https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

FMEA method application based on occupational risks in the construction industry on work at height: A theoretical contribution

Jhelison Gabriel Lima Uchoa[1], Marcos Jean Araujo de Sousa[2], Luan Henrique Varão Silva[3], André Luis De Oliveira Cavaignac[4]

[1]Ceuma University – UNICEUMA, Imperatriz, Maranhão, Brazil
jhelisong@hotmail.com
[2]Federal Institute of Science and Technology – IFMA, Imperatriz, Maranhão, Brazil
marcosjean.itz@ifma.edu.br
[3]Federal Institute of Science and Technology – IFMA, Imperatriz, Maranhão, Brazil
Luan.varao@gmail.com
[4]Ceuma University – UNICEUMA, Imperatriz, Maranhão, Brazil
andreluiscavaignac@gmail.com

***Abstract*— *Falls with height difference represents one of the greatest risks found in the construction industry. Because of this, there is a need for the development of tools to assist in risk analysis for occupational accidents. FMEA has been increasingly introduced to different construction environments and recent developments have allowed its application as a tool for risk analysis. With this, the present study applies the tool to work in height in the civil construction. For this FMEA were built consisting of working environments such as works near to peripheries, works on supported scaffolds, works on suspended scaffolding and works near openings in the floor. A total of 65 faults were analyzed, showing their relationship between severity, occurrence and detection. With the application of the FMEA, it was possible to perceive that 49,2% of the total number of failures of the analyzed subprocesses are at a moderate level and 35,4% have a high risky degree, thus demonstrating the need for further studies to improve conditions against the inherent risks of work at height.*

***Keywords*— FMEA; Accidents of Work; Work at height; Occupational risks; Civil Construction.**

I. INTRODUCTION

Even though it occupies a small part of the active workers (RINGEN et al. 1995; FAZENDA, 2016) civil construction is one of the sectors of the economy that most groups occupational hazards and accidents at work, being still one of the biggest causes of fatalities in comparison with other industries (MROSZCZYK, 2015; FAZENDA 2016).

Micro and small enterprises make up 94% of the construction industry (TEIXEIRA and LIMBORG, 2005), where the risk is higher compared to large companies because of the low risk control ability (HASLE and LIMBORG, 2006). Wrong employee behavior, stringent legal requirements and the involvement of workers in inappropriate locations compose the barriers to the application of adequate risk management (GARNICA and BARRIGA, 2018). There is still an assertion that construction accidents are caused by poor management and incorrect procedures for execution out the work (HAMID et al. 2008).

Although there are several types of accidents inherent in the industry, such as electrocutions, contact with objects and the use of machines, work at height persists as one of the major causes of accidents (WINGE and ALBRECHTSEN, 2018; HAMID et al. 2008; GUIMARÃES et al. 2000). This issue has attracted the attention from the scientific community and has been demonstrated as a community effort to reduce its severity in cases of failure (NADHIM et al. 2016).

Several studies show the fatalities due to the risks of working at a height. In North American contractors, 264 fatalities in 2009 were related to falls, 40% higher compared to transport-related operations, the second largest fatality generator (MROSZCZYK, 2015). In Europe the same scenario is repeated, of the 782 cases of fatalities recorded in 2014, falls are the most frequent type of accident, accounting for 26% (WINGE and ALBRECHTSEN, 2018). In China, falls represent 56% of the fatal accidents recorded between 2012 and 2016 (SHAO et al. 2018).

Because of the work environment, falls result in a high severity for the worker performing the activity, relating to fatal accidents, contributing to such statistics, however, falls in a general situation still presents as one of the major causes of accidents. In a study of 500 cases of human injuries induced by occupational accidents, 113 (22.6%) were related to falls, followed by 113 (22.6%) caused by fall of objects (Ahmad et al. 2016). Another study analyzed 455 cases of accidents on constructions, in which 101 (22.2%) were cases of falls at height and 78 (17.1%) were cases of fall of objects (Hamid et al. 2008).

Specific studies also reveal a series of patterns by the similarity of environments, actions or failures that lead to the occurrence of fall accidents (NADHIM et al. 2016). Scaffolding and roofing falls, for example, stand out even when presented together with data from outside the construction environment (TÜRKOĞLU et al. 2019; IÇER et al. 2013). Consequently, several authors have sought to demonstrate the conditions under which accidents occur, either in case studies or in documentary reviews. Some of the failures are worthy of attention: failure in scaffolding, openings or deficiencies in the floor, stair-related failures and absences or inadequate use of PPE (WINGE and ALBRECHTSEN, 2018; LEONAVIČIŪTĖ, 2016; LIPSCOMB, 2014; HAMID, 2008; HALPERIN and MCCANN, 2004).

Because of this, there is a need for the development of new tools to improve the current conditions for the prevention of occupational accidents, whether exploring new indicators, mappings or operations understandings (HOVDEN et al. 2009). FMEA is a tool that has gained a wide range of applications in several areas such as food safety (SCIPIONNI et al. 2002), clinical analysis (JIANG et al. 2015), environmental risk assessment (ZAMBRANO and MARTINS, 2007) and administrative procedures (MILAZZO et al. 2009; RHEE and ISHII, 2003).

The FMEA corresponds to a systematized group of activities that can recognize and evaluate the failures of a product or service in addition to identifying which actions can be applied to reduce the probability of their occurrence (FORD, 2011). For your application, it is essential that information or databases be available that complement the research (MACDERMOTT et al. 2009)and this becomes one of the major problems in the construction of the FMEA because the values of the indexes, in situations of little information, become subjective to the teams that perform it (BANGHART, 2018).

In areas of poor tool development, the values of the indexes are imprecise, making it impossible to use the FMEA efficiently in order to guarantee continuous improvement (LAURENTI et al. 2012). However new developments allowed to take the tool to civil construction, from the construction of gabions (PATRICIO et al. 2013) to the application in steel structures (SONG et al. 2007).The FMEA, however, presents the potential of integration in the analysis of occupational hazards within civil construction, Cavaignac and Uchoa (2018), proposed a model for adapting FMEA parameters as an attempt to reduce subjectivity.

