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A REVIEW OF POKA YOKE IN CONSTRUCTION PROJECTS: CLASSIFICATION, BENEFITS AND BARRIERS

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ABSTRACT

The construction industry is a critical sector in the economy of countries; however, it has low productivity and is associated with errors and rework. In response, poka yoke or mistake-proofing devices have been developed to avoid errors or reduce the possibility of committing them. Their application has been documented in manufacturing and, to a lesser extent, in the construction sector, where the literature on this subject is scarce. Therefore, the following article aims to develop a literature review of poka yoke in the construction sector. To this end, a literature review was conducted using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis). Twenty-five articles related to poka yoke were analyzed. From the literature review, it was obtained that the main poka yoke found corresponds to the principle of facilitation; the main benefits reported were improvement of quality and performance and reduction of errors, and the main barrier is the lack of training on the subject. The following article will contribute to professionals and researchers in the construction sector to have a better understanding of the applications of poka yoke.

KEYWORDS

Poka yoke, mistake-proofing, Lean Construction, PRISMA

INTRODUCTION

The construction industry is critical for economic strengthening and unemployment reduction (Bajjou et al., 2017). However, it faces significant challenges due to low productivity (Widjajanto et al., 2020), cost overruns, and low quality (Ramírez et al., 2021), among others. Challenges in the construction industry are often caused by errors during construction, making construction defects the main concern (Hosseini et al., 2012). Errors in the construction industry

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manifest themselves at various project stages, from planning to maintenance, affecting financial, safety, and human life aspects (García et al., 2015). These errors can be related to higher levels of the organization, such as problems in design, poor specifications, inadequate control and supervision, and a lack of specialization or training in the workforce (Peralta & Serpell, 1991). Others may be associated with operational work, such as incorrect proportions of water in mortar preparation (Dos Santos & Powell, 1999) and failures in construction machinery (Bashir et al., 2011).

To counteract errors, a technique called mistake-proofing or poka yoke generated in Japan was developed to help reduce errors in the manufacturing industry through devices (Shingo, 1986), and has been successfully applied in other industries, including the Architecture-Engineering-Construction industry (Tommelein, 2019) and has been shown to have multiple benefits in this industry, such as variability reduction, quality improvement, work safety (Baijjou et al., 2017), reduction of rework, production of more added value, improved productivity and increased customer satisfaction (Zavichi et al., 2010). Despite the benefits shown in the literature, no previous literature review study on poka yoke in the construction industry has been recorded. That is why the following article aims to review articles recorded in the literature and evaluate the types of poka yoke and the benefits and barriers to construction projects.

BACKGROUND

POKAYOKE IN CONSTRUCTION

Although poka yoke has its origins in the manufacturing industry, its use in construction is also possible (Tommelein, 2019). Koskela (1992), is one of the pioneers in mentioning the term poka yoke in the construction industry, where he proposes poka yoke as an alternative to reduce variability and thus avoid performing activities that do not generate value. Then, Dos Santos & Powell (1999) show its application in 6 construction projects in England and Brazil, showing benefits such as: reduction of variability and improvement in the quality of the final result. Also, Tommelein (2008) mentions the application of poka yoke in the design stage, which consists of using different colors for the walls of a design plan, to denote that they are different and thus avoiding a mistake at the time of construction.

In addition, in Chile, Zavichi et. al (2010) propose a poka yoke device for the transport of materials between floors of buildings to reduce accidents. One of the guides that proposes many poka yoke devices is the one developed by Tommelein and Demirkesen (2018), where different poka yokes applied in the construction industry are compiled. Also, Tommelein and Yiu (2022) present several examples of poka yoke devices that seek to solve problems such as manual welding and measurement errors.

POKAYOKE PRINCIPLES

Tommelein (2019) states that the error-proofing methodology, known as Poka Yoke, is based on six principles: eliminate, prevent, replace, facilitate, detect and mitigate. These principles are organized according to the degree of desirability of error correction, from the most preferable to the least desirable, but no less valuable. When scheduling an operation before its initiation, the risks associated with the steps that make up the operation and their possible consequences are identified. Subsequently, their possible occurrence is "designed" to avoid them altogether.

