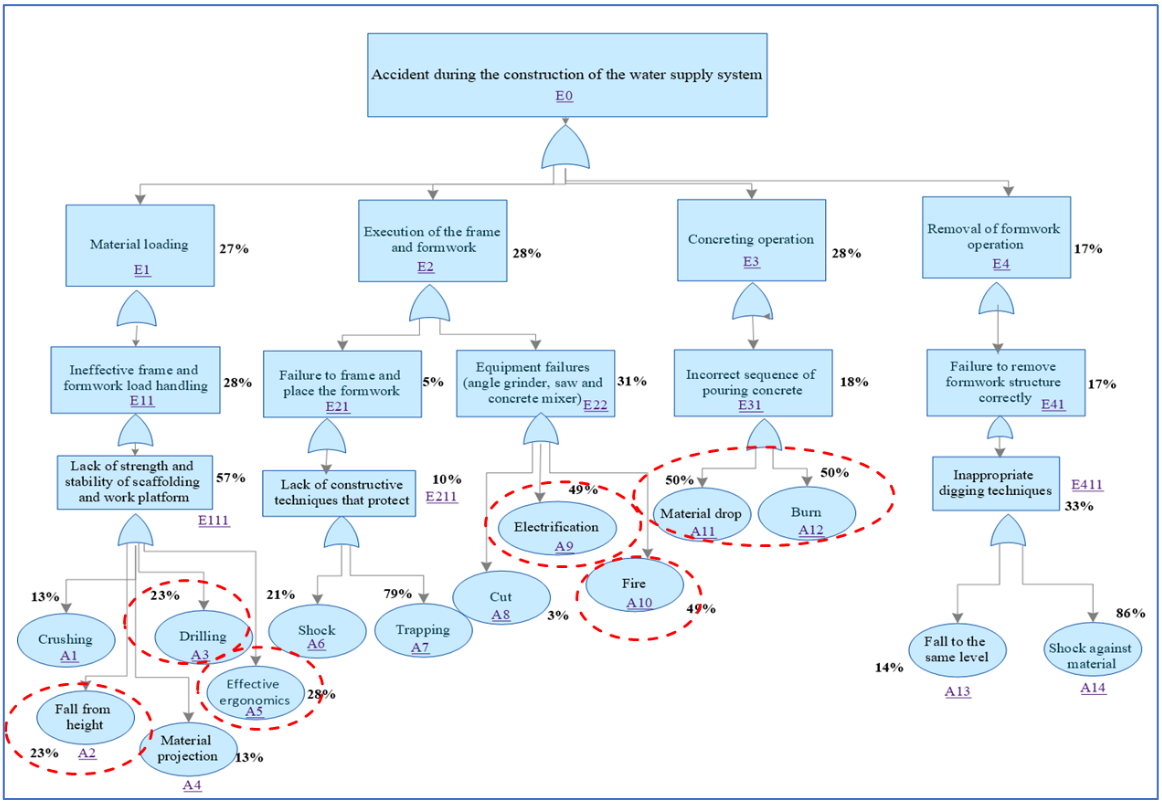
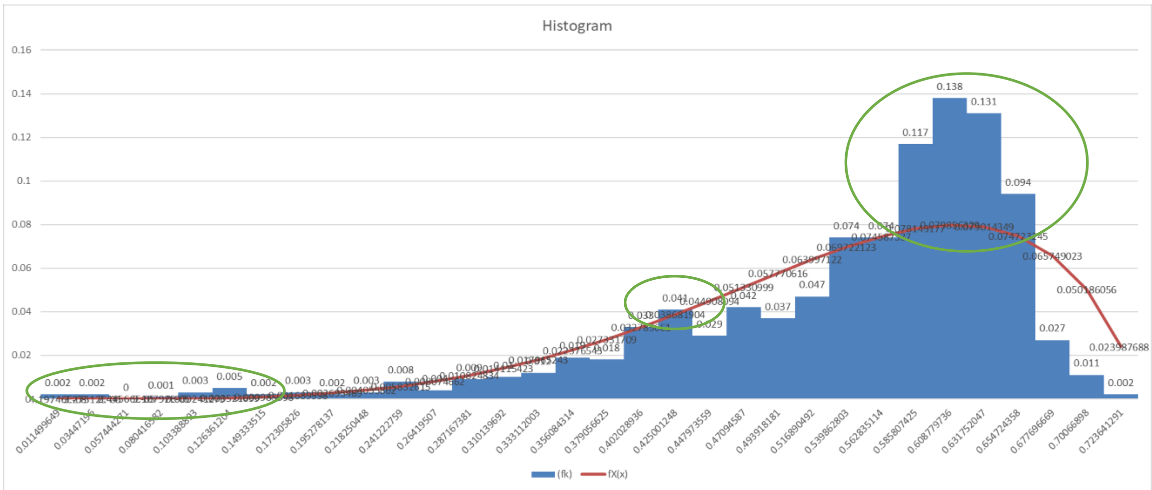


