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Optimizing security in architecture by design. Risk prevention in construction with a Lean perspective

Optimización de la Seguridad desde el Diseño de Arquitectura. Prevención de Riesgos en la Construcción Con una Perspectiva Lean

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Abstract

The construction industry remains one of the most dangerous in terms of occupational health and safety, with high rates of accidents and occupational diseases. Despite the efforts made, security is still managed reactively during the execution phase, leaving room for improved risk prevention. This study addresses the need to integrate safety from the earliest phases of architectural design, leveraging approaches such as Lean Construction and Prevention through Design (PtD).

The purpose of this article is to evaluate how the implementation of these approaches can improve safety in architectural projects in Uruguay. To this end, interviews, surveys and observations were carried out in architecture studios, as well as curricular practices with architecture and graduate students. The results reveal that the adoption of Lean Construction and PtD reduces accidents by up to 20%, although there are economic, cultural and training barriers to their widespread implementation.

These findings suggest that early safety integration not only reduces occupational risks but also optimizes operational efficiency. Going forward, the adoption of technologies such as Building Information Modelling and increased safety training are crucial to consolidate these preventive approaches in the construction industry.

Keywords: Construction Safety; Lean Construction; Prevention through Design (PtD); Building Information Modelling (BIM); Risk Management.

Resumen

El sector de la construcción sigue siendo uno de los más peligrosos en términos de seguridad y salud en el trabajo, con altos índices de accidentes y enfermedades profesionales. A pesar de los esfuerzos realizados, la seguridad se sigue gestionando de forma reactiva durante la fase de ejecución, lo que deja margen para mejorar la prevención de riesgos. Este estudio aborda la necesidad de integrar la seguridad desde las primeras fases del diseño arquitectónico, aprovechando enfoques como Lean Construction y Prevención a través del Diseño (PtD).

El propósito de este artículo es evaluar cómo la implementación de estos enfoques puede mejorar la seguridad en proyectos arquitectónicos en Uruguay. Para ello, se realizaron entrevistas, encuestas y observaciones en estudios de arquitectura, así como prácticas curriculares con estudiantes de arquitectura y posgrado. Los resultados revelan que la adopción de Lean Construction y PtD reduce los accidentes hasta un 20%, aunque existen barreras económicas, culturales y de formación para su implementación generalizada.

Estos hallazgos sugieren que la integración temprana de la seguridad no sólo reduce los riesgos laborales, sino que también optimiza la eficiencia operativa. De cara al futuro, la adopción de tecnologías como el modelado de información de construcción y una mayor capacitación en seguridad son cruciales para consolidar estos enfoques preventivos en la industria de la construcción.

Palabras clave: Seguridad en la Construcción; Construcción sin pérdidas; Prevención a través del Diseño (PtD); Modelado de información de construcción (BIM); Gestión de riesgos.

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1. Introduction

1.1 Safety in the construction industry

Construction has historically been one of the most dangerous sectors in terms of occupational health and safety. With high rates of occupational accidents and diseases, it continues to face significant challenges in worker safety and the social and economic costs that this entails (Mitropoulos et al., 2005). The Bureau of Labor Statistics (BLS) reported that in 2022, construction-related sectors recorded the highest rates of fatal workplace accidents. The main causes include falls from heights, operation of heavy machinery, and exposure to hazardous substances such as asbestos and toxic chemicals.

Globally, construction is one of the most vulnerable industries to occupational hazards due to the nature of the work, which involves intensive manual tasks, heavy machinery, and hazardous materials (Mitropoulos et al., 2005); (Zhou et al., 2015). According to the International Labor Organization (ILO), construction workers have an accident rate three times higher than the average for other sectors.

Social and economic costs include medical expenses, lost productivity, and litigation. In addition, construction projects often suffer from delays and cost increases when serious incidents occur, affecting the financial viability and reputation of construction companies.

1.2 Construction safety culture

The concept of "safety culture" has gained relevance in various industries, although in construction it has been slow to be adopted, especially from the early stages of design. A safety culture means that all actors, from designers to workers, consider safety a priority. According to the Lorent report (1997), more than 30% of accidents could be avoided with decisions made in the early stages of design. (Atkins, 2006) adds that 63% of the causes of fatal accidents in construction originate in decisions prior to the start of work.