The 6 types of poka yoke set out in Tommelein and Demirkesen (2018) will be explained below:

1. Eliminate: Eliminate involves eradicating the probability of an error occurring in a specific task, step, or sequence of operations by reconfiguring the product or operation so that the task (or associated part of the product) is no longer required. Zavichi et. al (2010) exemplify the removal of scaffolding in the construction industry, proposing the use of elevators with appropriate protective measures instead of scaffolding to ensure worker safety.
2. Prevent: Preventing involves designing and engineering the product or operation in such a way that no individual can make mistakes. Tommelein and Demirkesen (2018) present an example related to junction boxes in electrical installations, expressing concern about the possibility of faulty connections and the risks associated with the work at the height required to wire luminaires. As a poka yoke measure, they propose the installation of clips on each luminaire during the wiring process in a workshop environment. These clips, being designed to fit in only one way (asymmetry), ensure that the cables are always connected correctly. This practice significantly reduces the time required for overhead installation by electricians.
3. Replace: Replacing consists of substituting a task with a more reliable alternative to improve consistency. Tezel et al. (2010) give as an example a device that can virtually eliminate the need for statistical process control. They allow self-inspection in repetitive tasks by the line operator (which requires some vigilance and memory) by preventing errors using relatively simple and inexpensive mechanical, electrical and visual mechanisms.
4. Facilitate: Facilitate implies the use of resources to simplify the execution of a task, making it more affordable. Bajjou et al. (2017) provide a representative example of how water addition is commonly performed manually during mortar production without any strict control, which affects mortar quality, thus proposing strict monitoring of the added measurement as poka yoke.
5. Detect: Detect involves the quick identification of an error to correct it before it becomes a defect. Tezel and Aziz (2017) propose sensors in work helmets that vibrate or emit a sound to alert the worker of a work hazard.
6. Mitigate: Mitigate consists of using resources to minimize the impact of an error, especially in critical construction projects. Hosseini et al. (2012) provides an illustrative case where one of the critical errors in reinforcement operations involves improper delivery, cutting or bending of reinforcing bars. To prevent such errors, they propose a poka yoke method that involves coloring the ends of the tied bars, thus reducing the possibility of misuse.

METHODOLOGY

In the following research, a literature review was conducted on the application of the Poka Yoke method in construction projects using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. The PRISMA method has been used previously in Lean Construction literature reviews such as the study conducted by Erazo et al. (2023) in which after collecting data under the PRISMA method they conducted their research on the benefits of applying Lean Construction, during the pandemic era. In addition, Lee et al. (2022) mention that this type of review facilitates the authors to become familiar with the primary knowledge retrieved in the selected articles thus developing a research model through a solid approach, thus exploring future research directions with greater precision.

For the literature review, a search for publications related to the application of Poka Yoke in construction was conducted using Scopus, the IGLC database and the Web of Science database. This because Scopus is one of the databases with a wide domain in research on the topic of construction compared to other databases (Galaz et al., 2021); IGLC hosts most publications on the application of Lean Construction worldwide (Daniel et al., 2015); and Web of Science because it is one of the most recognized international multidisciplinary references (De Filippo, 2013).

In the first identification phase, the search was performed using 9 keywords from year 1998 to 2024, because the first paper that addresses poka yoke in construction is (Dos Santos et al., 1998). The keywords and their combinations are shown in Figure 1. Likewise, 112 results were obtained based on all the keywords. For the next phase of eligibility, after having the combinations of articles found from I to XXIV, 61 duplicate publications were eliminated from the reviewed articles and relevant articles were filtered for evaluation. A total of 33 articles were excluded through title and abstract review, articles were excluded because they were considered not to refer to the application of Poka Yoke in construction projects or were far from the topic in question. A total of 18 articles were left, which, in the next phase of exclusion, were filtered again through a complete reading, thus excluding 6 articles that did not meet the criteria to be considered in this study: They do not mention at least one application of any of the 6 types of Poka Yoke in construction projects, and 13 articles belonging to snowball were added because they were centrated in the topic showing at least one application of Poka yoke in construction, leaving a total of 25 articles that were considered for this research.