Figure 24. Fault tree analysis results of the system

Histogram and Homogeneity

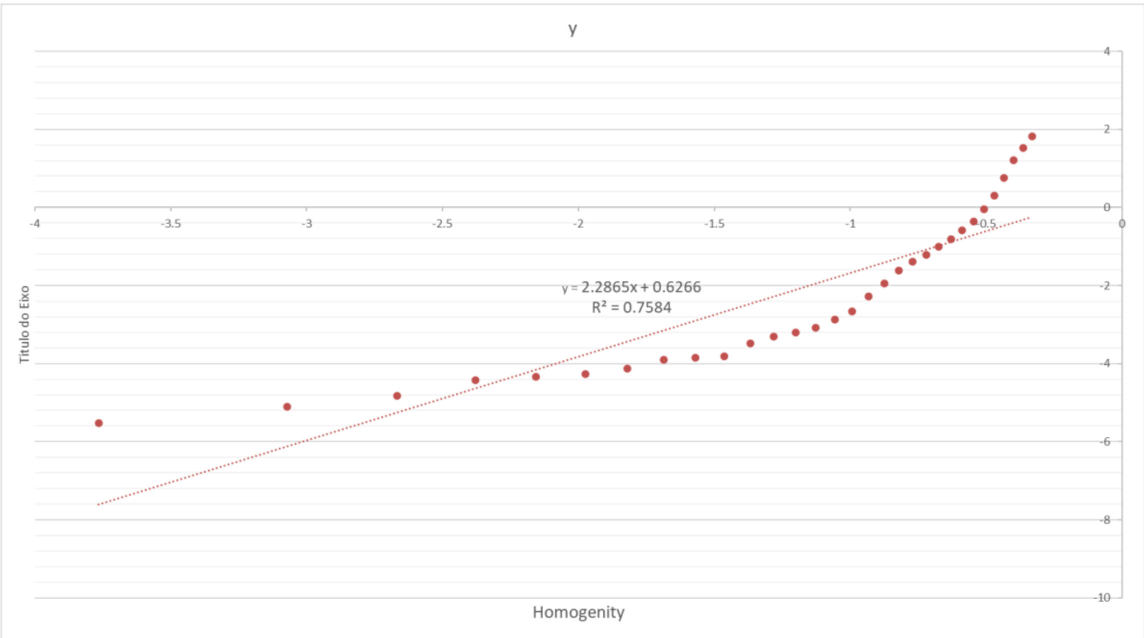


Graphic 1. Histogram

The three (3) group´s major risks are fall from height, material drops, and burn. In the Graphic 1 above, the level of risks has been divided by 3 groups (surrounded by green color) and these risks are increase and when they get in the highest hazard, the graphic stars to reduce until it gets down.

For the Graphic below, the non-homogeneous data is shown. As the homogeneity axis reduces, there is a discontinuity of the values, thus making the homogeneity irregular and the probability of occurrence of the top event risk being between 0 and 0.7, thus an extremely high value of these 14 risks occurs.

The coefficient correlation (R^2) is 0.75, which is extremely high, and it showed that the data is inconsistencies.



Graphic 2. Homogeneity

After studying the probabilistic analysis of the risks under study and knowing the percentage of each of the causes, it is possible to draw up an action plan. To reduce these percentages of the probabilities of these 7 major risks occurring, it would be interesting to implement preventive actions.

For this purpose, the simulation for our assumptions is assumed so that the homogeneity of the data and the histogram can be compared in this way, to know to what the extent, the use of this method is effective.

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

5.1.Conclusion

The civil construction sector is considered one of the most dangerous sectors in the world. The rate of reported accidents that occur is extremely high, showing that care is needed to protect the health and well-being of the worker. Thus, this was carrying out about risk assessment based on the risks and dangers of each task and for that this study has the follow results:

- The analysis of the matrices of possibilities together, with the results obtained showed that each method has its intrinsic behavior, and this influences the result of its analysis;
- There were 13 types of risks identified from 35 hazards;
- It is also noted that all these risks, which were identified in notable amounts, appear in practically all sub-processes, showing that they must be carefully evaluated to be able to implement adequate controls to mitigate or minimize them;
- The application of the PRA method proved to be subjective due to the way its parameters were described in the tables used for the application of the evaluation and the distribution of results by this methodology concentrated the results at the low level because it is very generalist with 96 references of risks found.
- The FMEA method presents better results in the distribution of risks and the way of its application was thought to present the minimum of subjectivity with fall from height and falling of materials as higher risks.
- About the FTA: 14 causes for the feared event which is accident during the construction work; The probability of occurrence with high percentage are: fall from height, drilling, and effective ergonomics, with 23% for the two causes and 28%, respectively; for material drop and burn with each other of 50% of probability risk occurrence and electrification and fire from execution of frame and formwork with 28%.
- The top event risk is between 0 and 0.7, so probability of having this top event is extremely high; Has 3 groups of risks based on the histogram as fall from height, drilling and effective ergonomics, fire and electrification has the major risks;

Using these 3 methods combined help us have data more consistency and designing strategies that will mitigate possible future damage that may arise. In general, the work was able to develop 3 analyses of risk methods based on the description of the production process and identify the best methodologies for the case study.

5.2. Recommendations

Given the importance of detailing the production system for risk assessment, it is important the study of other construction works using this methodology component, that is, the three methods developed in this study, with a view to obtaining more qualitative and accurate data consolidated, since civil construction is endowed with numerous technologies.

For future works, it is also suggested the inclusion of new factors related to characteristics of the work as well as personal characteristics of workers who perform the task studied, to obtain a risk assessment that is more faithful to the intrinsic characteristics of the place of study.

7 . REFERENCES

1. Almeida, C. G.; Nascimento, T. E. Nunes, N. M. S (2018). *A importância da Segurança no Trabalho Para as Organizações. Revista Científica Interdisciplinar Múltiplos Acessos*, [s.l],v 3, n 2, p. 85-98.

2. Bezzera, G. *Análise dos riscos ergonômicos e das doenças ocupacionais nos canteiros de obras e formas de prevenção.* (2015). *58 f. Trabalho de Conclusão de Curso (Graduação) – Curso Superior em Engenharia Civil.* Universidade Tecnológica Federal do Paraná, Campo Mourão.

3. Construtora do Messalo, Lda. (2022). *Relatório SAA Possulane*. *Empreitada para Elaboração do Desenho Executivo e Construção de 06 Sistema de Abastecimento de Água, Distribuidos em 06 Lotes na Provincia de Maputo*.

4. Guilherme, I. M. A. (2015). *Gestão de riscos na construção. Reparação da Doca de Recreio das Fontainhas*. *Dissertação (Mestre em Segurança e Higiene do Trabalho),* Instituto Politécnico de Setúbal.

5. ISO 31000. (2009). Risk management – Risk assessment techniques. Principles and guidelines. Genebra, Switzerland: International Organization for Standardization.

