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PRELIMINARY RISK ANALYSIS IN THE EXECUTION OF DIFFERENT STAGES OF A SMALL-SCALE CONSTRUCTION PROJECT

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ABSTRACT: This study addresses the expanding context of the construction market in Brazil, subject to stringent construction and labor regulations. Focusing on small-scale projects located away from urban centers, where the mandatory presence of a safety professional is not required, the research aims to apply the Preliminary Risk Analysis (PRA) methodology in different phases of a residential construction project in Cajazeiras, Paraíba. The objective is to identify construction phases that pose higher risks to health and workplace safety. The study employs qualitative analyses for each phase, culminating in a quantitative assessment of the severity of risk for each activity. The results indicate that the infrastructure phase poses the greatest risk to workers, given the presence of high-risk activities. The article proposes preventive and protective measures for the identified risks, thereby contributing to the promotion of safer environments in the construction industry.
KEYWORDS: Construction sites. Work safety. PRA.

INTRODUCION

The civil construction sector plays a crucial role in a country’s economy, directly influencing the national Gross Domestic Product (GDP); in job creation, as evidence by the increase of 38.965 formal new Jobs at the begging of 2023, according to data provided by the Brazilian chamber of the construction industry (CBIC,2023); and at the extraction of feedstock and the development of scientific studies and technologies.

In residential constructions, several different steps can be identified, from preliminary services, that involve the cleaning of the land and transportation of soil, to the step superstructure, that includes the concreting of pillars, beams and slabs. Each one of the steps can present specific occupational risks, ranging from safety issues at work on machinery and equipment to ergonomic risks, works at height and environmental risks.

Work security has become a study field dedicated to prevent accidents, occupational illnesses and risks to the workers' health. However, the presence of the security work laborers on constructions is limited, according to the Annex II of the Brazilian regulatory norm 4 (Norma Regulamentadora 4 -Serviço Especializado em Segurança e Medicina no Trabalho) SESMT and stipulates the obligatory need of said professionals on constructions that has over 50 employees, depending on the risk degree (BRASIL,2022). This makes small-scale projects, especially those where are distantly located form big urban centers or clandestinely executed, more likely to work accident during their execution. An example is Cajazeiras, located in backcountry of Paraíba, Northeast Region of Brazil, a developing town that extends to an area of 563 km² and an estimated population of 63.239 inhabitants (IBGE,2022).

To approach these challenges, the responsible professionals for small-scale projects, which are not included by SESMT, once the total number of employees throughout the construction does not exceed fifty (50), may utilize tools such as Preliminary Risk Analysis (PRA). The PRA is a qualitative approach which allows the identification of the main risks in a work environment and action course to minimize the occurrence of occupational accidents. Considering this scenario, this study has a general objective to apply PRA in the different steps (infrastructure, masonry and superstructure) of a small-scale residential construction in Cajazeiras, Paraiba, with the purpose of identifying the construction phases' that present greater risk to the employees' physical integrity and health.

STEPS OF A CONSTRUCTION

The execution of the construction, whether commercial or residential, follows a specific sequence of steps, once few of them relay on the completion of the previous one. Nascimento and Feldman (2013), table a sequence of execution phases, starting with the installation of the construction site and earthworks and finalizing with coatings, crockery and metals. This order is evident when considering that the structure must be assembled before receiving the cover. In the same way, the coating with mortar precedes the application of the paint to the walls.

One of most crucial first steps to initiate an engineering construction is the organization of the construction site and soil movement, especially on steep land or in the excavation for foundations. In this phase, is fundamental to pay attention to associated risks due to machine’s usage, water infiltration, landslide and falls. In small executions, it is common that laborers’ usage of shovels, levers and pickaxes to excavate, increasing the risk of accidents during the manipulation of these equipment. (SESI/DN,2015).