The above steps are described in Figure 1.

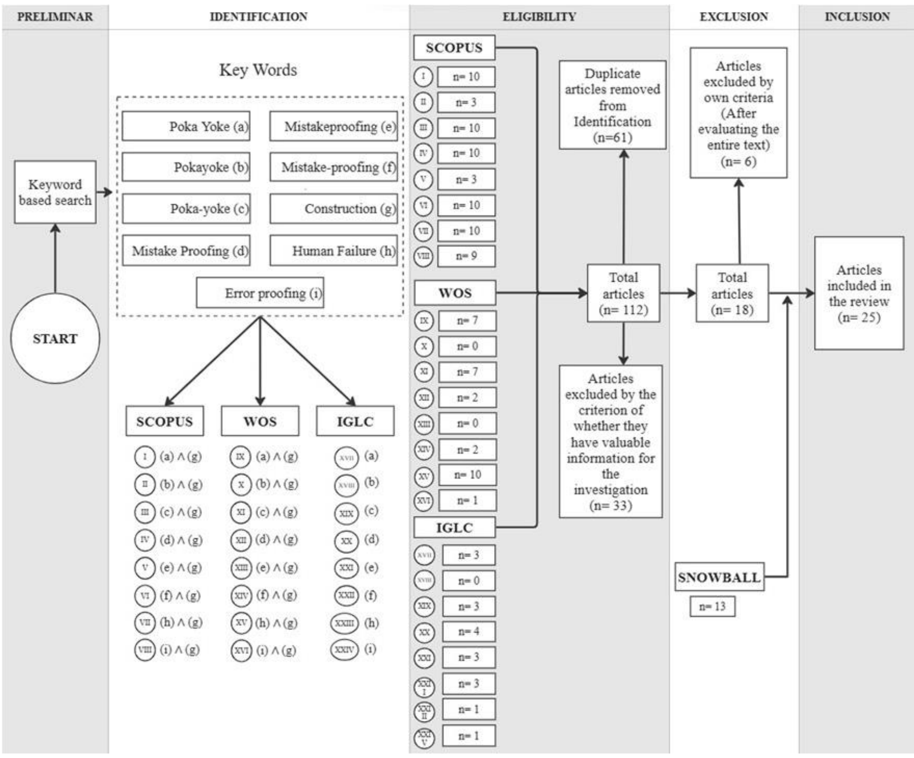

Figure 1. PRISMA flow diagram for the systematic review.

RESULTS AND DISCUSSION

PUBLICATIONS BY YEAR

In this section, the publications by year were divided into two graphs in Figure 2, an initial one where the number of articles per year is shown, and another one with the accumulated graph of poka yoke publications over time.