Considering these aspects discussed and supported by the development of the FMEA in occupational risk analysis, the present study seeks to bring the applicability of the tool to relate different data presented by several authors regarding failures present in activities on work at height, relating them with their respective environments in the construction industry. Through the study it will be possible to obtain an analysis of the present working conditions in which the workers are exposed, and to bring a representativity of the severity of the works in height to the industry of construction.

II. METHODOLOGY

For the elaboration of this work, research was carried out in the literature available in scientific journals on the subject.The data inserted in the table were obtained from the analysis of the current environment of work safety based on literature, study of the appliedregulations for work in height in the civil construction, searches in news or case studies from failure modes and field visits to study the most commonly used control methods.

Due to the amplitude of the process chosen, it was divided into subprocesses, designated from working environments in height. Four subprocesses were used to prepare the FMEA: works executed near the periphery - incorporates all work done near ends on floors above the ground floor; works carried out on supported scaffolds - incorporates works accomplished using supported scaffolding; works carried out on suspended scaffolds - incorporates works carried out using the suspended scaffold; works executed near openings in the floor – incorporates all work done near the internal ends of the building on floors above the ground floor.

These subsystems were then subdivided into three possible types of failures, to be assigned the potential failure modes. This subdivision seeks to relate failures from their common cause characteristics. The failure types assigned to the FMEA table were: human error – this aspect attributes the failures to problems related to human acts; structural failure – it considers structural failures either in the construction to be carried out or in work equipment; CPE or PPE failure – assigns failures to problems in collective or

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

personal protection systems. The failures were selected from the literature of the theme.

The FMEA will be applied from the parameters presented by Cavaignac and Uchoa (2018), with the objective of reducing subjectivity in the choice of severity, occurrence and detection indices, these values vary from 1 to 10 from their reality to the failure, shown by table 1. The severity value of each failure was selected by the worst situation, considering the more realistic possibilities by case studies presented from the literature. For the occurrence, the same statistical analysis of table 1 was maintained. And the detection was determined by field visits and interviews with professionals of the area.

Table 1 - Adapted indexes to ocupational safety

Severity (S)		Occurrence (O)		Detection (D)	
Index	Consequence of failure	Index	Accidentnature	Index	Detection methods
1	No real impact	6	Impactsuffered	1	Visual inspection
2	Irrelevant trauma	5	Drop with level difference	2	Tactiletest / manual test
3	Trauma requiring firstaid	5	Impactagainst	3	
4	Temporary incapacity without remoteness	5	Excessive or inappropriateeffort	4	
5	Temporary incapacity with small remoteness	5	Pressing or imprisonment	5	check-list/sequence of tests before process
6	Temporary incapacity with large remoteness	5	Fall on the same level	6	
7	Partial permanent disability	4	Noise exposure	7	
8	Total permanentdisability	4	Contact with harmful substance	8	Instrumental inspection /mechanicaltests
9	Death of those involved in the process	4	Electric shock	9	
10	Death of those not involved in the process	3	Friction or abrasion	10	Lack of effective methods
		3	Contact with extreme temperature		

Source: Cavaignac e Uchoa (2018).

III. RESULTS AND DISCURSIONS

The tables represent the body of the FMEA, translating the resulting values of occurrence, severity and detection into their respective RPN for failure modes. Each failure mode was analyzed separately, considering their respective situations and related regulations.

Table.2 - FMEA for works executed near the periphery

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence	Potencial Consequence of Failure	Severity	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
Human Error	Problems in ergonomics	Hamid et al. 2008; Wong et al. 2009	Excessive or inappropriate effort	5	Temporary incapacity without remoteness	4	Tactile	2	40	Moderate
Human Error	Neglect at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence	Potencial Consequence of Failure	Severity	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
Human Error	Imprudence at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Human Error	Disorganization of the work environment	Hamid et al. 2008; Wong et al. 2009	Impact against tools, machines and equipments	5	Trauma requiring first aid	3	Checklist	5	75	Moderate
CPE or PPE Failure	Absence of the guardrail	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
CPE or PPE Failure	Failure of the guardrail	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Tactile	3	135	High
CPE or PPE Failure	Absence of the toe board	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Impactfrom mfallingobjects	6	Death of those not involved in the process	10	Visual	1	60	Moderate
CPE or PPE Failure	Failure of the toe board	Winge and Albrechtsen, 2018	Impactfrom mfallingobjects	6	Death of those not involved in the process	10	Tactile	4	240	Critical
CPE or PPE Failure	Absence of the safety net	Leonavičiūtė et al. 2016	Impact from falling objects	6	Death of those not involved in the process	10	Visual	1	60	Moderate
CPE or PPE Failure		Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
CPE or PPE Failure	Failure of the safety net	Leonavičiūtė et al. 2016	Impact from falling objects	6	Total permanent disability	8	Instrumental inspection	9	432	Critical
CPE or PPE Failure		Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those involved in the process	9	Instrumental inspection	9	405	Critical

https://dx.doi.org/10.22161/ijaers.610.40 *ISSN: 2349-6495(P) | 2456-1908(O)*

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence	Potencial Consequence of Failure	Severity	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
CPE or PPE Failure	Absence of protection net	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Impact from falling objects	6	Death of those not involved in the process	10	Visual	1	60	Moderate
CPE or PPE Failure	Failure of PPE	Leonavičiūtė et al. 2016; Hamid et al. 2008	Drop with level difference	5	Death of those involved in the process	9	Tactile	4	180	High

Source: the authors (2019).

Problems in ergonomics consider the execution of work without adaptations of the environment for the employee, forcing him to long working days without pauses, while exposed to adverse conditions. This may result in temporary incapacity without remoteness, having as potential cause of failure excessive or inappropriate efforts. The worker's own tactile discomfort can be used as a control measure, triggering or not the need for adaptations of the work environment, so his degree of risk is classified as moderate.

Negligence in work implies in the omission of the correct use of the PPE or lack of attention in the execution of the activities, its potential consequence is the death by the fall with level difference of the employee, since the incorrect use of the EPI's can lead to an unnecessary risk. Check lists identify the need or lack of PPE for the execution of activities and in some cases of work that require more attention, help to maintain the correct sequence of execution. The high severity in cases of errors committed by negligence results in a critical degree of risk.