6. Jin, R., Zou, P. X. W., Piroozfar, P., Wood, H., Yang, Y., Yan, L., & Han, Y. (2019). A science mapping approach-based review of construction safety research.*SafetyScience,113*.https://doi.org/10.1016/j.ssci.2018.12.006.

7. Maia, A. L. M. (2014). *Análise preliminar de risco de uma obra de construção civil. Revista Tecnologia & Informação.*

8. Ministério do Trabalho, Emprego e Segurança Social. *Dados Cronológicas de Acidentes de Trabalho 2010 - 2016,* Maputo, 2016.

9. Radu, L.-D. (2009). Qualitative, Semi-Quantitative and Quantitative Methods For Risk Assessment: Case Of The Financial Audit. Analele Stiintifice Ale Universitatii "Alexandru Ioan Cuza" Din Iasi - Stiinte Economice. https://ideas.repec.org/a/aic/journl/y2009v56p643-657.html.

10. Roxo, Manuel; (2003). *Segurança e Saúde do Trabalho: Avaliação e controlo de riscos*; Edições Almedina; Coimbra.

11. Rubio, M. Carmen, et al., (2005). Obligations and Responsibilities of Civil Engineers for the Prevention of Labor Risks: References to European Regulations, Journal of Professional Issues in Engineering Education and Practice, Vol. 131, Issue.

12. Silva Junior, D. C., Cambraia, F. B. (2013). Modelo do processo de ação fiscal de segurança e saúde do trabalho na construção de edificações. Ambiente Construído, Porto Alegre, v 13, p. 29-41.

13. Stamatis, D. H. (2003) “Failure Mode Effect Analysis: FMEA from Theory to Execution.” Milwaukee: American Society for Quality, Quality Press.

14. Ostrom, L.T., & Wilhelmsen, C. A. (2019). Risk Assessment: Tools, Techniques, and Their Applications. Wiley.

15. Popov, G., Lyon, B. K., & Hollcroft, B. (2016). Risk Assessment: A Practical Guide to Assessing (1st ed.). Wiley.

16. Puente, J. et al. (2002). A decision support system for applying failure mode and effect analisys. Internetional Journal of Quality & Reliability Management, Bradford, Vol. 19, n. 2, 137-151.

APPENDIX

APPENDIX A - List of Risks and Hazards

Risks and Hazards	Total
Shock	**8**
Frame	4
Formwork	2
Charge	1
Iron mesh	1
Shock against material	**1**
Wood	1
Electric shock	**1**
Vibrator	1
Cut	**4**
Grinding wheel	2
Bench for bending stirrups	1
Binding iron	1
Electrification	**1**
Grinding wheel	1
Trapping	**10**
Formwork	5
Frame	2
Formwork sheet	1
Anchor	1
Concrete bucket	1
Crushing	**12**
Charge	1
Scaffolding	1
Trapping	2

Risks and Hazards	Total
Gloves	1
Hammer	1
Iron mesh	1
Formwork	1
Work platform	1
Frame element	1
Concrete bucket	1
Concrete mixer	1
Drilling	**6**
Iron	2
Starter iron	2
Iron mesh	1
Wood with nails	1
Material projection	**10**
Concrete	4
Hammer	4
Nails	1
Formwork	1
Fall to the same level	**13**
Electric cable	3
Material	2
Formwork	1
Frame	1
Steel bars	1
Concreting bucket hose	1
Formwork oil	1
Objects	1

Risks and Hazards	Total
Wooden board	1
Iron mesh	1
Material drops	**9**
Hammer	3
Scale	1
Material	1
Formwork	1
Concrete	1
Objects	1
Equipment (vibrator)	1
Anchor	1
Fall from height	**16**
Height	9
Shoring	1
Wood	1
Sand	1
Concrete bucket	1
Work platform	1
Electric cable	1
Formwork	1
Burn	**3**
Sawmill for wood	2
Grinding wheel	1
Total	**96**

APPENDIX B - Risk assessment tables – PRA

Identification of risks and hazards

Reference	**Subprocess**	**Tasks**	**Hazard**	**Triggering Event**	**Comments**	**Risks**	**Consequence**	**Control measures (to be implemented)**
1	Execution of the slabs	Movement of Charges in Formwork	Cartoon	Due to a sudden change in wind speed (change in weather conditions), the charge oscillates and collides with the collaborator	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Shock	Excoriation	* Preventive maintenance of the wind gauge; * Monitoring of meteorological development throughout the day;
2	Execution of the slabs	Movement of Charges in Formwork	Cartoon	Incorrect coupling of the Charge to the crane followed by the Charge falling over worker	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Crushing	Death	* Training on charging workers;
3	Execution of the slabs	Formwork	Height	Area where the Formwork panels are being assembled, not marked and the employee, while doing other work, falls into the gap	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Fall from height	Arm and leg fracture	* Marking of the places where the Formwork is taking place; * Planning the day's work, and in the 5

								min of security warning
4	Execution of the slabs	Formwork	Hammer	When levelling the Anchor with the help of a Hammer, a worker is distracted and projects the Hammer against another worker	* Task duration: 2 minutes and several times a day * Extension: 1 collaborator	Material projection	Excoriation	* Use of non-slip gloves;
5	Execution of the slabs	Formwork	Hammer	When hammering the Anchor Grader, the Hammer breaks off and is thrown into the worker's face.	* Task duration: 2 minutes and several times a day * Extension: 1 collaborator	Material projection	Head trauma	* Checking and replacing the Hammer if it is in poor condition;
6	Execution of the slabs	Movement of Charges in the Frame	Cartoon	When lifting the Charge, the strap breaks due to the poor state of repair and Charge falls on workers	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Crushing	Death	*Quarterly colour-based control of the straps on site; * Removal of material identified as being in poor condition or that has not been verified;

