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Identification of the Origins and Risks of Pathologies in Steel Structure Buildings Using Total Quality Management Tools

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Abstract: The steel structure construction is an interesting option to the already established concrete structure at a time when the Brazilian civil construction seeks more efficiency. To promote the use of this material it is necessary to have a better understanding of its characteristics and, especially, of its possible pathologies, to avoid degradation, costs, and even the collapse of the structure. In this study Total Quality Management tools were applied to analyze the pathologies found in five medium and large steel-structured buildings. The most frequent ones were structure corrosion, cracks in the closures, and infiltrations in the interface closure/structure. The Ishikawa Diagram is used to identify the origin of the causes of pathologies and the Gravity Urgency Tendency Matrix (GUT Matrix) is used inthe risk analysis of each pathology. The results obtained show that it is possible, through these Quality Management tools, to understand the origin of the pathologies, establishing their dangerousness and the degree of risk each one offers.

Key words: Civil construction, steel, pathologies, quality management, Ishikawa diagram, GUT matrix.

1. Introduction

Brazilian civil construction has been striving to define new project processes that make it more productive and efficient, generating a quality product. According to Melhado [1], the evolution of the building construction sector should increasingly provide collaborative work, because conventional practices no longer adequately meet market demands. The project management models in practice value exclusively the final product and are concerned with the development of the activities necessary for this, without thinking about the organization of the process as a whole and the development of new techniques and tools [2]. The search for efficiency goes through the prevention of pathologies that can occur during the useful life of this building, avoiding degradation, expenses and even the collapse of the structure.

A greater use of steel as a structural element in buildings, especially those with multiple floors, presents many advantages such as great freedom of creation, slenderness of beams and columns in relation to those equivalent in concrete, compatibility with traditional materials and innovative prefabricated, significant waste reduction, reduced foundation costs due to less structural weight, speed in the execution of the work, reduced consumption of wood in the work, besides being 100% recyclable [3, 4].

Brazil is internationally recognized for its strong representation in reinforced concrete construction, while steel structured construction represents only 14% of buildings in Brazil [5]. For political reasons, reinforced concrete has prevailed as hegemonic in Brazilian construction. Modernism, identified among architects in Europe from the late 1920s on, as a movement to reject the formal repertoire of the past and the aversion to the idea of style, was converted into government policy in Brazil with the arrival of Getúlio Vargas to power in the 1930s. The Modern movement was a form of protest and rebellion, breaking with ornamentation and its historical characteristics, making now an economical, clean and

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useful building. These new attributes were embraced by groups that supported Getúlio Vargas, who sought to find certain cultural traits that could be accepted, by the largest number of patriots, as what existed of more “Brazilian” in their country [6]. Thus, the state intervened in culture on an unprecedented scale in the country and became active in music, film, theater, books, education, and architecture and, consequently, in engineering.

The 1930s saw the spread of consulting firms in structural calculations. Architects and engineers acquired knowledge outside the undergraduate courses of these professions. Modernist calculators and architects were trained within consulting and design firms. There was an unsatisfied demand for higher education, to the point where calculus courses were offered by correspondence.

In 1931, a reform in education was instituted, known by the name of the minister of Education and Public Health, Francisco Campos, who interfered intensely in Brazilian higher education, in order to update it in face of the needs of the new Brazil that presented itself, more industrialized, purportedly showing a country on the road to development. Among other points, the reform introduced reinforced concrete as a mandatory subject in architecture and engineering courses. Within the schools, theoretical and practical teaching was focused on a broad knowledge of reinforced concrete, going beyond classroom teaching, but also meeting the demand of the private sector [7].

The modernization promoted by Vargas was directly linked to civil construction, giving rise to the creation of a “Brazilian school of reinforced concrete”, with the study of steel being relegated to a second plan, despite the degree of development of steel constructions in other countries, a scenario that remains until today.

The Brazilian civil construction is, admittedly, formed, in its majority, by a contingent of unprepared, poorly paid labor and with high accident rates. It is one of the sectors that employs the most people in Brazil, but it is also the one with the largest contingent of low or no education [8]. This is a common reason for the occurrence of errors, rework, waste of materials, and the low quality of many buildings. Thus, there is a need for an investigation in this process focused on performance, analyzing each stage, which can result in a high-quality building, without the occurrence of typical pathologies.

2. Objective

The objective of this work is to identify the point, or the causative reason that gives rise to the pathologies in a building.