Imprudence at work is the condition of the workeris put at risk by own responsibility, the worker takes inappropriate attitudes of risk with the mentality of ensuring the full functionality of PPE. This may result in the death of those involved in the process by the drop with level difference, as usually this risk action happens during absence of the supervisor, as NR 18 inhibits the execution of work at height without supervision, the control means to detect the failure is visual. This gives the failure a moderate degree of risk.

The disorganization of the work environment includes both the deposit of materials from the execution of previous activities and the inadequate disposition of the materials used in the actual activities. This failure mode considers the contact that the employee can have with these materials, making the activity difficult. In the event of accidents, a concussion or cuts may occur, trauma requiring first aid. Routine workplace checks should be maintained and controlled through check lists prior to performing any work at a height. The risk level is moderate.

Absence and failure of the bodyguard has the consequence of falling with a different level of worker, with the possibility of death of those involved in the process. The absence of the bodyguard, which is visually verifiable directly by the control methods, has its detection almost certain, its risk degree is moderate. Since its failure to be something unforeseeable and difficult to verify, considering several variables, such as failure of the structure by impact or mismatch during the installation, requires a tactile inspection of the perimeter of cover as a measure of control, its risk degree is moderate.

The absence and failure of the toe board has as potential cause of the failure the impact suffered by falling objects on the pavement below, either by falling tools or falling material. The impact of a high altitude can cause death of not involved in the process. The absence of the toe board, as it is visually detectable, has an almost certain probability of detection, which results in a moderate risk degree. Its failure, which does not present control methods and can occur either by the presence of small openings or by the failure of the materials resistance, requires tactile inspection as a control measure, because of this therisk degree is critical.

The safety nethas the objective, toprotect from the fall of materials and reduce the height of fall of people. Its absence due to being easily verified visually, has almost certain detection, two consequences are possible in this case: impact suffered by falling object with death of not involved in the process, having moderate risk degree; and the fall with death of the employees, due to the inability to reduce their fall height, this fault has a moderate risk degree.

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

The failure of the safety net can occur due to its poor design, small openings, poor fixation and bad anchoring in the structure. That is, when it is installed, but there is an impediment of the execution of its objectives. Failure of its building materials requires an instrumental inspection as a means of control, in other cases cited faults, requires visual or tactile inspections with installation. Its failure can result in the impact suffered by falling object with permanent disability or even the fall with level difference with death of involved in the process, both have With the absence of the protection net there is no impediment of objects thrown by the execution of the activities to reach areas outside the protection platforms. These thrown objects expose both the workers and the people close to the building. Its consequence is the impact suffered by falling objects with the possibility of death of not involved in the process. As your control measure involves a visual inspection, therisk degree is moderate.

As a consideration of PPE, respective failures to personal fall protection were analyzed, such as: Lifeline rupture, rupture of the lanyard, failure or rupture of the fall arrester, carabiner rupture, rupture on the body harness and anchor structure failure. These items are crucial to the maintenance of the life of the employee who performs the activity, and they failure causes to fall with level difference with death involved in the process.The lifeline and lanyard should be exposed as a control measure to a tactile inspection of its entire surface for imperfections or apparent failure of its materials prior to the execution of the activities. Their failure has a high risk degree.

Table3 FMEA for works carried out on supported scaffolds

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence	Potencial Consequence of Failure	Severity	ControlMeasures	Detection	RPN	Risk Degree
Human Error	Problems in ergonomics	Hamid et al. 2008; Wong et al. 2009	Excessive or inappropriat eeffort	5	Temporary incapacity without remoteness	4	Tactile	2	40	Moderate
Human Error	Neglect at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Total permanent disability	8	Checklist	5	200	Critical
Human Error	Imprudence at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Total permanent disability	8	Visual	1	40	Moderate
Human Error	Disorganization of the work environment	Hamid et al. 2008; Wong et al. 2009	Impact against tools, machines and equipments	5	Trauma requiring first aid	3	Checklist	5	75	Moderate
Structural Failue	Scaffold structure overload	Winge and Albrechtsen, 2018; Halpein and McCann, 2004; Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Structural Failue	Displacement of scaffold structure during use	Winge and Albrechtsen, 2018	Drop with level difference	5	Total permanent disability	8	Visual	1	40	Moderate

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence	Potencial Consequence of Failure	Severity	ControlMeasures	Detection	RPN	Risk Degree
Structural Failue	Irregular Scaffold Mounting	Winge and Albrechtsen, 2018; Halpein and McCann, 2004; Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those involved in the process	9	Checklist	6	270	Critical
Structural Failue	Slope on scaffold attachment surface	Winge and Albrechtsen, 2018; Halpein and McCann, 2004; Leonavičiūtė et al. 2016	Drop with level difference	5	Total permanentdisability	8	Tactile	3	120	High
Structural Failue	Absence of locking against undocking	Halpein and McCann, 2004	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Structural Failue	Scaffold with degradation in its state of use	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	6	270	Critical
Structural Failue	Irregular workingenvironment	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Structural Failue	Absence of complete scaffold floor	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Structural Failue	Rupture of scaffold floor	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical
Structural Failue	Poor floor fixing	Winge and Albrechtsen, 2018; Halpein and McCann, 2004	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical
Structural Failure	Absence of stairs	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Drop with level difference	5	Temporary incapacity with small remoteness	5	Visual	1	25	Minor / Secondary
Structural Failure	Stair case failure	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Drop with level difference	5	Temporary incapacity with large remoteness	6	Tactile	3	90	Moderate
Structural Failure	Incorrect material disposal	Winge and Albrechtsen, 2018	Impactfrom fallingobjects	6	Temporary incapacity	6	Visual	1	36	Minor / Secondary

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence	Potencial Consequence of Failure	Severity	ControlMeasures	Detection	RPN	Risk Degree
					with large remoteness					
CPE or PPE Failure	Absence of the guardrail	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Drop with level difference	5	Total permanent disability	8	Visual	1	40	Moderate
CPE or PPE Failure	Failure of the guardrail	Winge and Albrechtsen, 2018	Drop with level difference	5	Total permanent disability	8	Tactile	3	120	High
CPE or PPE Failure	Absence of the toe board	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Impact from falling objects	6	Temporary incapacity with large remoteness	6	Visual	1	36	Minor / Secondary
CPE or PPE Failure	Failure of the toe board	Winge and Albrechtsen, 2018	Impact from falling objects	6	Temporary incapacity with large remoteness	6	Tactile	4	144	High
CPE or PPE Failure	Failure of PPE	Leonavičiūtė et al. 2016; Hamid et al. 2008	Drop with level difference	5	Total permanentdisability	8	Tactile	3	120	High

Source: the authors (2019).