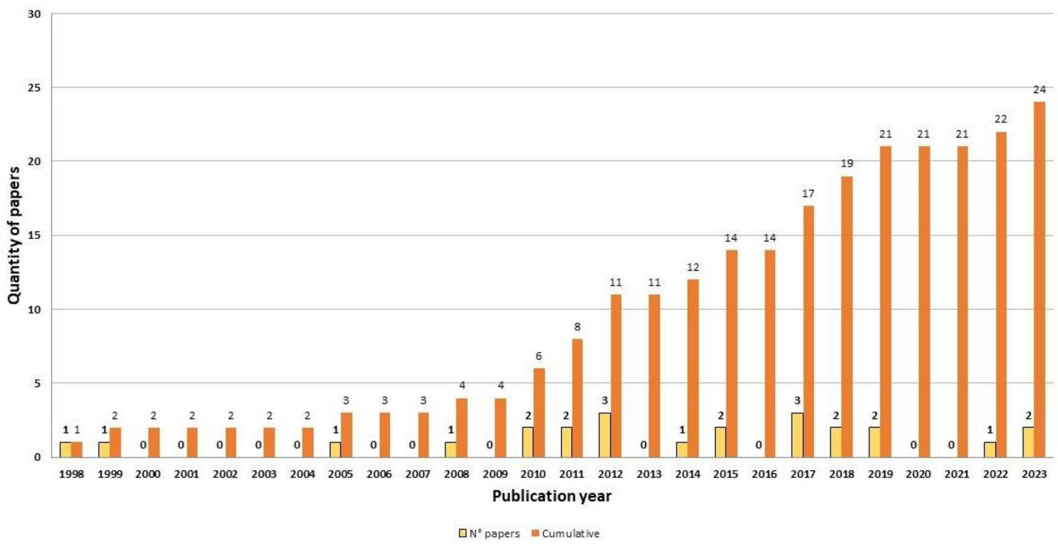

Figure 2. Number of poka yoke application papers in construction and their cumulative quantity vs year of publication.

From Figure 2, the first article dedicated to poka yoke, according to the review, was prepared by Dos Santos et al. (1998). This article explores the concept of Poka Yoke in the implementation of the principle of transparency in the construction sector. In this context, the use of an elevator control board is described as it prevents the elevator from moving if the door is open, thus constituting a PREVENT type of poka yoke. Later, in the following year, Dos Santos & Powell (1999) published an additional article, focusing exclusively on Poka Yoke devices under construction, being pioneers in addressing this topic in depth in this industry.

Between the years 2000 and 2009, there was little research on the topic, since only two articles were registered in that period: the research by Marosszeky et al. (2005) focusing on the use of quality control mechanisms to improve workflow reliability, and the article by Tommelein (2008) detailing the application of poka yoke in the manufacturing industry construction, providing a variety of examples and detailing different poka yoke devices. This work generated an increase in the production of research related to poka yoke, as reflected in the graph.

From 2010 onwards, a greater number of publications related to poka yoke in construction have been observed, addressing different topics such as: improving productivity in construction (Sadri et al., 2011), total quality management (Laguna et al., 2014), its relationship with Six Sigma (Vinod et al., 2015), safety (Bajjou et al., 2017), variation reduction in construction projects (Uhanovita et al., 2023b), among others.

Although the publications have been analyzed by year, Figure 2 also shows the cumulative analysis of publications. It is observed that until 2010, publications have been limited to slow growth. However, in the period from 2010 to 2020, there has been a significant increase in publications, going from 6 articles to 21 articles in 2020. This increase is attributed to the contributions of Tommelein (2008) and Zavichi (2010), who exhaustively explored the benefits of using Poka Yoke in the construction industry and provided various examples in their articles.

Likewise, as of 2020, 5 articles have been registered. In that sense, from the graph we can notice that there is a growing interest in the application of poka yoke and poka yoke principles in construction projects.

CLASSIFICATION OF POKA YOKE TYPES

In Table 1, the reviewed articles have been classified according to the 6 types of poka yoke presented in Tommelein & Demirkesen (2018):

Table 1: Number of examples of poka yoke principles found in the review.

Id	Principles	Examples in literature	Number of references	References*
P1	ELIMINATE	15	6	1, 3, 4, 5, 9, 11,16
P2	PREVENT	20	17	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 16, 18, 22, 23, 24
P3	REPLACE	12	8	2, 3, 4, 6, 11, 16, 19, 23
P4	FACILITE	30	13	1, 2, 3, 4, 5, 7, 11, 14, 15, 16, 20, 23, 24
P5	DETECT	17	12	1, 2, 5, 6, 7, 11, 12, 15, 16, 17, 21, 24
P6	MITIGATE	14	8	4, 5, 11, 13, 16, 19, 24, 25