7	Execution of the slabs	Movement of Charges in the Frame	Iron	Due to a sudden change in wind speed (change in weather conditions), the Charge oscillates and collides with the collaborator or drilling	* Task duration: 5 min and several times a day * Extension: 2 collaborators	Drilling	Puncture injury in the abdominal region	* Preventive maintenance of the wind gauge; * Monitoring of meteorological development throughout the day;
8	Execution of the slabs	Movement of Charges in the Frame	Iron	The crane driver is not aware of the worker and when lowering the Charge, it collides with the worker, drilling him	* Duration of the task: 5 min and several times a day *Operation: 9h with a break of 1h; * Extension: 2 collaborators	Drilling	Puncture injury to the arm	* Mandatory use of a signalling vest; * Camera installation on the crane boom; * Delineation and formation of a supervisor responsible for handling Charges;
9	Execution of the slabs	Frame	Iron mesh	Collaborator, when walking on the Iron mesh, catches his foot in the openings of the mesh and falls	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Fall to the same level	Excoriation	*Behavioural dialogue with workers to be attentive in circulation areas;

10	Execution of the slabs	Frame	Starter iron	When walking on the Iron mesh, an employee loses his balance and falls on top of the starting Irons	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Drilling	Puncture injury in the abdominal region	* Irons protection from starts; * Behavioural dialogue with workers to be aware in circulation areas
11	Execution of the slabs	Frame	Grinding wheel	Collaborator when cutting steel with Grinding wheel, positions himself incorrectly causing the spark to be projected on himself, setting fire to clothing and leading to Burns	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Burn	Burn on the leg	* Change of clothing for fire-resistant pants * Training for the correct use of the work tool;
12	Execution of the slabs	Frame	Steel filings	Collaborator cutting steel with Grinding wheel, does not pay attention to the direction in which the sparks are projected, and it hits another worker in the eye	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Burn	Temporary partial visibility loss	* Use of protection to contain sparks; * Use of protective glasses;

13	Execution of the slabs	Frame	Grinding wheel	When cutting the mesh of the Frame, the worker does not position himself correctly and at the end of the Cut, on the edge of the metal, he projects the Equipment against himself, cutting the leg	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Cut	Leg cut	* Training on best practices for using the Grinding wheel; * Obtaining protection for the legs;
14	Execution of the slabs	Frame	Grinding wheel	Grinding wheel with damaged cable and when used it electrifies the operator	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Electrification	Burn in hand	* Quarterly preventive maintenance of the material;
15	Execution of the slabs	Frame	Iron mesh	When manually moving the Iron mesh, the moment it rotates with the Charge it hits another employee	* Duration of the task: 10 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Shock	Excoriation	* Training for good practices in the manual handling of Charges;
16	Execution of the slabs	Concreting	Electric cable	Employee trips over the electric cable of the vibrator and falls	* Task duration: 7 continuous hours with a 1-hour break * Extension: 1 collaborator	Fall to the same level	Excoriation	* Behavioural dialogue with workers to be attentive in circulation areas;

17	Execution of the slabs	Concreting	Shoring	Formwork collapse due to insufficient Shoring when the Concreting work was carried out	* Task duration: 7 continuous hours with a 1-hour break * Extension: 5 collaborators	Fall from height	Death	* Training on the execution of construction methods; * Be incorporated into a verification work procedure before Concreting;
18	Execution of the slabs	Concreting	Concrete	When executing Concreting, there is the projection of Concrete in the eyes of the employee who was not wearing protective glasses	* Task duration: 7 continuous hours with a 1-hour break * Extension: 1 collaborator	material projection	Temporary visibility loss	* Training in good practices on site; * Use of protective glasses;
19	Execution of the slabs	Removal of formwork	Equipment	Worker performs the Removal of formwork from an unconcreted area that serves as a Work platform on the upper floor resulting in the fall of equipment on top of the employee	* Task duration: 3h * Extension: 1 collaborator	Crushing	Death	* Promotion of the communication of the work to be performed; * Marking of the areas to be removed;

20	Execution of the slabs	Removal of formwork	Height	When using the Scaffolding, the employee does not fasten the harness and when removing the panels, he becomes unbalanced and falls	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Fall from height	Arm fracture	* Training to reinforce the importance and use of the harness;
21	Execution of the slabs	Removal of formwork	Scaffolding	Maintenance of the Scaffolding was not carried out properly and when operating there is a failure in the controls causing the platform not to stop lifting, crushing the worker against the Formwork	* Task duration: 3 min and several times a day * Extension: 1 collaborator	Crushing	Death	*Periodic maintenance of the platform *Execution of work in pairs
22	Execution of the slabs	Removal of formwork	Anchor	When carrying out the first stage of the Removal of formwork, the worker, when disengaging the Anchor, becomes unbalanced and drops the material on another collaborator	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Material drop	Excoriation	*Training in Removal of formwork jobs

23	Execution of the slabs	Removal of formwork	Anchor	When removing the Anchors, the distracted employee places his hand in the extension zone and removes the pin that regulates the Height, resulting in the Anchor head falling over his hand	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Trapping	Hand fracture	*Training in Removal of formwork jobs
24	Execution of the walls	Frame	Steel bars	Worker walking through the shipyard trips over a steel bar and falls	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Fall to the same level	Excoriation	* Periodic work organization
25	Execution of the walls	Frame	Iron mesh	When positioning the Frame with the crane, a worker is hit with the tip of the Iron of the Frame	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Drilling	Puncture injury to the arm	* Training on mechanical movement of Charges;
26	Execution of the walls	Frame	Steel filings	The collaborator walks alongside a colleague who is cutting Iron with the grinding wheel and a steel filing is projected into his eye resulting in the	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Material projection	Partial visibility	* Use of protection to contain sparks; * Use of protective glasses;

				filings penetrating the retina				
27	Execution of the walls	Frame	Steel filings	When the employee is cutting the steel, he does not notice that the filings are being projected towards his trousers and they catch fire, causing Burns in the leg	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Burn	Burn on the leg	* Replacement of clothing with fire resistant pants; * Training for the correct use of the work tool;
28	Execution of the walls	Frame	Frame element	The employee responsible for attaching the Frame to the crane for transport decides to use the single-use straps, while transport is in progress the straps break resulting in the projection of all the material onto an employee resulting in a broken leg.	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Crushing	Leg fracture	* Use of suitable straps; * Immediate disposal of single-use straps; * Training on mechanical movement of Charges;