In several countries, the safety culture has been strengthened through government regulations and economic incentives for companies with low accident rates. In Japan, the concept of "Total Safety" holds that safety is a responsibility inside and outside of work (Ho et al., 2020). (Behm, 2005) defines "design for safety" as modifications to the permanent characteristics of projects to prioritize safety from the earliest stages.

1.3 Technological innovations and their impact on safety

Technological advancement has transformed safety in construction. Tools such as Building Information Modeling (BIM), drones, and monitoring sensors are being used to foresee and mitigate risks before accidents occur (Maali et al., 2024). BIM allows architects and contractors to simulate the construction process and anticipate safety issues. Drones and sensors allow inspections in hazardous areas and real-time monitoring of working conditions, issuing alerts in the event of dangerous situations.

1.4 International comparison in security

Globally, accident rates and the implementation of safety measures vary significantly. In Europe, Directive 92/57/EEC states that safety must be integrated from the design stage. Countries such as Germany and the United Kingdom impose severe penalties on companies that fail to comply with safety regulations, which has improved the integration of preventive practices (Martinez et al., 2018); (Martinez et al., 2024). In Latin America, countries such as Brazil and Argentina face difficulties in implementing effective regulations, in part due to a lack of resources and oversight.

2. Theoretical framework

2.1 Construction Safety and Risk Management Theories

The approach to construction safety has evolved over the years, integrating new concepts that seek not only to mitigate risks during the execution of the work but also to eliminate them from the initial phases of the design. Prevention through Design (PtD) states that architects and designers play a crucial role in occupational safety. According to authors such as (Gambatese and Hinze, 1997), a significant part of accidents could be avoided if risks were identified and mitigated in the conceptual design phase.

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PtD argues that architects should consider safety as a central variable in all decisions, from the selection of materials to the planning of construction methods (Gibb and Glass, 2009). The premise is that designers can directly influence the safety of workers, users, and maintenance personnel through informed and responsible decisions.

This approach has been applied in various areas of architecture and civil engineering. In public infrastructure, for example, the selection of materials that minimize the risk of fire or collapse is a decision that impacts both the safety of workers and future users. Similarly, in smaller-scale projects such as single-family homes, decisions related to space layout and evacuation routes are key aspects to consider from the conceptual design.

2.2 Application of PtD in complex infrastructures

The application of PtD in complex infrastructures, such as bridges and mass transit systems, is crucial, as the interaction between design, construction and safety is critical (Farghaly et al., 2022). In large bridge projects, engineers have employed technologies such as BIM to simulate structural loads and predict potential failures before construction, which has helped reduce accidents related to structural collapses, one of the most common causes of incidents in large-scale projects.

In the energy sector, especially in nuclear plants and wind farms, PtD has been vital in ensuring the safety of workers and operators. The selection of wear-resistant materials, the planning of safe evacuation routes, and the design of advanced monitoring systems are all considered in the design phase, minimizing risks throughout the life of the project.

2.3 Lean philosophy and safety in construction

The Lean philosophy has had a profound impact on the management of construction projects, promoting waste elimination and continuous improvement. Applied to safety, Lean seeks to eliminate activities that do not add value, such as accidents and injuries. According to (Ballard and Howell, 2020), Lean-based planning improves safety by coordinating responsibilities and reducing risks.

One of the key principles of Lean is Just-in-Time (JIT), which minimizes the unnecessary accumulation of materials on the construction site, delivering them exactly when they are needed. (Heravi et al., 2019) Demonstrate that this approach creates a safer and more organized work environment, decreasing the risks associated with the handling and storage of materials.

Another fundamental principle of Lean is Kaizen, which encourages continuous improvement and constant adjustment of processes to eliminate inefficiencies and risks. A study by (Alarcón et al., 2016) in Chile showed that applying Kaizen in construction projects significantly reduced accident rates, fostering a safety culture in which the entire team is committed to identifying and fixing problems before they become serious incidents. Continuous improvement promotes the active participation of workers in the identification of risks and the implementation of preventive solutions. According to (Peñaloza et al., 2020), the adoption of these principles significantly reduces operating costs and occupational risks, by eliminating activities that do not add value, such as accidents and rework. In addition, the JIT approach minimizes the accumulation of materials on site, reducing congestion and risks associated with a cluttered work environment.