*1. (Zavichi et al., 2010), 2. (Tommelein, 2008), 3. (Uhanovita et al., 2023a), 4. (Tommelein & Yiu, 2022), 5. (Tommelein, 2019), 6. (Rubio et al., 2019), 7. (Bajjou et al., 2017), 8. (Schmidt, 2013), 9. (Dos Santos & Powell, 1999), 10. (Dos Santos et al., 1998), 11. (Tommelein & Demirkesen S., 2018), 12. (Bajjou et al., 2017), 13. (Bashir et al., 2011), 14. (Hosseini et al., 2012), 15. (Laguna et al., 2014), 16. (Marosszeky et al., 2005), 17. (Mollo et al., 2018), 18. (Saurin et al., 2012), 19. (Tezel et al., 2010), 20. (Tezel & Aziz, 2015), 21. (Tezel & Aziz, 2017), 22. (Vinod et al., 2015), 23. (Sadri et al., 2011), 24. (Uhanovita et al., 2023b), 25. (Mollo et al., 2019)

From Table 1, the poka yoke principle most frequently cited in the literature for its application in the construction sector is the FACILITE (P4) principle, which was found in 13 articles and 30 examples of this type of poka yoke. Tommelein (2019) mentions that this principle is one that AEC practitioners tend to use the most because it is not a principle that consists of poka yokes designed to avoid errors. For example, Tommelein (2008) addresses design quality in construction systems and mentions examples of FACILITE type poka yoke, such as color coding for different types of walls on plans. Hosseini et al. (2012) discuss the implementation of Lean Construction in the Waste Management of construction processes and provides an example of FACILITE type poka yoke, which consists of coloring the end of grouped bars to prevent improper cutting or bending.

In second place in terms of mentions is the PREVENT (P2) type principle, where 17 related articles and 20 examples of this type of poka yoke were found. Tommelein (2008) provides two examples that belong to the PREVENT type, thus representing most of the examples identified in the present study. Examples of PREVENT type presented include the use of a connection plug to ensure proper wiring and the use of a sealant and return leg to ensure proper performance of the ceiling panels. Furthermore, Tommelein and Yiu (2022) point out an additional example of the PREVENT type, where CIVIL 3D software is used to link a 3D model with a 2D plan and prevent design mismatches and errors. On the other hand, Rubio et al. (2019) mention a specific example of the application of poka yoke, which consists of the use of safety railings to prevent falls from heights, also being an example of the PREVENT type.

The DETECT (P6) principle is documented in 12 references in the literature and 17 examples were identified in the analyzed articles. One of these examples consists of the implementation of an RFID detection system, which activates an alarm when an unauthorized worker accesses a dangerous area (Rubio et al., 2019). Additionally, another example is illustrated that involves the use of a dynamic information panel, which workers update in case of errors to alert their colleagues. Likewise, the use of understandable Squirter DTIs washers is mentioned, which indicates when a bolt reaches its target tension and becomes functional (Tommelein, 2019).

From Poka yoke principle of ELIMINATE (P1), 15 examples were found in 6 references. For example, Zavichi et. al (2010) provide as an example the change from the traditional work method (use of scaffolding) to a safer and more efficient alternative (use of an elevator with sufficient protection), this eliminates the possibility of errors or accidents associated with the use of scaffolding. and improves worker safety. Uhanovita et al. (2023b) illustrate some examples of ELIMINATE type poka yoke, among which is ensuring that the detailed designs provided to bidders are clear, precise and complete, as this would help avoid misunderstandings and errors during the pricing process and tender. Dos Santos and Powell (1999) illustrate an example of ELIMINATE by proposing an implementation of electronic and mechanical devices to avoid errors in the manual addition of water during mortar production, guaranteeing quality and efficiency on the job.

The MITIGATE (P6) principle was the second with the fewest examples that the literature provided, with only 14 examples in the literature in 8 references. Examples include the use of PPE to reduce the impact in the event of accidents that occur on site (Bashir et al., 2011), the use of SawStop saws which detect the moment in which human skin comes into contact with blade making it instantly hidden and thus causing the least possible damage to the user (Tommelein, 2019), the creation of protrusions with some nails on the heads of the tubes for a more precise installation, thus mitigating the possibility of incorrect installation (Tezel et al., 2010).