Another detrimental step in residential constructions is the construction of the structure. Reinforced concrete is commonly used on the execution of bridges, reservoirs, bleachers, as well as in small-scale projects. Concrete is a mixture of cement, sand, gravel and water, that, when in its stiffened state, presents significant resistance to compression forces, but low resistance to traction forces. The addition of steel bars in a convenient way gives greater resistance to different types of tensions and loads, forming the reinforced concrete (Bastos,2006). Its production can be done *in loco* in manual form or through equipment, such as the concrete mixer, and resulting mixture is transported and thrown in molds to solidify and gain resistance (Barros; Melhado,2006). During the first 14 days, it is crucial to shore up the structure to avoid undesired deformities or detachment of the molds (SESI/DN,2015).

The construction of fence walls can be done with ceramic or cement blocks and are intended to divide rooms, filling the spaces left by the structure, and should support only its own weight and the usage loads’ (Thomaz *et al* ,2009). These blocks, with 6 or 8 holes, of dimensions of 9x14x19 and 9x19x19, respectively, can be vertically and/or horizontally laid, using mortar to join them. This technique is common due to its practicality and ease execution of hydraulic and electric installations, as well as the frames, without the need of a rationalized technique, that being, the need of the internal dimensions to be multiple measure of the blocks (Moreira; silva,2017).

The coating phase involves a variety of materials, these materials must be impervious to water. In big structures, steel is frequently utilized, while smaller structures can be coated with wood and ceramic tiles. In the case of wooden structures, the ceramic tiles are supported by slats, that stay under rafters. The structure can be divided into one or more plans, having the nomenclature of “water” (moliterno,2010)

Each one of the phases of construction require distinct workers assessment, who encounter varied risks at the construction site, known as occupational risks.

OCCUPACIONAL RISKS ON CONSTRUCTION SITE

Within the construction industry, it is known that enacting any activity, workers can encounter present dangers and risks at the construction site. Hazard is the source with potential harm to workers. The risk can be defined as the combination of the probabilities of an event occurring and the severity of the contusion or illness caused by exposure of the risk (OHSAS 18001:2007). As for the classes of occupational risk present at the construction site, these may be mentioned as the following dangers (Ribas; Michaloski, 2017):

Physical risks: include sources of energy such as noises, vibrations, heat, radiation, among others that are present in the operation of equipment such as concrete mixer, concrete vibrations, as an example.

Chemical risks: these represent toxic substances, compounds, toxic chemical products that can be inhaled or absorbed by the organism, such as ashes or harmful gases present, for example, on the manipulation of cement.

Biological hazards: include microorganisms such as fungi, bacteria, viruses, among others, capable of causing diseases to workers working on construction sites.

Ergonomic risks: these include actions that cause physical stress to workers, such as: improper posture, lifting weights or carrying weight during construction sites.

Mechanical or accident risks: these are recurrent dangerous situations in the construction industry, inadequate storage of materials, failures or improper use of tools and equipment, among others.

The examples mentioned reveal the numerous situations that can result in injuries or health problems for workers on construction sites. Given this scenario, a thorough analysis of all the risks that exist in the workplace is essential. The Preliminary Risk Analysis (PRA) stands out as an extremely useful qualitative tool for this purpose.

PRELIMINARY RISK ANALYSIS

Risk analysis in the work environment aims to analyze an object in detail, whether it is a service, equipment or even the organization of the construction site. Risk analysis follows three essential steps: the identification of the hazard and its consequences, the identification of those exposed and the estimation of the risk (Amorim, 2010).

Also, according to Amorim (2010), the preliminary risk analysis is a tool for prior assessment of the work environment in order to identify and classify risks, being able to propose mitigating measures for the risks presented in a succinct and easy-to-understand way. As can be seen in Table 1, the data collected are all those available on the place where work activities are performed. To this end, in the ACTIVITY column, the activity of the work to be carried out will be identified; in the RISK column, the sources of risk will be described; the CAUSE column will itemize the causes of each identified risk, which may involve human error or technical failures; the CONSEQUENCE column will describe the possible effects generated by each cause. In addition, in the CATEGORY column, a combination of classifications will be used to identify frequency and severity, fundamental parameters for determining the degree of risk of each activity.