The human errors take the same assumptions discussed previously, for their causes and control measures were assigned the same coefficients of work near the periphery. To determine the severity of negligence and imprudence in the execution of the work was considered the height of fall of the use of supported scaffolding that can result in the total permanent disability of the employee.

Scaffold structure overload occurs when the load of both materials and people exceeds the material's resilience. Usually this can occur when there is a purpose to accelerate the activities that are being performed. This can result in a drop in level difference with death of those involved in the process, since in addition to the impact of your body against the ground there may be perforations or other impacts by the debris from the collapse of the structure. As there will usually be no generalized consensus in the work of the maximum load capacity of the scaffold, its overload load can be confirmed visually. Because of the high severity its risk degree is moderate.

The displacement of the structure of the scaffold during use occurs in situations in which, in order to accelerate the construction process, the requirement of the release of the use of the scaffold is not made, because of this it is carried from one point to another of the construction still loaded with people or materials. Therefore, this can result in the fall with difference of level of the worker, by the considered height of the scaffolding and the fall being outside of the structure, we have the total permanent incapacity of the worker. Because it is visually verifiable directly, the control means can almost certainly detect the fault, because of that its risk degree is moderate.

There is also the possibility that structural failure can arise from the irregular assembly of the scaffold structure, services not inspected by qualified professionals before the start of their use can result in the fall with level difference with death of involved in the process, because the contact with the structure during the failure can result in head impacts or perforations in the body. Checking the equipment prior to the execution of the activities can be done using check lists addressing crucial points of the structure assembly. Its risk degree is critical.

The installation of the scaffold on an irregular surface with unevenness can result in its tipping or the movement in the scaffold floor resulting in an imbalance of the employees, with that the consequence of the failure is the fall with difference of level of the worker with total

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

permanent incapacity. It may be visually verifiable prior to the use of the structure in case of more aggravating gradients. It has a moderate risk degree.

The detachable locking prevents full collapse of the structure in case of irregular assembly or other failures in the structure, its absence can then, in case of collapse, cause the fall with a difference of level of the employee, which in addition to the impact with the ground can be punctured by the collapsed structure, resulting in the death of those involved in the process. As this is an easily verifiable mechanism by visual inspection of the structure after assembly, it is almost certain that the fault will be detected. Its risk degree on account of its easy detection is moderate.

The state of degradation of the scaffold may be presentedfrom both the apparent oxidation and the appearance of lesions in the structure or irregular behavior of its fixations. The degradation can lead to a rupture of the structure, causing the fall with a difference of level of the contributing with death due to other injuries with the collapse. This degradation, although may be apparent in some cases, may occur in places of difficult verification, such as in joining the components or internally to metal parts, in some cases requiring a operation using check list to fully stats its condition. Itsrisk degree is critical.

It is also indispensable to check the work environment for the execution of the activities in the scaffold, since the proximity of the structure to electrical networks can result in the electric shock and fall with level difference with death of the employee. Although it is visually verifiable prior to the execution of the work, other factors must be considered, such as the possibility of anchoring for PPE, its risk degree is moderate.

The absence of complete work floor, rupture and poor fixation, consider the fall of the worker internally to the structure of the scaffold, with the possibility of impact with the fittings of the structure, with the consequence of the death of involved in the process. The absence of complete work floor is almost certain to be detected by visual confirmation of the structure and its risk degree is moderate. The rupture of the floor that can happen immediately due to the failure of the materials or overload requiring in some cases check lists to verify certain aspects of the scaffold floor, its risk degree is critical. The poor fixation of the work floor can be visually checked, but in some cases the irregular assembly of the platforms may not be apparent, so the tactile verification becomes necessary, its risk degree is critical.

Stairs must be fixed to the structure of the scaffold, therefore two possible failures were considered: Their absence and their failure. The absence of the ladder may result in a level difference during scaffold climbing, which consequently results in temporary disability with large remoteness, this failure mode being visually recognized, have arisk degree minor or secondary. However, its failure can occur either by rupture of the ladder structure or by slipping during its climb, has as a consequence the fall with temporary incapacity with large remoteness, its survey can be done tactile to confirm its structural stability and absence of other failures, itsrisk degree is moderate.

Incorrect disposal of materials considers the fall of materials during the execution of the activity, due to the low altitude of the execution of the activities on the supported scaffold this mode of failure has as consequence the temporary incapacity with large remoteness by the impact suffered by falling object. By supervising the execution of the work on the scaffold this mode of failure can be detected visually, because of this its risk degree is minor or secondary.

The absence and failure of the bodyguard has as severity the total permanent disability of the worker, this severity considers the fall in the external region of the structure of the scaffold. The risk degree of the absence of the bodyguard is moderate, due to the ease of its detection. The failure of the bodyguard has a high risk degree because of its high severity and difficult detection.

Absence and failure of the toe bard has as severity the temporary disability with large remoteness of the employee. The absence of the footboard has a minor or secondary risk degree due to its visual detection and the footboard failure has a high risk degree because of the difficulty of detection before the failure occurs.The failures of PPE also assume the same values assigned to work next to peripheries, only the severities had different values to better fit the execution of works in supported scaffolds.