2.4 Prevention through Design (PtD)

PtD complements Lean by eliminating risks from the early phases of a project, especially at the design stage. PtD makes it possible to foresee and mitigate risks before workers arrive at the construction site, promoting proactive anticipation and problem-solving.

According to (Zhao et al., 2021), the integration of PtD and Lean improves interdisciplinary collaboration, facilitating the implementation of solutions that minimize occupational risks. The use of technologies such as BIM allows designers to visualize and simulate risks during the design phase, ensuring that preventive measures are implemented from the outset. In addition, BIM improves communication between architects, engineers and contractors, ensuring that solutions are in line with the needs of the project.

In many European countries, the integration of PtD is mandatory by law, which has significantly reduced accidents compared to countries where this approach is not common (Martinez et al., 2010). However, in Uruguay, the adoption of PtD remains limited, due to the lack of clear regulations and adequate safety training applied to architectural design.

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2.5 Lean Construction and Safety: A Collaborative Approach

The Lean philosophy not only optimizes construction processes to improve efficiency and reduce costs but also encourages a collaborative approach that reinforces safety. Lean Construction encourages collaboration between all stakeholders in a project, from architects to contractors to on-site workers. This collaboration ensures that design and construction decisions consider risks and the best strategies to mitigate them.

The Last Planner System (LPS), a key tool of Lean Construction, improves the planning of activities on site, ensuring that everyone involved understands the tasks and associated risks. According to (Mossman et al., 2019), the use of LPS not only reduces workplace accidents but also improves productivity by minimizing coordination conflicts and unplanned interruptions.

2.6 The Safety Influence Curve

The safety influence curve, proposed by (Szymberski, 1997), has been a pillar in the conceptualization of the relationship between design and safety in construction. This curve states that the ability to influence safety is greatest in the early stages of design and decreases as the project moves into the execution phase. In the early stages of conceptual and preliminary design, architects and designers have the ability to make decisions that can prevent risks before they materialize. However, once the project enters the execution phase, the opportunities to mitigate these risks are greatly reduced, and the costs associated with implementing security measures increase.

(Szymberski, 1997) argued that the ideal situation for integrating safety into the project is to consider it as an explicit and relevant factor in the early design phases (conceptual design - preliminary project).

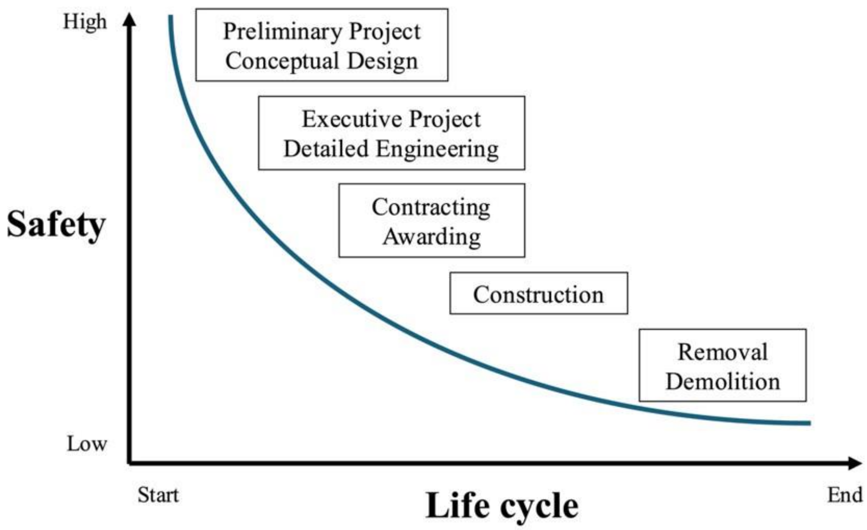

Figure 1. Safety influence curve - life cycle of a project. Adapted from (Szymberski, 1997).