Chart 1 – Preliminary risk analysis.

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk

Source: Adapted from Amorim (2010).

Taking into account the context of civil construction, for the risk classification, the frequency column can be filled in as shown in Table 2.

Chart 2 – PRA frequency categories.

Category	Denomination	Description
A	Extremely remote	Extremely improbable of occurring during the time of site mobilizing
B	Remote	Must not occur during the time of mobilization of the site
C	Improbable	Small probability of occurring during the time of mobilization of the site
D	Probable	Expected to occur at least once during the time of mobilization of the site
E	Frequent	Expected to occur multiple times during the mobilization of the site.

Source: Adapted from Amorim (2010).

According to Amorim (2010), risks can also be classified according to their severity, that is, the level of damage caused to employees, third parties and extramural people, according to Table 3.

Chart 3 – PRA severity categories.

Category	Denomination	Description
I	Negligible	No contusions or deaths occurs to the employees, third party and/or people outside of the site. Only occurring cases of first aid or slight medical treatment.
II	Marginal	Slight contusions in employees, third party and/or people outside site.
III	Critical	Moderate contusions on employees, third party and/or people outside site, with the possibility to employees or third party, demand immediate corrective actions to avoid catastrophes.
IV	Catastrophic	Causes deaths and severe contusions on multiple people, being employees, third party and/or people outside site.

Source: adapted from AMORIM, 2010.

Finally, by combining the frequency and severity classifications in a new table, the risk category for each activity presented in the APR can be obtained, as shown in Chart 4. This classification methodology allows for a succinct analysis of which services have the greatest impact on the civil construction industry.

Chart 4 – PRA risk rating.

FREQUENCY

A	B	C	D	E	SEVERITY
2	3	4	5	5	IV
1	2	3	4	5	III
1	1	2	3	4	II
1	1	1	2	3	I

Legend

5	Critical
4	Serious
3	Moderate
2	Smaller
1	Negligible

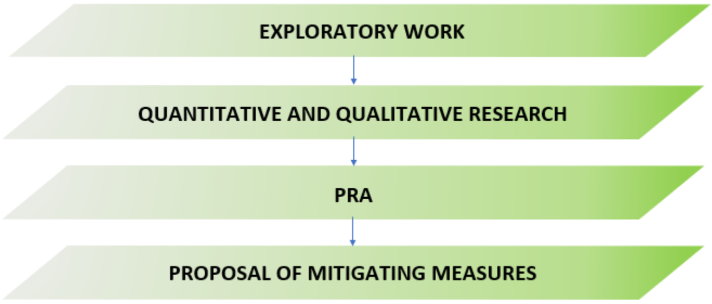
Source: adapted from AMORIM, 2010.

At the end of the analysis, it is possible to raise the level of awareness of employees by sharing the result of the analysis carried out, making the work environment more hygienic and organized. It is possible to reduce the probability of accidents and consequent drop in productivity as a whole through the measures proposed in this work.

METHODOLOGY

The methodology used in this study fits into the exploratory character, since it aims to provide a more in-depth understanding of safety in small civil construction works. In addition, the research adopts a qualitative and quantitative approach, collecting an extensive set of variables related to the activities performed by workers at different stages of the work. This allows the classification of the risks to which these workers are exposed, enabling an assessment of their magnitude, whether it is considered "major" or "minor". The study also seeks to propose preventive and protective control measures for the work environments evaluated (Markoni and Lakatos, 2003). Thus, the methodology follows according to the flowchart in Figure 1.

Figure 1 – Flow chart.



Source: own author (2023).