The REPLACE principle was the one with the fewest examples found, with only 12 examples in 8 references. Tezel et al. (2010) suggest an example of REPLACE-type poka-yoke, which is manifested through the implementation of adjustable metal struts designed to hold the benches in place during the construction process, replacing traditional struts to improve precision, safety and productivity in the work environment. Tommelein and Demirkesen (2018) propose a REPLACE-type poka-yoke to address the concern of potential worker falls from the edge of the roof. The solution involves installing a parapet along the perimeter as part of the permanent structure. This measure not only improves safety by mitigating the risk of falls, but it also replaces temporary protection, generating economic benefits throughout the life cycle of the building. Rubio et al. (2019) suggest dynamic information panels such as poka-yoke to improve static signs on construction sites, providing updated safety information and allowing remote updates by workers and the safety manager.

There are also potential poka yokes that are based on a combination of principles. For example, Tommelein (2008) mentions that design specialists use a color code as a type of pokayoke that facilitates and prevents. It prevents in the sense that they use it for their specific work and phase of a project to avoid confusion. And, it facilitates because color coding can be used to distinguish various types of walls, which makes it easier to clarify and categorize specified design requirements and helps better organize planning and cost.

BENEFITS AND BARRIERS OF ITS ADOPTION

In this section, the barriers and benefits that poka yoke generates in construction projects are described, which is why two summary tables have been developed: Table 2, where the benefits of poka yoke are seen, and Table 3, with the barriers found in the literature.

Table 2: Benefits of poka yoke in construction.

Id	Benefits	Absolute frequency	Relative frequency (n=45)	References*
B1	Improves quality and performance	8	17.78%	1,2,3,4,5,6,7,8
B2	Reduction of errors	8	17.78%	2,7,9,10,11,12, 13,14
B3	Reduction of rework	5	11.11%	6,9,10,15,16
B4	Reduction of time	3	6.67%	3,9,17
B5	Improves efficiency and minimizes resource usage	3	6.67%	3,13,20
B6	Continuous flow	3	6.67%	18
B7	Better customer satisfaction	2	4.44%	7,18
B8	Low investment cost	2	4.44%	10,18
B9	Reduction of variability	2	4.44%	3,8
B10	Reduction of interference	2	4.44%	7,19
B11	Improves profitability	2	4.44%	11,15
B12	User-friendly	2	4.44%	8,11
B13	Personnel reduction	1	2.22%	1
B14	Reduction of incompatibilities	1	2.22%	1
B15	Improves safety	1	2.22%	3

*1 (Tommelein & Yiu, 2022), 2 (Tommelein, 2019), 3 (Bajjou et al., 2017), 4 (Marosszeky et al., 2005), 5 (Tezel & Aziz, 2017), (Sadri et al., 2011), 7 .(Burlikowska & Szewieczek, 2009), 8 (Dos Santos & Powell, 1999), 9. (Zavichi et al., 2010), 10. (Tommelein, 2008), 11. (Bashir et al., 2011), 12 (Hosseini et al., 2012), 13. (Tezel & Aziz, 2015), 14 (Tezel et al., 2010), 15 (Laguna et al., 2014), 16 .(Li & Liu, 2016), 17 .(Bajjou et al., 2011), 18 .(Uhanovita et al., 2023a), 19 .(Dos Santos et al., 1998), 20 .(Saurin et al., 2012).

From Table 2, 15 benefits were identified from the literature, where the two main benefits were found with a frequency of 8 articles, which are “improvement of quality and performance” (B1) and “reduction of errors” (B2). Benefit B1 refers to the improvement in worker performance and processes. Uhanovita et al. (2023a) mentioned that Poka Yoke provides the opportunity to increase your ability to carry out a quality construction process, reducing variations that allow the parties to work collaboratively and help increase productivity and project success. Likewise, they also recommend that before starting the design stage, the requirements of the end users must be identified through the Poka-Yoke principles, and after that, the projects can be completed without variations in the stage. construction increasing productivity.