Table.4 - FMEA for works carried out on suspended scaffolds

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence (O)	Potencial Consequence of Failure	Severity (S)	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
Human Error	Problems in ergonomics	Hamid et al. 2008; Wong et al. 2009	Excessive or	5	Temporary incapacity	4	Tactile	2	40	Moderate

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence (O)	Potencial Consequence of Failure	Severity (S)	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
			inappropriateeffort		without remoteness					
Human Error	Neglect at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical
Human Error	Neglect at PPE use	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Human Error	Disorganization of the work environment	Hamid et al. 2008; Wong et al. 2009	Impact against tools, machines and equipments	5	Trauma requiring first aid	3	Checklist	5	75	Moderate
Structural Failure	Irregular Scaffold mounting	Winge and Albrechtsen, 2018; Halpein and McCann, 2004; Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those not involved in the process	10	Checklist	6	300	Critical
Structural Failure	Scaffold with degradation in its state of use	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those not involved in the process	10	Checklist	6	300	Critical
Structural Failure	Scaffold structure overload	Winge and Albrechtsen, 2018; Halpein and McCann, 2004; Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those not involved in the process	10	Visual	1	50	Moderate
Structural Failure	Instability of scaffoldstructure	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	7	315	Critical
Structural Failure	Absence of scaffold	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those	9	Checklist	5	225	Critical

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence (O)	Potencial Consequence of Failure	Severity (S)	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
	anchorage at work level				involved in the process					
Structural Failure	Irregular workingenvironment	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical
Structural Failure	Rupture of scaffold floor	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical
Structural Failure	Incorrect material disposal	Winge and Albrechtsen, 2018	Impactfromfallingobjects	6	Total permanent disability	8	Visual	1	48	Moderate
CPE or PPE Failure	Absence of the guardrail	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
CPE or PPE Failure	Failure of the guardrail	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	6	270	Critical
CPE or PPE Failure	Absence of the toe board	Winge and Albrechtsen, 2018; Leonavičiūtė et al. 2016	Impact from falling objects	6	Death of those not involved in the process	10	Visual	1	60	Moderate
CPE or PPE Failure	Failure of the toe board	Winge and Albrechtsen, 2018	Impact from falling objects	6	Death of those not involved in the process	10	Checklist	6	360	Critical
CPE or PPE Failure	Failure of PPE	Leonavičiūtė et al. 2016; Hamid et al. 2008	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate

Source: the authors (2018).

The human errors for suspended scaffolds follow the same work environments assigned to the peripheries, because of this the same parameters were applied for the occurrence, severity and detection.

There is the possibility that failure points in the structure of the scaffolding can be left during the assembly, this can lead to disassembly at critical points causing a drop with level difference with death of those not involved in the process. This failure can occur in several visible ways, such as disengagement and lack of pressure on the screws, check lists can be applied to check the most crucial points of the structure. It has critical risk degree.

The overload occurs when the specified design load of the scaffold is exceeded, in this case the overload refers to the structural failure of the metal beams in which the work floor is supported, which can result in the fall with level difference with the employee's death. Although the rupture can occur immediately, the overload is considered when

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

loading the scaffold, because of this the failure has a high probability of detection, its risk degree is critical.

Suspended scaffolds should have their stability guaranteed throughout the work execution time, the instability of the scaffolding may come from either poor fixation, poor leveling or irregular descent of the scaffold. The instability can cause the fall with a difference of level of the employee with death, its method of control is defined by the adequate training of the users of the scaffold and the supervision of those in charge of the control, being able to have as a control measure the tactile of the employee. Its risk degree is critical.

The suspended scaffolding must also be fixed at the work level. If there is no fixation, winds and movement inside the scaffold can lead to the displacement of the structure, resulting in the drop with level difference with death of the worker. This failure can be detected through the training and checklist application of the adequacy of the work environment before the execution of the activities, because of this there is a high probability of detection. Itsrisk degree is critical.

The working environment from which the scaffolding is to be passed should also be checked. Obstacles may meet the scaffolding pulley system, or the structure mayencounter power grids. Although it is a visual check, some obstacles can go unnoticed by the team that performs the activity, so there is a need to apply a checklist addressing all aspects that must be verified during the installation of the scaffolding, due to this its risk degree is critical.

There is also the possibility of rupture of the work floor, this can occur through overload, bad conditions of use and poor assembly. It can cause the fall with level difference with death of the worker. Its risk degree is critical.

Table.5 - FMEA for works executed near openings in the floor

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence (O)	Potencial Consequence of Failure	Severity (S)	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
Human Error	Problems in ergonomics	Hamid et al. 2008; Wong et al. 2009	Excessive or inappropriate effort	5	Temporary incapacity without remoteness	4	Tactile	2	40	Moderate
Human Error	Neglect at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Death of those involved in the process	9	Checklist	5	225	Critical
Human Error	Imprudence at work	Hamid et al. 2008; Cakan et al. 2014; Wong et al. 2009	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
Human Error	Disorganization of the work environment	Hamid et al. 2008; Wong et al. 2009	Impact against tools, machines and equipments	5	Trauma requiringfirstaid	3	Checklist	5	75	Moderate
Structural Failure	Rupture of the ladder structure	Winge and Albrechtsen, 2018	Drop with level difference	5	Temporary incapacity with small remoteness	5	Instrumental inspection	8	200	Critical

https://dx.doi.org/10.22161/ijaers.610.40 ISSN: 2349-6495(P) | 2456-1908(O)

Type of Failure	Potencial Failure Mode	Reference	Potential Cause of Failure	Ocurrence (O)	Potencial Consequence of Failure	Severity (S)	ControlMeasures	Detection (D)	RPN (SxOxD)	Risk Degree
Structural Failure	Absence of ladder attachment and support	Winge and Albrechtsen, 2018	Drop with level difference	5	Temporary incapacity with large remoteness	6	Tactile	3	90	Moderate
Structural Failure	Ladder resting on non-resistant floor	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	6	270	Critical
Structural Failure	Absence of walkways	Cakan et al. 2014	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
CPE or PPE Failure	Poorsizing of walkways	Cakan et al. 2014	Drop with level difference	5	Death of those involved in the process	9	Instrumental inspection	9	405	Critical
CPE or PPE Failure	Rupture of the provisional closure	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Checklist	6	270	Critical
CPE or PPE Failure	Absence of the elevator access closure	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Visual	1	45	Moderate
CPE or PPE Failure	Failure of the elevator access closure	Winge and Albrechtsen, 2018	Drop with level difference	5	Death of those involved in the process	9	Tactile	3	135	High

Source: the authors (2019).

In relation to the use of stairs were considered three failures, the rupture of the structure of the ladder, the absence of fixation of the support of the ladder and the ladder supported on non-resistant floor.

For the rupture of the ladder structure, it was considered a fall with a difference in level, resulting in temporary disability with a small remoteness. As the failure can occur suddenly, whether by overload or bad condition of the ladder, the control measure is made by instrumental inspection, its risk degree is critical.