29	Execution of the walls	Frame	Iron mesh	The employee directly engages the crane hooks at the ends of the Iron mesh and during transport this gives way resulting in the fall of all elements on the arm of an employee resulting in a broken arm.	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Crushing	Arm fracture	* Training on mechanical movement of Charges;
30	Execution of the walls	Formwork	Formwork	When lowering the Formwork panel, the collaborator tries to hold the panel while a strong gust of wind comes, and this is projected to the ground	* Duration of the task: 10 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Fall to the same level	Excoriation	* Awareness training for work on windy days; * Restrict jobs above 65 km/h;
31	Execution of the walls	Formwork	Formwork	When placing the panel on the floor, the worker is not attentive and places the panel on his foot	* Duration of the task: 10 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Crushing	Foot fracture	* Training on mechanical movement of Charges; * Training in good practices on site;
32	Execution of the walls	Formwork	Formwork	When touching the panels, the worker is not attentive and pinches his finger	* Duration of the task: 10 min and several times a day * Crane operation:	Trapping	Excoriation	* Training on mechanical movement of Charges; *

				between two panels	9h with a break of 1h; * Extension: 1 collaborator			Training in good practices on site;
33	Execution of the walls	Formwork	Hammer	By squeezing the tinges, the Hammer escapes from the hands hitting a co-worker	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Material projection	Arm injury	*Replacement of gloves with a non-slip model
34	Execution of the walls	Formwork	Hammer	When tightening the Formwork clamps, the Hammer escapes and is projected against the panel, ricochets, and hits the worker	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Material projection	Arm injury	*Replacement of gloves with a non-slip model
36	Execution of the walls	Formwork	Formwork oil	During the application of the Removal of formwork oil on the panel, a worker to move around the work goes over and slips	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Fall to the same level	Excoriation	*Delimitation of a circulation path
37	Execution of the walls	Formwork	Formwork	During the transport of the panel comes a gust of wind and this is projected against a block wall causing it to give way and fall on top	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h;	Crushing	Leg fracture	* Awareness training for work on windy days; * Restrict jobs above 65 km/h;

				of a worker.				
38	Execution of the walls	Formwork	Formwork	Worker is positioning the Formwork stuck on the crane without protection for work in Height. It destabilizes and hits the ladder causing the worker to fall into two other workers.	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 3 collaborators	Fall from height	Bruise	*Awareness training for jobs in Height
39	Execution of the walls	Formwork	Work platform	Work platform is not properly placed and when disengaging from the crane, it falls on the worker	* Task duration: 20 min and 1 time a day * Extension: 1 collaborator	Crushing	Arm fracture	*Training on construction process
40	Execution of the walls	Concreting	Equipment (vibrator)	When on the Work platform, the employee leaves the vibrator at the base and kicks it, falling on another worker	* Task duration: 3h * Extension: 1 collaborator	Material drop	Excoriation	* Training of good practices on site;

41	Execution of the walls	Concreting	Electric cable	During Concreting, the vibrator gets stuck in the Iron and the worker, when pushing hard, falls to the same level	* Task duration: 3h * Extension: 1 collaborator	Fall to the same level	Excoriation	*Replacement of vibrator by one with reduced diameter; *Awareness for the risks of the task to be carried out;
42	Execution of the walls	Concreting	Concrete	When concreting the worker is not wearing glasses and Concrete is designed for the eyes	* Task duration: 3h * Extension: 1 collaborator	Material projection	Temporary partial visibility loss	* Training in good practices on site; * Use of protective glasses;
43	Execution of the walls	Concreting	Electric cable	No lateral barrier is placed on the Work platform during Concreting. Worker trips over vibrator cable and falls onto slab	* Task duration: 3h * Extension: 1 collaborator	Fall from height	Excoriation	*Training in good practices on site *Training on the construction process
44	Execution of the walls	Concreting	Wood	The status of the platform Wood was not checked, it was in poor condition. During the execution of Concreting, Wood gave way and the whole team fell	* Task duration: 3h * Extension: 3 collaborators	Fall from height	Multiple fractures	*Periodic maintenance of material on site *Verification of material to be used

45	Execution of the walls	Concreting	Concreting bucket hose	The state of the bucket hose of Concrete was not checked and when pulling the rope, Concrete is designed for workers who become unbalanced and fall	* Task duration: 3h * Extension: 1 collaborator	Fall to the same level	Excoriation	*Periodic maintenance of material on site *Verification of material to be used
46	Execution of the walls	Concreting	Concreting Bucket	Concreting Bucket loses stability due to a manoeuvre by a worker and it runs into another worker's hand, jamming it in the Work platform	* Task duration: 3h * Extension: 1 collaborator	Trapping	Hand fracture	* Training on good practices on site;
47	Execution of the walls	Concreting	Starter iron	Worker while concreting, loses balance and falls on unprotected Starter iron and is punctured	* Task duration: 3h * Extension: 1 collaborator	Drilling	Puncture injury in the abdominal region	* Placement of protection in the starting Irons; Training on good practices on site;
48	Execution of the walls	Concreting	Concreting Bucket	The condition of the crane chain was not checked, it breaks during Concreting and the bucket falls on the worker	* Duration of the task: 7 continuous hours with a 1-hour break; * Extension: 1 collaborator	Crushing	Leg fracture	*Periodic maintenance of material on site *Verification of material to be used