3. Total Quality Management

The search for Total Building Quality has made builders and developers aim to increasingly meet the demands of consumers. The concept of Total Quality, from the consumer’s point of view, has been established as the adequacy of the product to its use, being applied in most business segments as a competitiveness factor and as an incentive to the search for technological improvement. Thus, the achievement of Total Quality implies the need for continuous improvement of projects, processes, products, and people training. There are few specific studies and practical cases of Total Building Quality in the real estate industry, because this segment is different from the others because each building is unique.

Quality, in a general context, has been thought about, planned, implemented, and improved since the 1930s in the United States and since the 1940s in Japan and in several other countries. Kaoru Ishikawa was the first mentor of total quality management. He has been associated with the development and advocacy of QC (quality control) tools in organizations for problem solving and process improvement. These tools have the significant function of monitoring, obtaining and analyzing data to detect and solve problems in production processes to facilitate the

Table 1 GUT matrix.

Degree	Grade	Gravity	Urgence	Tendence
Maximum	10	Risk to life of users, building collapse, serious environmental damage.	Immediate Evolution	In occurrence
High	8	Risk of injury to users, non-recoverable building damage, localized contamination.	Developments in the short term	Taking place
Medium	6	Unhealthy for the users, high deterioration of the building, waste of natural resources.	Evolution in themedium term	Prognosis for the near future
Low	3	Nuisance to users, degradation of the building, non-rational use of natural resources.	Evolution in thelong term	Prognosis for the future
Minimum	1	Real estate depreciation.	It will not develop	Unforeseen

achievement of excellence in the performance of an organizational structure [9].

One of its best-known tools is the Ishikawa Diagram or Fishbone Diagram. Its technique consists of a cause-and-effect analysis. The diagram systematically investigates and analyzes all the actual or potential causes that result in a single effect [9]. The causes that can generate a problem are grouped under six categories known as the 6M: method, labor, material, machine, measure, and environment [10].

Another tool is the GUT Matrix, by Kepner and Tregoe, which analyzes the criticality of an anomaly or construction inaccuracies. The GUT Matrix (severity, urgency and trend), is based on the weighting of the degree of commitment (or criticality) for each approach analyzed, and subsequent technical interaction, thus enabling a better understanding of the solutions to be adopted [11]. Thus, the GUT Matrix provides a global understanding of the problems, determining the order of priority in the management and resolution of the situation [12].

According to Pestana, Veras, Ferreira and Silva [13], for the construction of this matrix the problems should be scored for analysis, following the GUT classification, in this order:

- Severity, which refers to the risk of the analyzed situation, studying the result that may arise in the medium and long term;
- Urgency, which refers to the deadline for interference in problem solving;
- Tendency, which deals with the possibility of the problem growing over time.

Each approach presents 5 degrees of commitment (or criticality levels), with each degree representing a previously established score (or weight) (Table 1). Finally, the 3 scores resulting from the weighted grades for each approach are added or multiplied, obtaining a numerical result that allows ordering the pathologies detected in the building [11].

In this study, by applying the Ishikawa Diagram and the GUT Matrix, the causative elements and the risk analysis of the pathologies present in 5 medium and large steel-structured buildings are surveyed.

4. Materials and Method

The development of this research is based on 2 previous studies: the study by Sales [14], who presents a mapping of the problems generated by the association between sealing systems and steel structures and an acoustic and vibration characterization of the sealing panels used; and the study by Bastos [15], who evaluates the semi and/or industrialized constructive systems of multi-story buildings through the perspective of their users. Sales [14] takes an investigative approach to the performance of sealing panels associated with steel construction, with the objective of analyzing the execution processes of steel structure buildings. To this end, information is collected on the events and conditions that each building goes through at the time of its construction. Using this study, Bastos [15], makes an evaluation of the post-occupancy use, where he presents the problems found. One of the results of this research is the survey of the most common pathologies and their frequency.

With the data on the pathologies found, their causes are defined, using the Ishikawa Diagram (6M). Thus, it was possible to understand the origin of each problem.