However,the absence of upper and lower attachment of the ladder supports may lead to accidental slippage of the structure, resulting in a fall with temporary injury with large remoteness. This failure can be tactile and visually recognized before the activity is executed. Its risk level is moderate.

There is also the chance that the ladder will be supported on non-resistant flooring, leading to falling between floors causing death of involved in the process. Detection of this failure is unlikely since a direct verification of the bearing surface is required, and rupture may occur immediately due to overload. This failure has a critical risk degree.

When crossing people or moving materials through an opening in the floor, it is necessary to install walkways. The absence of the walkways can result in a fall with a difference of level of the worker with death of those involved in the process, this fault can be verified visually, then it is almost certain that it will be detected, its risk degree is moderate. Poor sizing should also be considered because of the movement of loads on the walkways, the walkways should be monitored through instrumental inspection after its installation. Its risk degree is critical.

Provisional floor closuresprevent falling between floors in case of landslides. These closures can rupture in the event of major impacts, resulting in employee death. As there is unpredictability related to the rupture, it may be due to the quality of the material or the impact load, it becomes necessary a application of a check list to verify all openings. Its risk degree is critical.

Absence and failure to elevator access closure should also be considered. The absence can result in the fall of the worker with death, however it has its detection almost certain in visual form by the methods of control, its risk degree is moderate. The failure of the closure considers the bad installation or the failure of the material, can result in the fall of the employee with death, the control measure is tactile to verify its stability and installation, its risk degree is high.

3.1. Discussion

Several studies have demonstrated the link between different characteristics related to fall in height, such as the distribution between genders, age, place of fall and height of fall (TÜRKOĞLU et al. 2019; IÇER et al. 2013). In addition to the construction work, these characteristics go deeper into the analysis of the function performed, the type of construction and the activity that was being carried out during the accident (SHAO et al. 2008; WINGE and ALBRECHTSEN, 2017; AHMAD et al. NADHIM et al. 2016; LIPSCOMB et al. 2014). However two things become preponderant in these analyzes, the work environment performed and the causes of the accident, here being referred to as the 'failure' which translated an error during the operation to the accident.

From the data obtained by the FMEA, it is possible to be observed which work environments translate to a greater danger for the worker. Suspended scaffolds have an average RPN of 192.4, followed by openings in the floor with a mean of 159, works near the periphery with average RPN of 152 and scaffolds backed with 115. Winge and albrechtsen (2019) and Kang (2018) demonstrate in their studies that failures related to falls from the roof / platform / floor and falls from scaffolding are the biggest cause of accidents in work at height.

. In total, 65failure modes were investigated, varying by failure types and subprocess. The following table shows the result obtained and its statistical relationships.

Table.6 - Statistical Relationship from the FMEA

Index	Subprocess	Periphery	Supported Scaffolds	Suspended Scaffolds	Openings in the floor	Total	%
Ocurrence (O)	Drop with level difference	7	17	12	10	46	70,8%
	Impact from falling objects	5	3	3	0	11	16,9%
	Impact against tools, machines and equipments	1	1	1	1	4	6,2%
	Excessive or inappropriate effort	1	1	1	1	4	6,2%
	Total	14	22	17	12	65	100,0%
Severity (S)	Trauma requiring first aid	1	1	1	1	4	6,2%
	Temporary incapacity without remoteness	1	1	1	1	4	6,2%
	Temporary incapacity with small remoteness	0	1	0	1	2	3,1%
	Temporary incapacity with large remoteness	0	4	0	1	5	7,7%
	Total permanent disability	1	7	1	0	9	13,8%
	Death of those involved in the process	7	8	9	8	32	49,2%
	Death of those not involved in the process	4	0	5	0	9	13,8%
	Total	14	22	17	12	65	100,0%
Detection (D)	Visual	6	10	6	3	25	38,5%
	Tactile	4	6	1	3	14	21,5%
	Checklist	2	6	10	4	14	33,8%
	Instrumental inspection	2	0	0	2	12	6,2%
	Total	14	22	17	12	65	100,0%
Risk Degree	Minor / Secondary	0	3	0	0	3	4,6%
	Moderate	8	10	8	6	32	49,2%

High	2	4	0	1	7	10,8%
Critical	4	5	9	5	23	35,4%
Total	14	22	17	12	65	100,0%

Source: the authors (2019).

The occurrence of drop with level difference represented the potential cause of the failures with the highest result, with 70,8%, followed by impact suffered by falling objects with 16,9%. Impact against tools, machines and equipment represented, along with excessive or inadequate effort, 6,2% of the cases, because they were attributed to only one failure mode in each subprocess.This same pattern of linkage of the occurrence of failures is revealed in the case study of construction accidents, as demonstrated in the studies by Winge and albrechtsen (2019) and Ahmad et al. (2016), where falls in height are the main cause of failure, followed by contact with falling objects or thrown objects and contact with tools.

Through each work environment and the types of failure explored, severities were established from their consequences for workers. Because of this, the severities seek to correlate the failures of the execution of the work activities at height, with the physical incapacitation of the worker. Of the failure methods surveyed, 49,2% resulted in the death of those involved in the process, followed by 13,8% with total permanent disability and 13.8% with death of those not involved in the process. This is due to the critical nature of the activities, which usually expose employees to life-threatening activities. These summed values result in 76,8% of the analyzed severities, the remaining values come from temporary, permanent incapacity and traumas that require first aid.

Supported scaffolding has the greatest number of failures in which the consequence is permanent incapacity, this is due to the work environment, in which the fall height considered for the failures is smaller than those of the other subprocesses. In contrast, suspended scaffolds have death of those involved in the process as the severity with greater number of cases.Several studies demonstrate how scaffolding results in the greatest amount of fatality in high-rise construction work. Türkoğlua et al. (2019) relates in his study 16 fatality by scaffolding of the 23 cases related to construction. Leonavičiūte et al. (2016) shows scaffolds as the major cause of fatalities with 6 recorded cases. Mroszczyk (2015) places scaffolding as the third largest generator of fatalities in construction, with 37 deaths.

The detection is determined from the control measures for the studied process. To delimit this index, was considered the ways in which faults can be discovered by the control system. Failure modes that have a visual inspection method represent 38,5% and that require a tactile or check lists represents 21,5% and 33,8% respectively, and instrumental inspection characterize 6,2% of the analyzed failures.