The theoretical curve in (Figure 1) represents the influence of considering safety throughout the life cycle of a building and raises two important concepts:

I. the relationship between the progression of a project through its design phases (from conceptual design or preliminary project to detailed design or executive project, through acquisition, construction and disposal or demolition) and the ability to influence security.

II. The claim that the ability to influence safety rapidly decreases from the design stages to the pre-construction stages. At the beginning of the design stages, the capacity to influence is very high, but already at the beginning of construction, this capacity to influence safety decreases significantly.

The concept of the influence curve has been validated by studies such as those by (Weinstein et al., 2005) and (Swuste et al., 2012), who demonstrated that early design decisions, such as the choice of construction systems and site planning, have a direct impact on safety during the

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construction phase. These studies suggest that early safety planning not only reduces the likelihood of accidents but also improves project efficiency by avoiding delays and cost overruns related to unexpected incidents.

In addition, the influence curve reinforces the importance of architects' education and training on safety issues, as only through a deep understanding of risks can prevention be effectively integrated into the design. This curve also raises the need for greater cross-disciplinary collaboration, as architects, engineers, and contractors must work together from the earliest phases to identify and mitigate potential risks.

2.7 New technologies and their impact on safety

The adoption of new technologies has radically transformed the way construction projects are managed, and one of the areas where this has had the greatest impact is safety (Maali et al., 2024). BIM is one of the most innovative and promising technologies in this field, as it allows architects and contractors to visualize and simulate the project in a digital environment before construction begins (Martinez et al., 2018); (Akram et al., 2019); (Farghaly et al., 2022). Through BIM, designers can identify and mitigate risks from the earliest stages of design, by creating three-dimensional models that represent all elements of the project, including the materials, construction systems and equipment required for its execution.

Recent studies, such as those by (Eastman et al., 2011), have shown that the use of BIM not only improves the accuracy and efficiency of construction projects but also offers powerful tools for risk prevention. BIM allows designers to simulate different construction scenarios, identify potential risk points, and design preventative solutions before problems materialize on the construction site (Martinez et al., 2018); (Jin et al., 2019). This proactive approach represents a significant change from traditional practices, where security was primarily considered in the execution phase.

In addition, BIM has the potential to improve communication between all actors involved in the project. By using a common platform, architects, engineers, contractors, and safety specialists can collaborate more efficiently, share information in real time, and make design adjustments before construction begins. This reduces the likelihood of errors, improves construction planning and ensures that safety measures are effectively integrated from the start.

3. Methodology

3.1 Study design

The design of this research was based on a mixed methodological approach, combining quantitative and qualitative methods to provide a complete view of the integration of safety in architectural design in Uruguay. An exploratory study was conducted covering five years, from March 2017 to December 2022, and included the participation of architects, engineers, contractors and architecture students.

Table 1. Categories of analysis.

Categories to be identified	Description	Data Source
Knowledge	Ability to describe the general nature of security, its barriers, and benefits	• Exploratory study in studies • Online survey • In-depth interviews with experts • Student Internships
Acceptance	Think about safety when making design decisions	• Exploratory study in studies • Online survey • In-depth interviews with experts • Student Internships
Systematization	Systematically and consciously maintain safety at the design stage	• Exploratory study in studies • Online survey • In-depth interviews with experts • Student Internships
Implementation	Indicate practices to be developed at the design times	• Exploratory study in studies • Online survey • In-depth interviews with experts • Student Internships

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From the bibliographic review, four categories were identified as relevant for the analysis of these professional practices on which the searches for evidence were deepened, as shown in (Table 1):

• Knowledge refers to the ability of technicians to describe the general nature of the concept of safety, as well as the strategies to integrate it as a relevant variable in the early stages of the project

• Acceptance refers to the ability to think about safety when making design decisions during the life cycle of a project and particularly in the initial stages of the project; a greater acceptance of the subject allows the safety variable to be operated in an integrated way with the others

• Systematization, refers to the ability to operate and manage safety in a systematic, explicit, and conscious way in the design stages; A high capacity for systematization allows the identification of good practices in relation to the forms of visibility and mapping of risks and preventive actions

• Implementation, this category includes the analysis and study of the different proposals to put into practice strategies, tools and techniques to manage possible risks, identify them and anticipate them; it is about the ability to indicate practices to be developed at the time of project that they tend to enhance prevention for the rest of the phases of the life cycle of a project

The quantitative approach included online surveys distributed among professionals in the sector, while the qualitative approach was based on in-depth interviews, focus groups and direct observation in architectural studios. In addition, curricular internships were carried out with undergraduate and graduate students, which made it possible to analyze how future professionals integrate security into their projects.