The object of study consists of a single-storey residential construction, with a reinforced concrete structure, covering approximately 99.00 m² of built area. The building is located at Rua Antônio de Souza Mangueira, in the Casas Populares neighborhood, in the city of Cajazeiras-PB, CEP 58900-000, as illustrated in Figure 2. The construction site encompasses the entire area available on the land for the execution of construction activities, while the storage of equipment and supplies takes place in a building on the outskirts of the site. The mobility of workers varies depending on the time required to perform specific tasks, the availability of labour, materials and equipment. The team has an average of five employees per stage, two masons and three assistants, working a daily shift of 8 hours, from Monday to Friday, with breaks of up to 2 hours, including breaks for lunch and snacks, totaling 40 hours of work per week.

Figure 2 – Location map of the construction.

Source: Adapted from Google Maps, 2023.

The observations made at the construction site were included in the Preliminary Risk Analysis (PRA), identifying the activity of the work carried out, the sources of risk, the causes of each identified risk, in addition to the possible effects generated by each cause. In addition, frequency and severity are identified, fundamental parameters for determining the degree of risk of each activity. By combining the frequency and severity ratings in an PRA, a succinct analysis of which activities may present the greatest risk to the safety and health of employees on the construction site is possible.

RESULTS

The elaboration of the PRAs of these stages was carried out based on a preliminary theoretical review in visits to the construction site for an observant evaluation of work practices and interactions. These observations are presented into Charts 1, 2 and 3, which show the PRAs of each stage.

The first stage analyzed was the infrastructure phase, which can be subdivided into specific stages: trench excavation, infrastructure concreting, and backfilling and compaction. The manual excavation of the foundation trenches involved the work of five workers, two masons and three helpers, equipped with tools such as shovels, hoes and levers, carrying out excavations on the site in specific locations and dimensions, as defined by the rental project. In this context, the work comprised 22 shallow foundations of the isolated footing type, with dimensions of 60 x 65 centimeters and an average depth of approximately two meters.

In the concreting stage of the infrastructure included the concreting of the 22 footings, 22 column starts with dimensions of 20 x 25 centimeters and 16 ballast beams of 20 x 20 centimeters, responsible for connecting and transmitting the loads to the foundations. The concrete used was dosed by the engineer in charge and produced on site through a concrete mixer. The frame of the structural elements was manufactured by a third party, transported to the site and positioned by the workers. After the infrastructure reinforcement was placed, the concrete was poured by hand using wheelbarrows, shovels or buckets. In the backfilling and compaction stage, granular material, such as sand or the soil itself removed during the excavation of the foundations, was added to fill the trenches and the spaces left by the beams up to floor level. Workers compacted the soil by hand to eliminate voids between the grains and ensure the stability of the building's floor.

Based on these observations, the APR of the infrastructure stage was formulated and is presented in Chart 5. At this stage, the main occupational hazards identified include noxious dust, falls due to differences in level, poor posture, cuts, and collapse. Manual trench digging stood out as the activity most likely to cause harm and injury to workers. This is due not only to the significant variety of associated occupational hazards, but also to the higher degrees of risk attributed, mainly due to poor posture, with risk grade 4.

Chart 5 – Preliminary risk analysis of the infrastructure stage.

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
Trenches manual excavation	Harmful Dust	Inhalation of harmful Dust due to the movement of earth removed from the trenches.	Dermatitis; conjunctivitis; respiratory issues.	D	II	3