The RPN value is the product of occurrence, severity, and detection values. Consequently, the high degree of risk of the failure may be the result of a single specific index, which should then be the focus of the RPN reduction action. 49,2% of the failures had a degree of moderate degree, while 35,4% had a critical risky degree. This is due both to the high severity of accidents at work because deaths are attributed to most of the failures, as well as to the inability of the control methods to detect failures efficiently.Failure modes considered as minor or secondary were cases where there is a non-compliance with the basic safety means, which are easily found by control methods or cases where the severity is low.

The sub-processes of periphery andsupported scaffolding followed the same pattern as the suspended scaffold, with a degree of risk mostly at critical level. Openings in the floor had the same number of critical and moderate cases, this was due to the detection, in which the faults have a high probability of being detected.

Zeng et al. (2010) through a case study with the application of FMEA, notes the importance of integrating a cycle of continuous improvement, such as the Deming cycle, to achieve the desired reliability. In its study, it also classifies falls of the periphery, impact by falls of objects and openings in the floor of the construction as unacceptable faults. Patricio et al. (2013) obtained a moderate criticality for most of the faults in his case study of gabion construction using only severity and occurrence.

Reduction of RPN is possible by increasing the probabilities that failures are detected before they occur by adding new control methods to the work routine. Consequently, with the standardization of more efficient control methods in the detection of failures, there will be a reduction in its occurrence, further reducing RPN. The severity values can be reduced by the restructuring of CPE and PPE or even means of carrying out the activity that can expose employees to less risky situations.Table 7 presents actions that can be taken for the five largest RPNs resulting from the FMEA.

Table.7 – Actions to be taken on the fivelargestRPN

Position	Potencial Failure Mode	Risk Degree	Actions
1	Failure of the safety net	Critical	Professional set up; Utilize technological agent: safety monitoring system; Improve to the ergonomics
2	Poorsizing of walkways	Critical	Professional set up; Utilize technological agent: safety monitoring system;
3	Failure of the toe board	Critical	Professional set up; Frequent revision of safety regulation and regular inspection of sites
4	Instability of scaffold structure	Critical	Training for unskilled workers; Courses on how to use scaffolding agents; Stimulate emplyees to follow safety regulations;
5	Irregular scaffold mounting	Critical	Develop of scaffold safe erecting and dismantling; Professional set up; Frequent revision of safety regulations and regular inspections of sites

Source:Nadhim et al. 2016 adapted.

IV. CONCLUSION

This study allowed a better vision of the possible flaws found in work at height. The high number of failure modes defined as critical by RPN only showed the importance of actively maintaining security and control measures for these activities. These control measures should consider not only the maintenance and correct functioning of the equipment, but also the mental and physical well-being of the employees involved in these risky activities. Because of this, frequent training should be maintained, activities with guaranteed ergonomics should be attributed and recovery time between activities must be respected.

With recent developments FMEA has become a very useful tool for developing risk assessments. He demonstrated the determination of quantitative values for the prioritization of qualitative problems. However, in order to have a greater view on the possible causes of failures within a system, there is a need to have a multidisciplinary team and a history of data documenting failures of this process.

Therefore, the application of FMEA as demonstrated here does not demonstrate all possible failure modes, but only with this perspective is it possible to observe the criticality of safety in works at height.With the completion of this study, the next step is then the application of a quality system based on the data obtained by the FMEA. This quality system may privilege the analysis of risk degree for the prioritization the execution of corrections in failure modes, seeking to mitigate or reduce its consequences.

One of the major limitations of the study is the lack of information about work accidents in construction. This information would allow a better delimitation of the occurrences for each construction process, helping to give a better characterization for the faults.

The same process presented here can be applied in different systems and work environments in the construction industry, trying to select which equipments or actions offer a greater risk to the employee. The FMEA can also have its indexes adapted to other areas of construction, aiming at a perspective beyond safety at work. Because of this, it is necessary to develop and demonstrate the application of these methods in areas such as projects, budgets or constructive models. The flexibility of the FMEA can extend the entire civil construction, ensuring a continuous improvement of the different processes.

REFERENCES

[1] AHMAD, S. IRAJ, M. ABBAS2, M. MAHDI, A. 2016. Analysis of occupational accidents induced human injuries: A case study in construction industries and sites. Journal of Civil Engineering and Construction Technology, v. 7, n. 1, p. 1-7. DOI: 10.5897/JCECT2015.0379

[2] BANGHART, M. BABSKI, K. BIAN, L. STRAWDERMAN, L. 2018. Subjectivity in Failure Mode Effects Analysis (FMEA) Severity Classification within a Reliability Centered Maintenance (RCM) Context. International Journal of Aviation, Aeronautics, and Aerospace, v. 5, n. 1, p. 2. DOI: 10.15394/ijaaa.2018.1191

[3] CAKAN, H. KAZAN, E. USMEN, M. 2014. Investigation of factors contributing to fatal and nonfatal roofer fall accidents. International Journal of Construction Education and Research, v. 10, n. 4, p. 300-317. DOI: 10.1080/15578771.2013.868843

[4] CAVAIGNAC, A. UCHOA, J. 2018. Obtaining FMEA's indices for occupational safety in civil construction: a theoretical contribution. Brazilian Journal of Operations & Production Management, v. 15, n. 4, p. 558-565. DOI: 10.14488/BJOPM.2018.v15.n4.a9

[5] Fazenda, M. D. 2016. Anuário estatístico da previdência social, Instituto Nacional do Seguro Social, Brasília. Available from: http://www.previdencia.gov.br/wp-content/uploads/2018/07/aeps2016.pdf (access 22 jun 2018).

[6] FORD MOTOR COMPANY. 2011. Failure Mode and Effects Analysis: FMEA Handbook, Version 4.2.

[7] GARNICA, G; BARRIGA, G. 2018. Barriers to occupational health and safety management in small Brazilian enterprises. Production, v. 28 DOI: 10.1590/0103-6513.20170046

[8] GUIMARÃES, L. COSTELLA, M. CREMONINI, R. 2000. Analysis of work accidents and professional diseases in Rio Grande do Sul state construction industry. Proceedings of the IEA 2000/Human Factors and Ergonomics Society Annual Meeting.