49	Execution of the walls	Removal of formwork	Formwork	When storing the panels at the shipyard, the worker does not stack them correctly, causing them to fall on another worker	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Crushing	Leg fracture	* Training on good work practices; * Training on mechanical handling of Charge;
50	Execution of the walls	Mechanical movement of charge in the removal of formwork	Formwork	Panel storage is done in a no-visibility zone and wedges a worker against stacked formwork	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Trapping	Excoriation	* Training on mechanical movement of Charges; Camera installation on the crane boom;
51	Execution of the pillars	Frame	Frame	When positioning the Frame attached to the crane at the stipulated location, the worker does not remove his hand in time and wedges it in the starter iron	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Trapping	Cutting injury to the hand	* Training on mechanical movement of Charges;
52	Execution of the pillars	Frame	Frame	When removing Frame from the shipyard, a worker does not wear a safety vest, meaning that the crane operator does not	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1	Shock	Excoriation	* Training in good practices on site;

				see him and collides with Frame against him	collaborator			
53	Execution of the pillars	Frame	Material	When walking through the shipyard to pick up material for making Frame, a worker trips over unorganized Irons and falls	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Fall to the same level	Excoriation	*Execute planning on organization on site by the person in charge;
54	Execution of the pillars	Frame	Iron to tie	Worker preparing the Frame trips over material and while holding on to the Frame, cuts his arm on the tying Irons	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Cut	Cutting injury to the arm	* Improved organization of the workplace; * Mandatory use of PPE's;
55	Execution of the pillars	Frame	Frame	When lifting a Frame at the construction site, a worker does not correctly engage the hook and the hook is released like a pendulum and collides with the worker	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Shock	Excoriation	* Training on good work practices; * Training on mechanical handling of Charge;
56	Execution of the pillars	Formwork	Hammer	Worker Tightening Scales at Formwork Hammer Hand	* Task duration: 5 min and several times a day	Crushing	Hand injury	* Training on good practices on site;

					* Extension: 1 collaborator			
57	Execution of the pillars	Formwork	Formwork	When positioning Formwork, the crane cables lose stability due to the strong wind and the Formwork collides with the worker	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Shock	Excoriation	* Awareness training for work on windy days. * Restrict jobs above 65 km/h;
58	Execution of the pillars	Formwork	Formwork	When placing the panel in the defined location, the worker is not aware, and the panel is placed on the foot	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Trapping	Foot fracture	* Training on mechanical movement of Charges;
59	Execution of the pillars	Formwork	Formwork	When closing an L-shaped Formwork, the worker does not remove his hand and it is trapped	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Trapping	Bruise	* Training on good practices on site;
60	Execution of the pillars	Concreting	Hammer	When doing Concreting over Scaffolding, worker does not put Hammer correctly on his waist and he falls from the	* Task duration: 3h * Extension: 1 collaborator	Material drop	Excoriation	* Training on good practices on site;

				platform onto the worker				
61	Execution of the pillars	Concreting	Height	When Concreting, Worker Does Not Attach Harness to Work Platform and Falls	* Task duration: 3h * Extension: 1 collaborator	Fall from height	Arm fracture	* Training on good work practices in Height;
62	Execution of the pillars	Concreting	Height	Worker uses ladder instead of Scaffolding in Concreting and due to the pressure of Concrete in the hose, this gives a bump that results in loss of balance and fall of the worker	* Task duration: 3h * Extension: 1 collaborator	Fall from height	Arm fracture	* Training on good practices in work and work in Height;
63	Execution of the pillars	Concreting	Concrete	Worker does not wear goggles and Concrete is designed for the eye	* Task duration: 3h * Extension: 1 collaborator	Material projection	Partial visibility loss	* Training in good practices on site; * Use of protective glasses;
64	Execution of the pillars	Concreting	Electric cable	Worker trips over an Electric cable and falls onto the Work platform	* Task duration: 3h * Extension: 1 collaborator	Fall to the same level	Excoriation	* Improved organization on site;

65	Execution of the pillars	Concreting	Concreting Bucket	Due to the wind, Concreting Bucket swings and collides with a worker causing him to fall off the Work platform	* Task duration: 3h * Extension: 1 collaborator	Fall from height	Leg fracture	* Awareness training for work on windy days; * Restrict jobs above 65 km/h;
66	Execution of the pillars	Concreting	Vibrator	Vibrator has not been inspected and worker when using takes electric shock due to cable in poor condition	* Task duration: 3h * Extension: 1 collaborator	Electric shock	Burn in hand	* Periodic maintenance of material on site; * Verification of the material to be used;
67	Execution of the pillars	Concreting	Height	Concreting Bucket rope is rolled up in Scaffolding and when lifted by the crane the platform is lifted and the worker falls	* Task duration: 3h * Extension: 1 collaborator	Fall from height	Leg fracture	* Improved organization of the workplace;
68	Execution of the pillars	Concreting	Height	Worker does not use a ladder to climb the Work platform and climbs the panels. This slips and falls	* Task duration: 2 min and several times a day * Extension: 1 collaborator	Fall from height	Arm fracture	* Training in good practices on site;

69	Execution of the pillars	Removal of formwork	Formwork	Worker is not aware of the Formwork attached to the crane and collides with the material	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Shock	Excoriation	* Training on mechanical movement of Charges;
70	Execution of the pillars	Removal of formwork	Formwork	Worker positions himself in the wrong way to perform the Removal of formwork and has his hand wedged between the wall and Formwork	* Task duration: 5 min and several times a day * Extension: 1 collaborator	Trapping	Excoriation	* Training in good practices on site;
71	Execution of the pillars	Removal of formwork	Scale	Worker does not remove the Scale from the Formwork and when it is lifted it falls on the worker	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 employee	Material drop	Shoulder injury	* Training on construction process; * Training in good practices on site;
72	Execution of the pillars	Removal of formwork	Scaffolding	When using a Scaffolding the worker when driving to the pillar, gets distracted and runs over the foot of	* Task duration: 10 min and several times a day * Extension: 1 collaborator	Crushing	Bruise	* Training in good practices on site; * Training in the use of a lift platform;

