Application of total quality management tools in the risk analysis of pathologies in steel-structured buildings

Aplicación de herramientas de gestión de la calidad total en el análisis e riesgos de patologías en edificios de estructura metálica

Giane Alfenas Antunes Hofmann[1]* https://orcid.org/0000-0001-7783-4781
Henor Artur de Souza[1] https://orcid.org/0000-0002-6249-438X

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ABSTRACT

Structured steel construction is an interesting option to the already established concrete structure at a time when Brazilian civil construction seeks more efficiency. Encouraging the use of this material requires a better understanding of its characteristics and especially its possible pathologies to prevent degradation, costs, and even structural collapse. This study uses Total Quality Management tools are applied to analyze the pathologies present in five medium and large steel-structured buildings. The causative elements are identified with the information about the buildings' pathologies, and the risk analysis of the pathologies is performed using, especially, the Ishikawa Diagram and the GUT Matrix. The most frequent pathologies highlighted in the study are corrosion in the structure, cracks in the closures, and infiltrations in the interface closure/structure. The main causes, according to the Ishikawa diagram and the GUT matrix, are related to construction technique, labor, environmental conditions, and raw material used. The results show that it is possible, through the tools of Quality Management, to establish the risk of each pathology and its origin and determine the degree of risk that each one offers.

Keywords: Building construction, steel, pathologies, quality management.

RESUMEN

La construcción con estructura de acero es una opción interesante a la ya establecida estructura de hormigón en un momento en que la construcción civil brasileña busca más eficiencia. Para incentivar el uso de este material, es necesario conocer mejor sus características y, especialmente, sus posibles patologías, para evitar la degradación, los costes e incluso el colapso de la estructura. En este estudio se aplican las herramientas de Gestión de la Calidad Total al análisis de las patologías presentes en cinco edificios de estructura metálica de mediano y gran tamaño. Con la información sobre las patologías de estos edificios, se identifican los elementos causantes y se realiza el análisis de riesgo de las patologías utilizando, especialmente, el Diagrama de Ishikawa y la Matriz GUT. Las patologías más frecuentes destacadas en el estudio son la corrosión en la estructura, las grietas en los cierres y las infiltraciones en la interfaz cierre/estructura. Las principales causas, según el diagrama de Ishikawa y la matriz GUT, están relacionadas con la técnica constructiva, la mano de obra, las condiciones ambientales y la materia prima utilizada. Los resultados obtenidos muestran que es posible, a través de las herramientas de Gestión de la Calidad, establecer el riesgo de cada patología, su origen y determinar el grado de riesgo que ofrece cada una.

Palabras clave: Construcción de edificios, acero, patologías, gestión de la calidad.

[1] Programa de Pós-Graduação em Engenharia Civil. Departamento de Engenharia Civil, Escola de Minas, Universidade Federal de Ouro Preto. Ouro Preto, Brasil. E-mail: g.alfenas@gmail.com; henorster@gmail.com
* Autor de correspondencia: g.alfenas@gmail.com

INTRODUCTION

Brazil is internationally recognized for its strong representation in reinforced concrete construction. The modernization promoted by Vargas in the 1930s 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 construction in other countries at that time. This scenario remains until today [1].

Oliveira [2] suggests, among several hypotheses regarding the low expressiveness of steel construction, that design professionals lack the familiarity and knowledge to propose steel-framed construction systems to their clients.

The pathological manifestations can cause from discomfort and fear to the total collapse of the structure. It is, therefore, of great importance to understand the problem, identify the causative factor of each occurrence, and also the level of danger and urgency to remedy this problem. The GUT Matrix, a Total Quality Management (TQM) tool, has been used for this purpose, according to Alawag, Alaloul, Liew, Al-Aidrous, Saad and Ammad [3]. The Ishikawa Diagram has been used to identify causes of problems in organizations or procedures since, according to its creator, the reasons always originate in six possibilities, as stated by Liliana [4]. This paper investigates the origin of pathologies arising in steel-structured buildings and determines their level of danger using these two tools from TQM.

THEORETICAL REFERENCE

Brazilian civil construction

Civil construction employs approximately 7% of the world's working-age population. It is one of the economy's largest sectors, with annual expenditures of US$ 10 trillion in goods and services related to this activity. Worldwide, labor productivity growth in this sector averaged 1% per year between 2000 and 2017, while the growth of the world economy was 2.8%. In the industrial sector, this growth was 3.6% [5]. The strong connection of civil construction with other activities allows it to be classified as a key sector for the Brazilian economy. This importance is due to its ability to generate effects on production, income, and employment. The high level of interconnection with other sectors makes the activity fundamental for Brazilian economic development.

Quality management policies, as well as planning and knowledge of the processes that involve a building, whether at the design stage or during post-occupation, result in a better sector performance.