[9] HALPERIN, K. MCCANN, M. 2014. An evaluation of scaffold safety at construction sites. Journal of Safety Research, v. 35, n. 2, p. 141-150. DOI:10.1016/j.jsr.2003.11.004

[10] HAMID, A. MAJID, M; SINGH, B. 2008. Causes of accidents at construction sites. Malaysian journal of civil engineering, v. 20, n. 2.

[11] HASLE, P; LIMBORG, H. A. 2006.Review of the literature on preventive occupational health and safety activities in small enterprises. Industrial health, v. 44, n. 1, p. 6-12.

[12] HOVDEN, J. ALBRECHTSEN, E. HERRERA, A. 2010. Ivonne. Is there a need for new theories, models and approaches to occupational accident prevention?. Safety Science, v. 48 p. 950-956. DOI:10.1016/j.ssci.2009.06.002

[13] İÇER, M. GÜLOĞLU, C. ORAK, M. ÜSTÜNDAĞ, M. 2013. Factors Affecting Mortality In Falls From Height. UlusTravmaAcilCerrDerg, v. 19, n. 6. DOI: 10.5505/tjtes.2013.77535

[14] JIANG, Y. JIANG, H. LIU, S. 2015. Application of failure mode and effects analysis in a clinical chemistry laboratory. Clinica Chimica Acta, v. 448, p. 80-85. DOI: 10.1016/j.cca.2015.06.016

[15] LAURENTI, R. VILLARI, B. ROZENFELD, H. 2012. Problemas e melhorias do método FMEA: uma revisão sistemática da literatura. P&D em Engenharia de Produção, Itajubá, vol. 10, nº 1, p. 59-70.

[16] LEONAVIČIŪTĖ, G. DĖJUS, T. ANTUCHEVIČIENĖ, J. 2016.Analysis and prevention of construction site accidents. Građevinar, v. 68, n. 05., p. 399-410. DOI: 10.14256/JCE.1428.2015

[17] LIPSCOMB, H. SCHOENFISCH, A. 2014. CAMERON, W. et al. How well are we controlling falls from height in construction? Experiences of union carpenters in Washington State, 1989–2008. American Journal of Industrial Medicine. v. 57, n. 1, p. 69-77. DOI: 10.1002/ajim.22234.

[18] MCDERMOTT, R. MIKULAK, R. BEAUREGARD, M. 2009. The basics of FMEA. SteinerBooks.

[19] MILAZZO, M. ANCIONE, G. LISI, R. VIANELLO, C. MASCHIO, G. 2009.Risk management of terrorist attacks in the transport of hazardous materials using dynamic geo events. Journal of Loss Prevention in the Process Industries, vol. 22, nº 5, p. 625-633. DOI: 10.1016/j.jlp.2009.02.014

[20] MROSZCZYK, J. 2015. Improving construction safety: A team effort. Professional Safety, v. 60, n. 06, p. 55-68.

[21] NADHIM, E. HON, C. XIA, B. STEWART, I. FANG, D. 2016. Falls from Height in the Construction Industry: A Critical Review of the Scientific Literature. Int. J. Environ. Res. Public Health, v. 13, n. 638. DOI: 10.3390/ijerph13070638

[22] PATRICIO, R. CATAI, R. MICHAUD, C. NAGALLI, A. 2013. Model of risk management based in the FMEA technique–a case study in the construction of Gabions. Electron J Geotech Eng, vol. 18, p. 4183-4199.

[23] RHEE, S. ISHII, K. 2003. Using cost based FMEA to enhance reliability and serviceability. Advanced Engineering Informatics, vol. 17, nº 3-4, p. 179-188. DOI: 10.1016/j.aei.2004.07.002

[24] RINGEN, K. SEEGAL, J. ENGLAND, A. 1995. Safety and health in the construction industry. Annual review of public health, v. 16, n. 1, p. 165-188, 1995. DOI: 10.1146/annurev.pu.16.050195.001121

[25] SCIPIONI, A. SACCAROLA, G. CENTAZZO, A. ARENA, F. 2002.FMEA methodology design, implementation and integration with HACCP system in a food company. Food Control, vol. 13, nº 8, p. 495-501. DOI: 10.1016/S0956-7135(02)00029-4

[26] SHAO, B. HU, Z. LIU, Q. CHEN, S. HE, W. 2009. Fatal accident patterns of building construction activities in China. v. 111, p. 253-263. DOI:10.1016/j.ssci.2018.07.019

[27] SONG, J. YU, J. KIM, C. 2007. Construction safety management using FMEA technique: Focusing on the cases of steel frame work. In: 23rd Annual ARCOM Conference. p. 3-5.

[28] TEIXEIRA, L; CARVALHO, F. 2005. A construção civil como instrumento do desenvolvimento da economia brasileira. Revista Paranaense de Desenvolvimento, n. 109, p. 9-26.

[29] TÜRKOĞLUA, A.SEHLIKOĞLU, K. TOKDEMIRC, M. 2019.A study of fatal falls from height. Journal of Forensic and Legal Medicine, v. 61, p. 17-21. DOI: 10.1016/j.jflm.2018.10.008

[30] WINGE, S. ALBRECHTSEN, E. 2018. Accident types and barrier failures in the construction industry. Safety Science, v. 105, p. 158-166. DOI:10.1016/j.ssci.2018.02.006

[31] WONG, F. CHAN, A. YAM, M. WONG, E. TSE, K. YIP, K. CHEUNG, E. 2009. Findings from a research study of construction safety in Hong Kong: Accidents related to fall of person from height. Journal of Engineering, Design and Technology, v. 7, n. 2, p. 130-142.DOI: 10.1108/17260530910974952

[32] ZAMBRANO, T; MARTINS, M. 2007. Utilização do método FMEA para avaliação do risco ambiental A method

to analyze the environmentalimpacts of small companies. Gestão & Produção, v. 14, n. 2, p. 295-309. DOI: 10.1590/S0104-530X2007000200008

[33] ZENG, S. TAM, C. TAM, V.2010. Integrating Safety, Environmental and Quality Risks for Project Management Using a FMEA Method, InzinerineEkonomika-Engineering Economics, vol. 21, nº 1, p. 44-52.