The 6M categories (raw material, measure, environment, labor, method, and machine) are considered, within the context of civil construction, according to the following criteria:

- Raw material: possible causes referring to the materials used.
- Measurement: possible causes referring to any dimensional value that impacts the product's performance. These values can be characteristic of the material (thickness, weight, size) or relative to the magnitude of the elements executed on site (thickness, quantity).
- Environment: possible faults referring to interferences caused by rain, humidity, heat, possible causes referring to problems caused by the task performers: errors, haste.
- Imprudence, which are caused by the employee's contradicting/ignoring/not understanding superior guidance.
- Method: possible causes referring to problems caused by procedures, routines or construction techniques used, determined in project or through superior orders.
- Machine: possible causes referring to problems caused by machinery or tools.

For this research 5 buildings in the city of Belo Horizonte were considered. Sales [14] defines their main characteristics:

- Building 1, with 19 floors, was built in 1998, with steel structure (welded profiles, not apparent). The external vertical closure is made of masonry of cellular concrete blocks and the internal one of plasterboard. The slabs are steel, with embedded formwork. The labor was hired by specific service, by contract, and so no training program was adopted, outsourcing most of the work and only managing the assembly of the construction.
- Building 2, with 12 floors, was built in 1997, in steel structure (welded profiles, not visible). The external vertical closures are in cellular concrete masonry and the internal ones in gypsum plasterboard panels. The company does not have a permanent staff and does not have a training program.
- Building 3, with 9 floors, was built in 2000, with a steel structure (with welded profiles that are not visible). The external vertical closure is in autoclaved cellular concrete panels and masonry in cellular concrete blocks. The internal vertical closure is in gypsum plasterboard panels. The slabs are made of cast-in-place concrete. The site labor was, almost in its totality, hired by service companies, which sold the respective construction component systems to the construction company, which took on the function of coordinating the process.
- Building 4, a three-story building, was built in 2000, with a steel structure (rolled steel profiles), external vertical closure in perforated ceramic brick, and internal closure in gypsum plasterboard. The floor slabs are made of pre-molded reinforced concrete panels. The labor was hired per project.
- Building 5, with 3 floors, was built in 2000, with a steel structure of light, non-apparent profiles and internal closure in gypsum plasterboard panels and external closure in reinforced concrete panels with expanded polystyrene cores. The floor slabs are made of pre-molded concrete panels. The company does not have a fixed workforce, so it does not have any kind of training program. The finishing stages are contracted out, so the work becomes a set of outsourced services.

After this analysis, each of the pathologies is analyzed in a GUT Matrix, thus establishing the degree of risk that each one represents.

5. Results and Discussion

The main pathologies identified by building users in Basto' survey [15] and their quantification are presented in Table 2.

Table 2 Pathologies and occurrence rates.

Pathology	Results in %
Infiltrations	62.3%
Cracks	54.2%
Sound transmission through walls	40.7%
Sound transmission through slabs or vertical installations	40.4%
Leaking slabs between floors	38.0%
Detachment of floor slab	18.8%
Unevenness of the floor slab	12.5%
Detachment of wet area coverings	11.2%
Corrosion of apparent structural elements	9.1%
Warping and/or movement of internal walls	7.5%

Source: Bastos [15].

There were 134 possible causes identified for the 10 pathologies presented, as shown in Table 3.

Among the possible causes, 68 of them are related to the method, 19 to labor, 17 to the environment, 16 to the raw material, 11 to the measure, and 3 to the machine (Fig. 1).