The objective of this methodology was to evaluate how Uruguayan architects perceive their role in risk prevention and how they integrate, or not, safety in the early stages of design.

3.2 Data sources and collection techniques

The techniques and sources of evidence that were used are shown in (Table 2) and described below:

Table 2. Techniques and sources of evidence.

Techniques	Actors	Tools	Researcher
Architecture studios	6 studies	18 visits 184 statements 72 photographs 15 videos	Participant
Online survey	42 professionals	27 closed questions	Non-participant
In-depth interviews with experts	5 meetings 5 experts	Guideline 11 open questions	Non-participant
Focus Group	1 meeting 6 professionals	5 scenarios 30 replies	Participant
Student Internships	368 students	128 internships	Non-participant

1. Exploratory study in 6 architectural offices: 17 visits were made to local architectural offices, where design processes were observed, and project teams were interviewed about their safety management. These visits made it possible to document real practices and evaluate the degree of systematization in risk prevention.

2. Online survey of 42 professionals: An online survey was applied to architects and designers from different sectors, to assess their perceptions of safety in design. The survey included closed and open-ended questions, which allowed for a statistical analysis of the responses and a more qualitative view of perceived barriers and opportunities.

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3. In-depth interviews with 5 experts: Interviews were conducted with security and architectural experts, who provided detailed information on the challenges and opportunities for integrating security into architectural design. These interviews also served to explore how current regulations affect design decisions in Uruguay.
4. Focus Group with 6 professionals: A focus group session was held with six architects, where concrete examples of preventive practices in architectural design were discussed. This technique made it possible to evaluate the feasibility of implementing changes in current practices and to explore possible collaborative solutions.
5. Curricular internships with 368 undergraduate and graduate students: Students participated in practical exercises designed to identify risks in real projects and propose preventive solutions from design. These exercises made it possible to assess the level of awareness and knowledge about safety in future professionals in the sector.

The use of BIM was also evaluated in some of the observed projects, where simulations were carried out to identify possible risks in the initial phases of the design. These simulations provided additional data on the effectiveness of preventive methodologies in practice.

4. Results

Comparative Case Analysis

Data analysis was carried out using a mixed approach. The quantitative data obtained from the online surveys were analyzed using statistical tools, such as frequency and correlation analysis, to identify patterns in the professionals' responses. The qualitative data, obtained through interviews and focus groups, were analyzed using thematic analysis techniques, which allowed the identification of recurring themes and common barriers in the integration of safety in the design.

4.1 Impact of Knowledge and Systematization

Comparative analysis revealed significant variations in the integration of safety into the design. In most local architecture studios, security is not systematically integrated into the design stages, being addressed in the execution phase, when the capacity for influence is lower. Only two of the six studies held regular meetings to discuss risks in design. The surveys showed that 43.9% of professionals consider security to be a secondary variable, with costs and execution times taking precedence.