Benefit B2 is equally often about “reduction of errors” (B2), maintaining the idea that errors decrease thanks to the timely detection of their cause and in some cases preventing them from occurring. The goal of error reduction is to achieve a better system by avoiding more defects in the product and process by eliminating waste, trying to reduce variation, and not tolerating poor quality (Tommelein & Demirkesen S., 2018). For example, Marosszeky et al. (2005) mentioned that thanks to the implementation of Poka Yoke, the possibility of changes in requirements can be prevented in the design stage since the client must be given a complete idea about the design and once the client realizes Depending on the form, type and functions of the construction project, design changes and identified requirements will not arise during the construction phase.

The third most cited benefit is the “reduction in rework” benefit (B3), which has a positive effect since it prevents the error from getting worse. Through poka yoke, unnecessary use of personnel to correct an error can be avoided, which has the benefit of a “reduction of time” (B4), a “continuous flow” (B6) and a “personnel reduction” (B13). By avoiding the production of a defect in the product with a better one with no defect and in a shorter time, it produces “Better customer satisfaction” (B7). Moreover, the implementation and development of these mechanisms have a “low investment cost” (B8).

The use of these mechanisms produces a “reduction in variability” (B9) and a “reduction in interference” (B10). The reduction in errors, time, rework, interference and variability produces “improves efficiency and minimizes resource usage” (B5) which produces “improved profitability” (B11). Furthermore, poka yoke mechanisms often are “user-friendly” (B12).

On the other hand, Table 3 shows the 9 barriers obtained from the literary review of poka yoke.

Table 3: Poka yoke barriers in construction.

Id	Barriers	Absolute frequency	Relative frequency (n=10)	References*
C1	Lack of training	2	20%	5,6
C2	Uncertainty in the nature of construction	1	10%	3
C3	Tool immaturity	1	10%	5
C4	Resistance to change	1	10%	5
C5	Difficulty in identification	1	10%	1
C6	Lack of consensus	1	10%	2
C7	High investment cost	1	10%	5
C8	On-site work pressure	1	10%	5
C9	Limited research	1	10%	4

*1. (Tommelein & Yiu, 2022), 2. (Tommelein, 2019), 3. (Rubio et al., 2019), 4 .(Dos Santos et al., 1998), 5. (Uhanovita et al., 2023a), 6. (Tezel & Aziz, 2017)

The literature on barriers to implementing poka yoke in construction is sparse compared to the manufacturing industry, where detailed studies have been conducted, such as (Lazarevic et al., 2019), which identified obstacles such as high costs and lack of training. In construction, the review shows that most of the barriers are derived from the study of Uhanovita et al. (2023a) on the construction industry in Sri Lanka.

The most cited barrier is "Lack of Training" (C1), indicating that there is little knowledge about poka yoke and its benefits in the works. Tezel and Aziz (2017) highlighted the importance of management being well-trained for successful implementation. Given the uncertain nature of construction, identified as the "most uncertain industry" (C2) due to its unique characteristics (Ilyas & Ullah, 2019), it becomes a barrier as it implies a continuous change in the conditions of risks and defects in construction (Rubio et al., 2019).

The barrier "Lack of maturity of the tool" (C3) refers to the professionals' perception that poka yoke is a new tool, generating fear of not obtaining good results (Uhanovita et al., 2023a). "Resistance to change" (C4) is also observed, as in other lean tools such as LPS (Alarcón et al., 2002), indicating that professionals are reluctant to abandon traditional work practices.

CONCLUSIONS

From the present research, it was noted that the literature regarding poka yoke has increased in the last 10 years, due to greater research and interest in the topic of reducing errors. Likewise, it has been observed that one of the most used principles is facilitate, followed by prevent, and noticing few applications in mitigate and replace. Furthermore, the main benefits of using poka yoke devices have been improvement of quality and performance, and reduction of errors; and also, barriers to its use have been observed such as: lack of training, construction uncertainty, immaturity of the tool, among others. The authors recommend exploring the adoption of new technologies such as poka yoke devices and conducting workplace studies that will identify a greater number of poka yoke devices, identify the benefits observed in the field, and explore the barriers associated with their implementation on site. of construction.

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