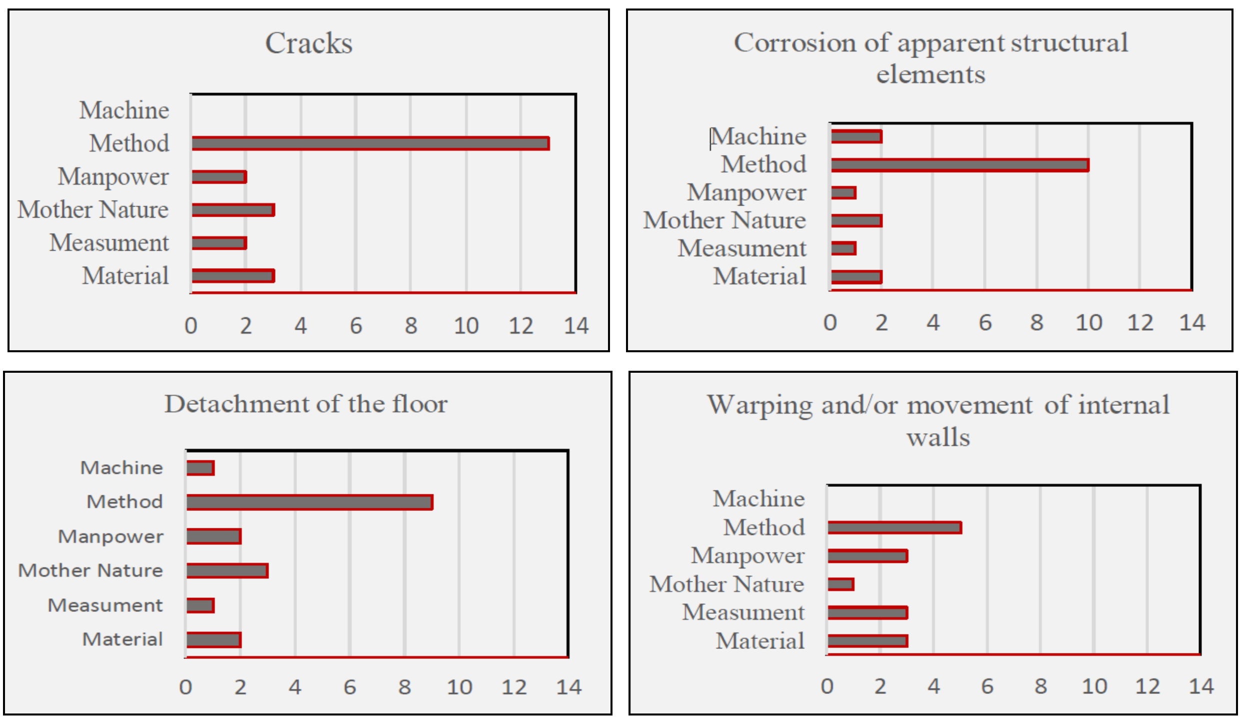
Applying the Ishikawa Diagram, it is identified that 54% of the pathologies found in the surveyed buildings originate from the Method. It can be seen, therefore, that the way a work is executed, following guidelines set out in the project and guided by engineering professionals, is the main cause of pathologies. This fact invalidates the widespread belief that low quality workmanship is responsible for construction problems in Brazilian buildings.

By subjecting the pathologies presented to an analysis in the GUT Matrix we can obtain the risk that each pathology offers, as shown in Table 4.

Applying the GUT Table, it can be determined that among the main pathologies that offer risks to the building (corrosion, infiltrations, and cracks), corrosion is the most serious, which can lead to the collapse of the structure and total ruin of the building.

Table 3 Possible causes for each pathology.

Pathology	Number of total causes
Cracks	23
Corrosion of apparent structural elements	18
Detachment of the floor	18
Warping and/or movement of internal walls	15
Leakage of slabs between floors	15
Detachment of wet area coverings	13
Infiltrations	10
Sound transmission through the slab or electrical installations	10
Sound transmission through the walls	7
Unevenness of floor slab	5