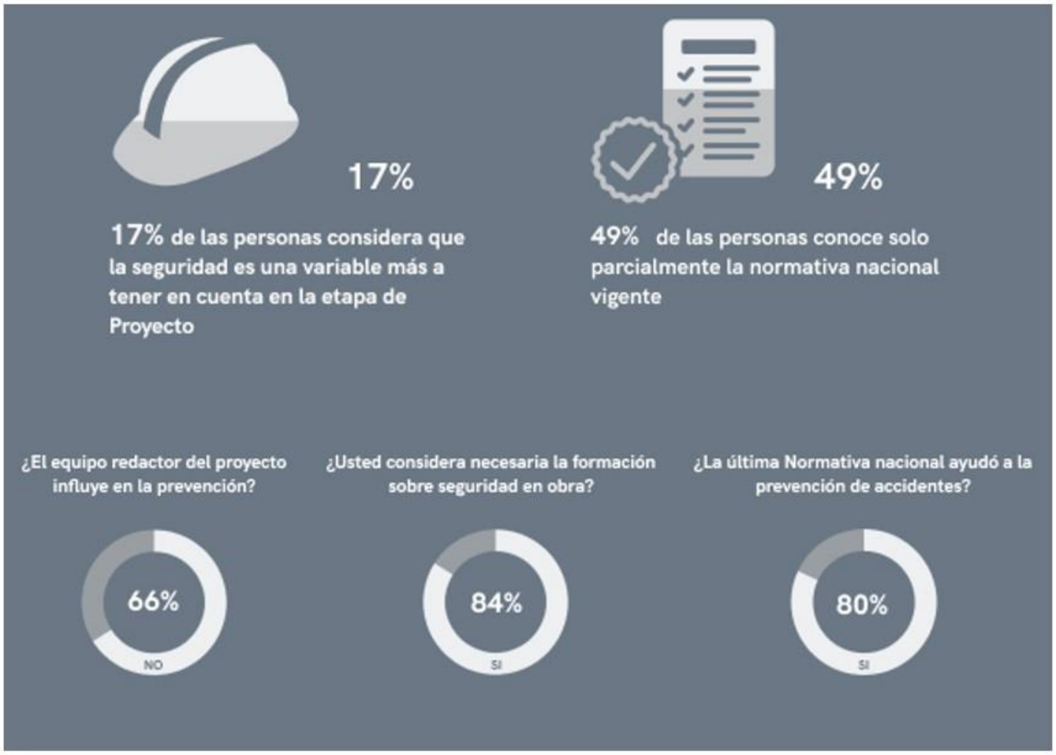

Figure 2. Online survey data summary.

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In relation to the online survey as shown in (Figure 2), of the total responses, almost half (43.9%) indicate that security is one more variable to be taken into account, not presenting any relevance and in their opinion, it is difficult to prioritize it over others such as costs and deadlines (39% - 22%). In general, it is recognized that the greatest aid for implementations external to the project teams (49%) is linked to the mandatory application of regulations, being the main cause to promote prevention (80%).

Figure 3. Summary of data from interviews with qualified experts.

As shown in (Figure 3), 100% of the interviewees stated that they did not have specific training on the subject. Although all the interviewees consider safety to be an integral part of the design, only 40% of the interviewees consider it consciously and systematically in their professional practice, or only in particular or rare cases. When asked directly about their understanding of the concept of PtD all of them indicated that they had not heard of it, although some of them gave their opinion on what they associated the term with. The acceptance of the concept of design for safety was evaluated in several ways, allowing us to verify that a high percentage of the interviewees (80%) stated that they thought about safety when making design decisions (choice of materials and construction systems, tools and equipment, design of components). The same percentage of interviewees (80%) indicated that they do it intuitively and unconsciously and only 10% apply conscious systematization methods in the identification of risks during the initial stages of the project.

Interviews with experts indicated that 80% of those interviewed consider that design decisions impact the safety of the work, but only 10% apply a systematic approach in the identification of risks. Most designers make decisions intuitively, without the support of formal methods.

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Figure 4. Example of curricular internships for graduate students.

4.2 Student Internships

From the curricular internship work with undergraduate and graduate students (Figure 4), the most relevant data are related to the identification of risks, identification of actors involved, identification of specific prevention instruments or practices, and analysis of stages of the life cycle to apply prevention practices. The quantitative data are summarized as follows: for the specific risks to be addressed: clear identification of risks 23%, confusing identification of risks 49% and no identification of risks 28%. The curricular work carried out by the students showed a limited ability to identify risks in the initial stages of design. Only 23% of students were able to clearly identify risks in their projects, and less than 5%

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proposed concrete prevention measures. The curricular internships carried out by the 368 architecture and postgraduate students also provided valuable information on the level of integration of safety in design by future professionals. The students participated in exercises in which they had to identify risks in real projects and propose preventive solutions. The results showed that only 23% of students clearly identified the risks associated with their projects, while 49% had difficulty identifying the risks and 28% did not identify any risks at all.