				another worker				
73	Execution of the pillars	Removal of formwork	Formwork	Worker lands small Formwork in crossing area and another trips and falls	* Task duration: 9h * Extension: 1 collaborator	Fall to the same level	Excoriation	* Improvement of organization on site; * Delimitation of circulation path; * Training in good practices on site;
74	Execution of the beams	Frame	Frame	When positioning the Frame attached to the crane in the stipulated location, the worker does not remove his hand in time and wedges it between the Iron of the pillar and the beam	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Trapping	Excoriation	* Training on construction process; * Training in good practices on site;
75	Execution of the beams	Frame	Frame	When removing Frame from the site, the crane operator does not have visibility due to the position of Objects in the site and when	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1	Shock	Excoriation	* Training on mechanical movement of charges; Camera installation on the crane

				descending the Charge, it collides with a worker	collaborator			boom;
77	Execution of the beams	Frame	Frame	When lifting Frame at the construction site, the tower crane operator lifts it without the two sides being engaged, causing the Frame to slip, and hit a worker	* Duration of the task: 5 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Shock	Excoriation	* Training on mechanical movement of Charges;
78	Execution of the beams	Frame	Material	When landing the Frame on the Formwork with the help of the tower crane, an employee trips over material on the floor and falls	* Duration of the task: 15 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Fall to the same level	Excoriation	* Improvement of organization on site; * Delimitation of circulation path; * Training in good practices on site;
79	Execution of the beams	Formwork	Height	When assembling the support tower, the worker does not use a harness and, when he loses his balance, he falls on the same work floor	* Duration of the task: 9h with a break of 1h; * Extension: 1 collaborator	Fall from height	Leg fracture	* Formation of works in Height; * Training in good practices on site;

80	Execution of the beams	Formwork	Height	When assembling the tower, a worker fastens the harness in the wrong place, on the tower itself, and when he loses his balance, he falls from the tower that is not anchored, thus falling the tower and the worker from the facade of the slab	* Duration of the task: 9h with a break of 1h; * Extension: 1 collaborator	Fall from height	Death	* Formation of works in Height; Use of lifeline; * Training on construction process;
81	Execution of the beams	Formwork	Hammer	Worker when nailing Wood from the platform in the tower docks the Hammer slips and is designed for pedestrians walking on the street	* Task duration: 5 min and several times a day; * Extension: 1 collaborator	Material drop	Death	* Glove replacement for non-slip model;
82	Execution of the beams	Formwork	Formwork Panel	When placing the Formwork panel on the Work platform, the worker is not attentive and lands it on his foot	* Duration of the task: 10 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Trapping	Excoriation	* Training on mechanical movement of Charges;

83	Execution of the beams	Formwork	Material	The baseboard was not placed in the guardrail system, and the worker, when passing by, kicks a piece of Wood that is on the floor and projects it to the lower floor, hitting the worker.	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Material drop	Excoriation	* Training on good practices on site; * Training for correct assembly of guardrails;
84	Execution of the beams	Formwork	Work platform	When assembling the support tower, it is not anchored properly and due to a gust of wind, the entire structure is projected by the facade together with a worker	* Task duration: 9h with a 1h break; * Extension: 1 collaborator	Fall from height	Death	* Training on construction process; * Training in good practices on site;
85	Execution of the beams	concreting	Concrete	The panels were not properly closed, and they gave way under the pressure of the concrete that fell through the façade, hitting a worker passing underneath.	* Task duration: 7h * Extension: 1 collaborator	Material drop	Excoriation	* Training on construction processes;
86	Execution of the beams	concreting	frame	Concreting worker trips over Frame and falls	* Task duration: 7h * Extension: 1 collaborator	Fall to the same level	Excoriation	* Behavioural dialogue with workers to be

								attentive in circulation areas;
87	Execution of the beams	concreting	Concrete	Worker does not wear glasses during Concreting and Concrete is designed for eyes	* Task duration: 7h * Extension: 1 collaborator	Material projection	Partial visibility loss	* Training in good practices on site; * Use of protective glasses;
88	Execution of the beams	Removal of formwork	Formwork	The Formwork panel is attached to the Concrete and a crane is used to help remove it, the panel is projected vertically and reaches a poorly positioned worker	* Duration of the task: 10 min and several times a day * Crane operation: 9h with a break of 1h; * Extension: 1 collaborator	Material projection	Excoriation	* Training on good practices on site; * Training on mechanical movement of charges;
89	Execution of the beams	Removal of formwork	Hammer	When the worker lowers the towers to remove the beam, the Hammer escapes and hits a worker from the same team.	* Task duration: 9h with a 1h break * Extension: 1 collaborator	material drop	Bruise	* Replacing gloves with a non-slip model;
90	Execution of the beams	Removal of formwork	Height	Worker when dismantling the support tower does not use a harness, loses balance, and falls into the work.	* Task duration: 9h with a 1h break; * Extension: 1 collaborator	Fall from height	Arm fracture	* Training on work in height and good practices on site;

91	General	General	Height	When descending from the crane on a rainy day, a worker slips and falls down the stairs	* Task duration: 15 min and 2 times a day; * Extension: 1 collaborator	Fall from height	Death	* Placement of non-slip rubber on the crane access stairs;
92	General	General	Objects	Objects fall on workers who are at a lower level	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Material drop	Excoriation	* Placement of protection net; * Delimitation of a safety zone of 5m around the work;
93	General	General	Sand	When entering through the access to the work, an employee slips and loses his balance on the unstable ground and falls in vain	* Task duration: 5 min and several times a day; * Extension: 1 collaborator	Fall from height	Arm fracture	* Placement of protection in vain;
95	General	General	Objects	When walking around the site, an employee trips over material on the floor and falls	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Fall to the same level	Excoriation	* Improved organization on site; * Delimitation for passing zones;
96	General	General	Wood with nails	In the removal of formwork the area was not organized and Wood was left with nails.	* Task duration: 9h with a 1h break * Extension: 1 collaborator	Drilling	Foot puncture wound	* Improved organization on site; * Delimitation for passing zones;