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
	Fall by difference of height	Failure to use a safety harness.	Fractures or excoriation.	B	III	2
	Inadequate posture	Bad posture and/or repetitive movements.	Spine or lower back injuries, low productivity, LER, DORT, etc.	D	III	4
	Cuts	Not utilizing or inadequate usage of epi (boots, gloves, among others); lack of training.	Infections, excoriations, loss of limbs as toes or fingers of the hand.	C	III	3
	Collapse	Moving the soil around the trench.	Excoriations, fractures or casualty.	B	III	1
Infrastructure concreting	Cuts	Inadequate usage of EPI.	Excoriations, infections.	C	II	2
	Inadequate posture	Bad posture; excessive weight lifting; repetitive movements.	Spine or lower back injuries, low productivity, LER, DORT, etc.	D	III	4
	Harmful dust	Inhalation of harmful dust in the movement of material for the production of concrete.	Dermatitis; conjunctivitis; respiratory issues.	D	II	3
	Noise	Direct and frequent contact with noises produced by the concrete mixer.	Total or partial hearing loss.	E	I	3
Landfill and compacti	Harmful Dust	Harmful dust inhalation in the earth moving	Dermatitis; conjunctivitis; respiratory issues.	D	II	3

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
	Inadequate posture	Bad posture and/or repetitive movements.	Spine or lower back injuries, low productivity, LER, DORT, etc.	D	III	4

Source: own author (2023).

With regard to the sealing masonry stage, this phase involved the performance of five collaborators, two masons and three assistants, consisting of the laying of ceramic blocks with 6 holes and dimensions of 9 x 14 x 19 centimeters, covering a total area of 144.2 square meters of masonry, with mortar-filled joints. The mortar itself was dosed by the engineer in charge, prepared with the use of a concrete mixer and later transported to the laying site by means of wheelbarrows or buckets. The laying process began on the baldrame beams and progressed vertically until it reached the height of the ceiling height, which was three meters. This height gain was achieved through the use of ladders or scaffolding. Based on these observations, the PRA of the activities associated with the masonry stage was developed, as shown in Chart 6. The main occupational hazards identified included noxious dust, noise, poor posture, cuts, and the risk of falling due to a difference in level. Inadequate posture stood out as the activity with a serious category (risk level 4), especially in relation to cuts and falls due to level differences during work at height, thus becoming the activity in which workers faced greater possibilities of compromising their health and safety.

Chart 6 – Preliminary risk analysis of the masonry stage.

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
Mortar production	Harmful dust	Inhalation of harmful dust produced when the inputs are dumped into the concrete	Dermatitis; conjunctivitis; respiratory issues.	D	II	3

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
		mixer.				
	Noise	Direct and frequent contact with noises produced by the concrete mixer.	Total or partial hearing loss.	E	I	3
	Inadequate posture	Bad posture and/or repetitive movements.	Spine or lower back injuries, low productivity, LER, etc.	D	III	4
Block laying	Cuts	Inadequate usage of tools; contact with broken blocks pieces.	Excoriations; infections.	B	I	1
	Inadequate posture	Bad posture; excessive weight lifting; repetitive movements.	Spine or lower back injuries, low productivity, LER, etc.	D	III	4
	Fall by difference of height	Failure to use a safety harness.	Excoriations; infections.	C	III	3

Source: Own author, 2023.

After the completion of the infrastructure stage and part of the sealing masonry phase, we move on to the superstructure stage. This stage also had an average operation of 5 employees, two masons and three assistants, and began with the concreting of 22 pillars, with a section of 20 x 25 centimeters. The concrete was dosed under the supervision of the engineer in charge and produced on site by means of a concrete mixer, in order to achieve the design strength as accurately as possible. The manufacture of the reinforcement and the molds of the columns was outsourced, and these elements were transported and fixed to the existing structure by means of wires. In the same way, after concreting the columns, we proceed to the concreting of 14 beams, with dimensions of 20 x 30 centimeters, and an additional beam with dimensions of 20 x 35 centimeters, which serve to interconnect the columns. The beams were molded at the level of the building's ceiling height, located 3.10 meters above the floor. The use of scaffolding was necessary for the pouring of the concrete at this point. As in the previous stages of the work, the concrete was transported using wheelbarrows and poured in the appropriate places by means of buckets.