This finding reflects a lack of specific training on design safety in academic programs. The students who identified the risks most accurately were those who already had previous work experience in architectural studios or who had worked on construction projects. This suggests that safety in design is not adequately integrated into architectural educational programs and that there is a significant gap between academic training and labor market demands in terms of risk prevention.

4.3 Impact of Lean Construction on Safety

The results of the study show that the implementation of Lean principles in architecture studios in Uruguay has significantly improved safety in the early phases of the project. Projects that adopted Lean Construction, such as collaborative planning through the LPS, experienced a 20% reduction in accident rate compared to those that did not apply these approaches. Proactive planning and improved communication between teams allowed for better anticipation of risks and greater allocation of responsibilities for safety.

The integration of BIM as part of the Lean approach also showed positive results. By enabling early visualization of risks and improved coordination between teams, BIM helped mitigate risks before construction began, thereby reducing the likelihood of accidents and improving the operational efficiency of the project.

4.4 Integrating Safety in the Early Stages of Design

One of the key areas of analysis was to assess how architects and designers integrate security during the early phases of architectural projects. Overall, the results revealed that safety is not systematically integrated into design decisions, although there is a general awareness of its importance. However, security tends to be seen as an issue that comes into play later in the process, particularly in the execution phase or at the time when security specialists are hired to conduct risk assessments.

In visits to the six architectural firms, considerable variability was observed in how security was managed in the design process. Only two of the studies visited demonstrated more structured practices, where safety was periodically discussed as part of the design process. In these studies, weekly or biweekly meetings were held to identify potential risks in architectural design and consider preventive solutions. In one particular case, a studio working on a historic building rehabilitation project took a collaborative approach with safety engineers and heritage conservation specialists to assess the risks associated with structural interventions from the preliminary design phase. This practice made it possible to anticipate problems such as the risk of collapse in deteriorated areas and exposure to hazardous materials (such as asbestos), developing preventive solutions before work began.

In contrast, the other four architecture firms showed a more reactive trend in terms of security integration. The designers in these studies indicated that they usually leave security in the hands of the construction team or specialized technicians who supervise the construction. In many cases, safety was seen as a responsibility delegated to contractors, reflecting a disconnect between the design process and risk prevention. These practices are mostly seen on smaller projects, where resources to include safety specialists in the design phase are limited.

4.5 Barriers to Implementing Safety in Design and Lean

Despite the observed benefits, the study also identified significant barriers to the adoption of Lean Construction in Uruguay. The main barriers were resistance to change by key players, lack of adequate training in Lean principles, and low adoption of advanced technologies such as BIM. Interviewees noted that the initial costs of implementation and training were perceived as high, making it difficult to widely adopt these approaches, although they acknowledged that the long-term benefits far outweigh these initial costs.

Through in-depth interviews with the five industry experts and surveys of 42 professionals, several barriers were identified that hinder the systematic implementation of safety in design. These barriers can be grouped into three main categories: economic barriers, organizational barriers, and knowledge barriers.

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4.5.1 Economic barriers

One of the barriers most cited by the interviewees was the lack of financial resources to incorporate security in the initial stages of the project. Many architects indicated that limited project budgets restrict the ability to hire security specialists from the outset. In addition, several interviewees stated that customers are often more concerned with keeping costs low and meeting project deadlines, which reduces interest in including preventive safety measures from the design phase. In the words of one of the architects interviewed:

"Often, customers don't see the value in investing in security from the start. For them, safety is something that is handled later, once the project has been approved and is under construction."

This short-term vision, focused on upfront costs, seems to be one of the key reasons why architects don't prioritize safety in design.

4.5.2 Organizational barriers

Another important finding was that security is not organically integrated into the design processes within architecture studios. Only two of the studies visited had formal protocols that required explicit consideration of safety during design meetings. In the other four studies, the architects stated that safety is not an issue that is proactively addressed in the early stages, and that it tends to arise only when obvious problems or risks arise.