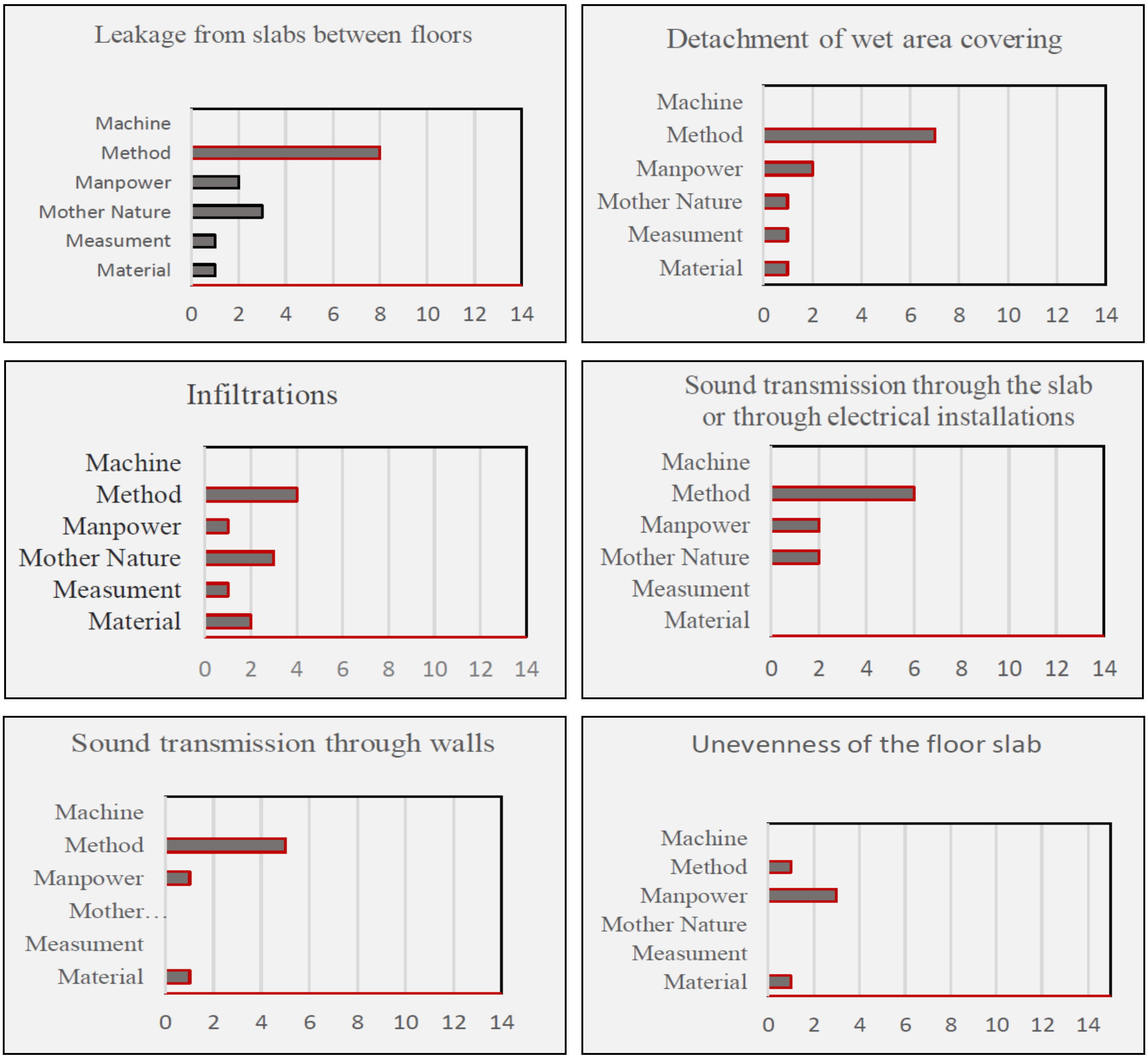


Fig. 1 Pathologies and causes.

Table 4 GUT matrix results.

Pathology	Gravity	Urgence	Tendence	Total
Corrosion of apparent structural elements	10	10	10	30
Infiltrations	6	10	10	26
Cracks	8	8	10	26
Detachment of wet area coverings	3	6	6	15
Floor decolourization	1	6	6	13
Leakage in the slabs between floors	6	3	3	12
Unevenness of the floor slab	2	1	1	4
Sound transmission through walls	1	1	1	3
Sound transmission through slabs orvertical installations	1	1	1	3
Warping and/or movement of internal walls	1	1	1	3

Source: Hofmann [16].

6. Conclusions

Structured steel construction presents itself as an alternative to the already established concrete construction, with some advantages. However, for historical and cultural reasons, its use has not spread as much in Brazil as it has in other countries. A greater knowledge and mastery of the steel structure building process is required. The results of this study confirm Oliveira [17], who, among several hypotheses for the low expressiveness of steel construction and industrialized construction in general in the Brazilian market, suggests that design professionals are not familiar with and do not have enough knowledge to propose the steel structure constructionsystem to clients.

The pathologies in buildings depreciate the property, cause inconvenience to the user, putting him at risk and may lead to the collapse of the building. To build with quality, and ensure a long useful life and good performance, it is very important that the correct way to build be considered already foreseeing the appearance of pathologies.

In a moment of change in the economic scenario, companies seek to improve their processes, becoming more competitive and profitable. Civil construction in countries with a high degree of development is guided by clean construction, with a low volume of waste and errors.

Considering these characteristics, steel construction has become less usual in Brazil, where the low educational level of the unskilled labor force, due to historical, cultural, and educational factors, and the unpreparedness of the specialized labor force to work with this material are latent. As identified in this work, the way of doing and the technical decisions made during the building process are the main reasons that lead to pathologies in the future. Therefore, it is essential that the professionals responsible for the decisions at the construction site have full control of the process, knowing each stage and thus interfering in the ideal moment for the prevention of pathologies.

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