During the execution of these activities, all procedures were recorded and the PRA was filled out with all activities involving the superstructure stage, shown in chart 7. The main occupational hazards observed were noxious dust, noise, poor posture, cuts, as well as falls due to level differences. Concrete production was the activity most likely to cause harm to workers, since a risk grade of 4 was assigned to inadequate posture and risk grade 3 to dust and noise. This evaluation was due to the non-use of adequate/ergonomic equipment for the transportation of materials, repetitive movements, inhalation of toxic dust produced by the inputs and frequent contact with the noise produced by the concrete mixer.

Chart 7 – Preliminary risk analysis of the superstructure stage.

Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
Concrete production	Harmful dust	Inhalation of harmful dust produced when the inputs are dumped into the concrete mixer.	Dermatitis; conjunctivitis; respiratory issues.	D	II	3
	Noise	Direct and frequent contact with noises produced by the concrete mixer.	Total or partial hearing loss.	E	I	3
	Inadequate posture	Bad posture and/or repetitive movements.	Spine or lower back injuries, low productivity, LER, etc.	D	III	4

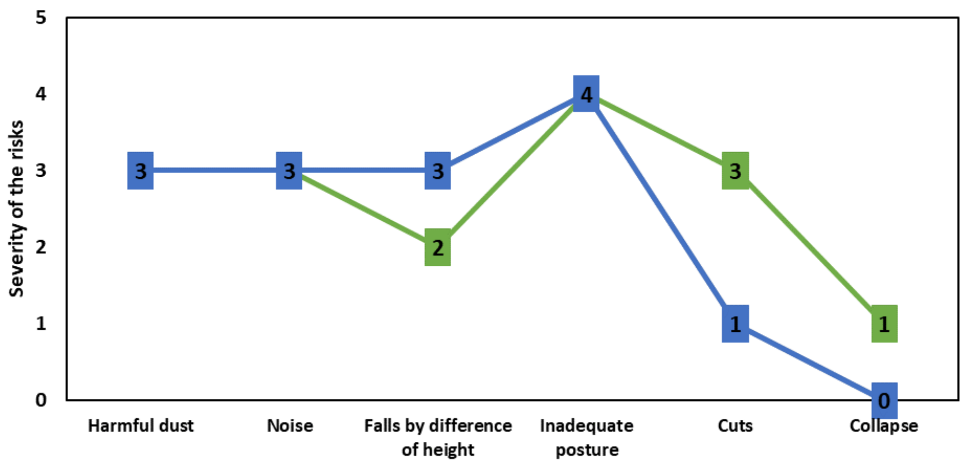
Activity	Risk	Cause	Consequences	Category		
				Frequency	Severity	Risk degree
Concreting of the columns	Cuts	Inadequate usage of tools as gloves or pliers.	Excoriations; infections.	B	I	1
	Inadequate posture	Bad posture; excessive weight lifting; repetitive movements.	Injures on the spine or lower back; low productivity; LER.	D	III	4
Beams concreting	Cuts	Inadequate usage of tools as gloves or pliers.	Excoriations; infections.	B	I	1
	Inadequate posture	Bad posture; excessive weight lifting; repetitive movements.	Spine or lower back injuries; low productivity; LER.	D	III	4
	Falls by difference of	Failure to use a safety harness or a ladder that is properly secured/supported.	Fractures or excoriations	C	III	3

Source: Own author, 2023.

In view of the observations made in the work of the elaboration of the PRAs of infrastructure, masonry and superstructure, the infrastructure stage evidenced a wide range of risks. Six specific activities were identified as posing a significant threat to worker safety. Of these, one was classified as presenting a "serious" risk with a risk grade 4, while three others received a severity rating of "moderate" risk with a grade 3. One activity was categorized as having a "lower" risk and grade 2, while a last activity was classified as having a "negligible" risk with risk grade 1. On the other hand, in the superstructure and masonry stages, five activities with considerable risk were identified, one less compared to the infrastructure stage. In both stages, an activity was classified as presenting a "serious" risk, with a risk grade 4. In addition, three activities received a "moderate" risk rating with grade 3, and one activity was categorized with a "negligible" risk, presenting a risk grade 1.