A common organizational barrier was the lack of coordination between the different actors involved in the project. In particular, a disconnect between architects and safety engineers was observed. The architects interviewed indicated that they often do not interact with safety technicians until the project is at an advanced stage, which limits opportunities for preemptive adjustments to the design. In addition, some architects noted that safety engineers are often more focused on the construction phase, which contributes to the lack of integration of safety from design.

4.5.3 Knowledge barriers

Finally, barriers to knowledge and vocational training were frequently mentioned as major obstacles. In interviews with experts, 80% of professionals indicated that they had not received formal training in safety and that much of their knowledge about risk prevention came from practical experience. In many cases, architects claimed that they had not been taught how to integrate safety into their design decisions during their academic training.

The online survey also reflected this trend: 49% of respondents indicated that they do not feel fully prepared to identify and mitigate risks in the design phase, and 28% noted that security is not a priority issue in their daily professional practice. As a result, many designers tend to rely on specialist safety technicians or common sense, rather than following a systematic, knowledge-based approach.

4.6 Use of technologies such as BIM

One of the most promising areas in terms of risk prevention is the adoption of technologies such as BIM. In the two architecture firms that integrated BIM as part of their design process, a greater ability to identify and mitigate risks was observed from the early phases of the project. BIM allows the creation of three-dimensional models that include detailed information about materials, construction methods and the project environment. These models can simulate the construction process and anticipate potential risk points.

One of the most successful examples of the application of BIM in research was a rehabilitation project of a historic building in which this technology was used to plan the demolition and reconstruction phases. The use of BIM made it possible to simulate the impact of the partial demolition of certain structures and to design temporary support systems that guaranteed the safety of workers. In addition, BIM facilitated coordination between architects, structural engineers and safety specialists, significantly improving communication and reducing the likelihood of errors during the execution of the work.

However, one of the most important findings was that, although BIM offers considerable potential to improve design security, its adoption in Uruguay is still limited. Only two of the six architecture firms visited use BIM as a regular tool in their projects, and the professionals surveyed indicated that the cost of implementation and the learning curve are significant barriers to its widespread adoption.

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5. Conclusions

The results of this study reveal a major disconnect between the architectural design phase and risk management in construction in Uruguay. While there is a general awareness of the importance of safety, economic, organizational and knowledge barriers limit the systematic integration of risk prevention from the earliest phases of the project. In addition, the adoption of technologies such as BIM remains limited, restricting the potential to improve safety through simulation and proactive planning.

To improve the situation, it is necessary for architecture studios in Uruguay to more proactively integrate security in the early phases of design. Not only would this reduce the likelihood of accidents during construction, but it could also improve project efficiency and reduce costs related to risk mitigation in later stages. It is also suggested the implementation of training programs that allow architects and designers to acquire the necessary skills to identify and mitigate risks from conceptual design.

The study also concludes that the integration of the principles of Lean Construction and PtD significantly improves safety and efficiency in architectural projects. Despite the initial barriers, such as lack of training and resistance to change, the long-term benefits, both in terms of accident reduction and resource optimization, justify the adoption of these approaches.
This study has shown that, although architectural design professionals in Uruguay recognize the importance of safety, the systematization of its integration in the early stages of the project is limited. Most designers make decisions intuitively, reflecting a lack of training and adequate tools to manage risks by design. To improve this situation, the following recommendations are suggested:

1. Training and awareness: Implement training programs that train designers in risk identification and safety integration from the earliest design phases.
2. Systematization of safety: Develop clear and accessible methodologies that allow designers to systematically and consciously integrate safety into their professional practices.
3. Stricter regulations: Review and update local regulations to include designers' responsibility for risk management from the project conception phase.
4. Adoption of new technologies: Promote the use of BIM and other digital tools that allow risks to be anticipated and mitigated throughout the life cycle of a building.

To maximize benefits, it is critical that educational institutions and regulatory bodies promote training in Lean and PtD, preparing future professionals to implement these approaches in their projects. In addition, the adoption of technologies such as BIM should be encouraged due to their crucial role in the early identification of risks and in improving coordination between interdisciplinary teams.

Finally, it is critical for academic institutions to update their curricula to include more in-depth training on architectural design safety. This would prepare future architects to face the challenges of the world of work.

6. Notes on Contributors

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