APPENDIX C - Risk assessment tables – FMEA

Process	Function	Failure Mode	Failure Causes	Failure Effetcs	Severity (S)	Occurence (O)	Detectability (D)	Criticality S*O*D	Recommended Action(s)
Execution of the slabs	Formwork	Shock between the operator and the load	Due to a sudden change in wind speed (change in weather conditions), the charge oscillates and collides with the collaborator in the scaffolding	Excoriation	3	3	2	18	* Preventive maintenance of the wind gauge; * Monitoring of meteorological development throughout the day.
	Movement of Charges in the Frame	Projecting material/load drop	Incorrect coupling of the charge to the crane followed by the charge falling over worker	Death	5	3	3	45	* Training on charging workers;
	Frame	Fall from height	Area where the Formwork panels are being assembled, not marked and the employee, while doing other work, falls into the gap	Arm and leg fracture	3	3	3	27	* Marking of the places where the Formwork is taking place; * Planning the day's work, and in the 5 min of security warning.
	Concreting	Fall to the same level	Worker walking through the shipyard trips over a steel bar and falls	Excoriation	3	2	2	12	*Behavioral dialogue with workers to be attentive in circulation areas;
	Removal of formwork	Crushing	Maintenance of the Scaffolding was not carried out properly and when operating there is a failure in the controls causing the platform not to stop lifting, crushing the worker against the formwork	Head trauma and death	5	2	3	30	* Training on the execution of construction methods; * Be incorporated into Anchorgem's verification work procedure before Concreting.

Execution of the walls	Frame	Drilling	When positioning the frame with the crane, a worker is hit with the tip of the Iron of the frame	Puncture injury to the arm	4	2	3	24	* Training on mechanical movement of Charges;
	Formwork	Crushing	When placing the panel on the floor, the worker is not attentive and places the panel on his foot	Foot fracture	4	3	2	24	* Training on mechanical movement of Charges; * Training in good practices on site;
	Concreting	Hazard w/ electric cable and fall to the same level	No lateral barrier is placed on the work platform during concreting. The worker trips over vibrator cable and falls onto slab	Excoriation	3	3	2	18	*Training in good practices on site *Training on the construction process
	Removal of formwork	Crushing	When storing the panels at the shipyard, the worker does not stack them correctly, causing them to fall on another worker	Leg fracture	4	4	3	48	* Training on good work practices; * Training on mechanical handling of Charge;
	Mechanical movement of charge in the removal of formwork	Trapping	Panel storage is done in a no-visibility zone and wedges a worker against stacked formwork	Excoriation	3	2	2	12	* Training on mechanical movement of Charges; * Camera installation on the crane boom;
Execution of the pillars	Frame	Cut	Worker preparing the Frame trips over material and while holding on to the frame	Cutting injury to the arm	4	3	3	36	* Improved organization of the workplace; * Mandatory use of PPE's;
	Formwork	Shock	When positioning formwork, the crane cables lose stability due to the strong wind and the formwork collides with the worker	Excoriation	3	3	3	27	* Awareness training for work on windy days; * Restrict jobs above 65 km/h;

	Concreting	Fall from height, material projection, electric shock	Worker uses ladder instead of Scaffolding in concreting and due to the pressure of the concrete in the hose, this gives a bump that results in loss of balance and fall of the worker	Arm fracture, partial visibility loss, excoriation	4	4	3	36	* Improved organization on site; * Training in good practices on site; * Use of protective glasses; * Periodic maintenance of material on site; * Verification of the material to be used;
	Removal of formwork	Ttrapping, material projection, fall at the same level	Worker positions himself in the wrong way to perform the removal of formwork and has his hand wedged between the wall and formwork	Shoulder injury, bruise, excoriation	4	4	4	64	* Training on construction process; * Training in good practices on site; * Training in good practices on site; * Training in the use of a lift platform; * Improvement of organization on site; * Delimitation of circulation path; * Training in good practices on site;
Execution of the beams	Frame	Fall to the same level, shock, trapping	When landing the frame on the formwork with the help of the tower crane, an employee trips over material on the floor and falls	Excoriation	3	3	2	18	* Improvement of organization on site; * Delimitation of circulation path; * Training in good practices on site; * Training on mechanical movement of Charges; Camera installation on the crane boom; * Training on construction process;
	Formwork	Fall from height	When assembling the tower, a worker fastens the harness in the wrong place, on the tower itself, and when he loses his balance, he falls from the tower that is not anchored, thus falling the tower and the worker from the facade of the slab	Death	5	4	4	100	* Formation of works in Height; Use of lifeline; * Training on construction process;
	Concreting	Material projection	Worker does not wear glasses during concreting and the concrete is designed for eyes	Partial visibility loss	5	3	4	60	* Training in good practices on site; * Use of protective glasses;

	Removal of formwork	Material projection	When the worker lowers the towers to remove the beam, the hammer escapes and hits a worker from the same team.	Bruise	4	4	3	48	* Replacing gloves with a non-slip model;
General	General	Drilling	In the removal of formwork from the walls, slab or beams, the area was not organized and Wood was left with nails. Worker when passing, steps and sticks his foot	Foot puncture wound	3	2	2	12	* Improved organization on site; * Delimitation for passing zones;
		Cut	When cutting the tying Iron with the help of the grinding wheel, the worker loses his balance and cuts himself	Leg cut	3	3	2	18	* Training for good practices in the use of cutting equipment;
		Shock against material	Worker changes table saw cable changing phase, resulting in inversion of saw rotation. The worker cutting wood, this is projected on himself	Bruise	3	3	2	18	* Training for good practices in the use of cutting equipment;
		Crushing	Worker when using table saw does not remove his gloves, this catches the saw and breaks his finger	Finger fracture	4	5	2	40	* Training for good practices in the use of cutting equipment;
		Fall from height	When entering through the access to the work, an employee slips and loses his balance on the unstable ground and falls in vain	Arm fracture	4	4	2	32	* Placement of protection in vain;