Thus, the infrastructure stage stands out as the one that receives the highest rating in terms of risk severity, due to the largest number of activities, most of which have a risk grade 3 or higher. This results in more frequent exposure to risk, with the possibility of mild or moderate injuries to workers and/or third parties. The results of this analysis are more clearly presented in Figure 3, which shows a graph correlating the degrees of risk attributed to each activity in the infrastructure (green), masonry (gray), and superstructure (blue) stages. The masonry and superstructure stages exhibited identical levels of risk in their activities, resulting in an overlap between them. It is worth noting that the activity of mechanized production of mortar/concrete stood out as the one that represents the greatest risk to workers, since it is present in all stages analyzed and has the highest risk classifications among the other activities.

Figure 3 – Classification of the severity of the risks present in the construction.



Source: Own author, 2023.

To more effectively ensure health, safety and productivity at the aforementioned construction site, as well as in similar enterprises, it is recommended to implement preventive measures. This includes the implementation of minimization measures, such as the installation of EPC's such as safety nets and signposts, the insertion of administrative measures, such as the application of the Daily Safety Dialogue (DSD), rotations and breaks during the workday, as well as regular training for workers. These trainings would cover execution methods for each service, presentation of materials, work and protection equipment, as well as guidance on the layout of the construction site.

Another recommended mitigating measure is the adoption of protective measures, with the provision of Personal Protective Equipment (PPE) free of charge and appropriate to the risks. All activities analyzed require the use of PPE, such as boots, gloves, respirators, goggles, helmets and belts to perform work at height, in accordance with the specifications of the Brazilian Regulatory Norm 6 (NR 6 – Equipamento de proteção individual). Unlike preventive measures, the purpose of which is to prevent accidents from occurring during work activity, protective measures are intended to minimize the damage suffered by workers at the time of an accident, thereby reducing the risk of fatal or serious injuries.

CONCLUSION

The purpose of this study was to implement Preliminary Risk Analyses (PRAs) in three stages (infrastructure, masonry and superstructure) of a small residential project in Cajazeiras, Paraíba. The objective of identifying the stages that present the most inherent risks to the health and physical integrity of workers was met. The APR presented itself as a simple and effective tool, providing a proactive approach to mitigating occupational risks and improving working conditions.

The infrastructure stage was highlighted, which has 3 activities; Among the activities analyzed, the infrastructure stage was the one with the highest number of sources of risk, with five sources of generation for the first activity, four sources of generation for the second activity and two sources of generation for the third activity. For the sources of risk analyzed, in all activities there was a source of risk "inadequate posture" classified as "serious" (grade 4), the other generating sources indicated were "noxious dust", "cuts" and "noise" classified as "moderate" (grade 3), "fall due to level difference" classified as "minor" (grade 2) and "collapse" classified as "negligible" category. In view of the quantitative analysis, obtained through the qualitative analysis, it was possible to conclude that the infrastructure stage presents itself as the stage with the highest degree of risk compared to the others, since it presents a greater number of activities and harmful agents for each activity.

With regard to suggestions for mitigating measures, preventive measures can be mentioned, such as the use of EPC's and administrative measures such as the implementation of DSD, a rotation system and breaks during the workday, in addition to regular training for the team. There are also individual protective measures, such as the provision of PPE by the person in charge of the work, among them we can mention boots, gloves, goggles, straps and helmets.

Based on these findings, this study contributes to the improvement of occupational safety in civil construction by sharing the results of the research with the academic environment and especially with the employees of the work in question. The return of the research to the evaluated construction site is of paramount importance for the awareness of employees in relation to safety and health at work in small works, where the presence of professionals in the safety area is still scarce.

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