Quality Management

In general, quality has been thought of, planned, implemented, and improved since the 1930s in the United States and since the 1940s in Japan and in several other countries. In Brazil, Total Quality Management began in the 1980s, when professors started a research project at the Federal University of Minas Gerais (UFMG) on process control and whose goal was to bring cutting-edge knowledge to the Brazilian market, especially to steel companies, thus facilitating the insertion of young people from UFMG Engineering in the labor market [6].

According to Neyestani [7], Kaoru Ishikawa was the first researcher on total quality management. Ishikawa has been associated with developing and advocating quality control (QC) tools in organizations for problem-solving and process improvement. He proposed seven basic tools in 1968 by publishing the book entitled "Gemba no QC Shuho," in which he was concerned with managing quality through techniques and practices for Japanese companies. These tools have the significant roles of monitoring, obtaining, and analyzing data to detect and solve the problems in the production processes to facilitate the achievement of performance excellence in organizations.

One of its best-known tools is the Ishikawa Diagram, or Fishbone Diagram, because of its shape. Its technique consists of a cause-and-effect analysis [8].

A cause-and-effect diagram is a problem-solving tool that systematically investigates and analyzes all actual or potential causes that result in a single effect [7]. Ishikawa Diagram is a graphical tool that helps in management and Quality Control (QC) in different processes whose main objective is to identify the causes of an effect or problem.

For effective management, it is imperative to identify the "root causes" and the "main causes" of the problem, which can only be found if there is a proper understanding of the process, using a good experience the innovative tools, and the use of the appropriate techniques [8]. The cause and effect diagram provides a structural approach for searching for possible causes of the problem [9]. According to Tubino [10], this diagram simplifies processes that are considered complex by breaking them down into more straightforward and, therefore, more manageable processes.

The main causes that can generate a problem can be grouped under six categories known as the 6 M's: method, labor, material, machine, measure, and mother nature (environment) [4], Figure 1.

Another tool is the GUT Matrix by Kepner and Tregoe, which analyzes the criticality of an anomaly or construction flaws. The GUT Matrix (gravity, 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. Thus, the GUT Matrix provides a global understanding of the problems, determining the order of priority in the management and resolution of the situation [11].

Source: The authors.

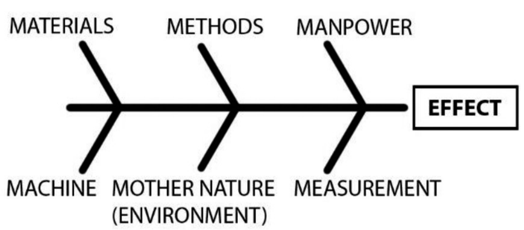

Figure 1. Ishikawa diagram model.

According to Pestana, Veras, Ferreira, and Silva [12], for the construction of this matrix, the problems should be scored for analysis, following the GUT classification, in this order:

- Gravity, referring 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, deals with the possibility of the problem growing over time.

Each approach presents five degrees of commitment (or criticality levels), with each degree representing a previously established score (or weight) (Table 1). Finally, the three 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 [13].

Pathologies

Castro [14] divides construction pathologies into acquired, transmitted, and atavistic, largely resulting from design errors. According to the author, designing a steel structure requires in-depth knowledge of the characteristics and properties of the materials involved. The absence of this knowledge can lead the designer to a solution incompatible with the structural system, causing problems of various natures.

According to Souza and Ripper [15], pathology in buildings can be defined as low performance (or

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 the medium term.	Prognosis for the near future.
Low	3	Nuisance to users, degradation of the building, non-rational use of natural resources.	Evolution in the long term.	Prognosis for the future.
Minimum	1	Real estate depreciation.	It will not develop.	Unforeseen.

Source: [13].

even the end of the performance) in a building. The study of this phenomenon and its action by engineering is characterized by analyzing the origins, manifestation forms, consequences, and mechanisms of occurrence of failures and wear and tear processes of the elements that compose the building.

Castro [14] considers that most pathological problems in buildings have their origin credited to man's ignorance, carelessness, or greed. Within this panorama, he lists the causes of pathologies in construction. This list is not restricted to steel structure buildings but can be linked to any engineering work (Table 2).

MATERIALS AND METHODS

The development of this research was based on two previous works. In "Mapping the problems generated in the association between sealing systems and steel structure and acoustic and vibration characterization of sealing panels", de Sales [16] makes an investigative approach regarding the performance of closing panels associated with steel construction, having as objectives to analyze the execution processes of steel-structured buildings. Thus, information was collected about the events and construction conditions that each building went through.

Using the aforementioned work, Bastos [17], in 2004, assesses post-occupancy use, where he presents the problems found in "Evaluation of semi and/or industrialized constructive systems of multi-story buildings through the perspective of their users." One of the results of this research is the survey of the most common pathologies and their frequency.

The information contained in these two works provided subsidies for the present research. A survey is done on the occurrences at the time of construction of each building and the possible interference of these conditions in the appearance of pathologies [18]. Thus, it is possible to identify the pathologies related to the structure being made of steel and the pathologies common to any building.

The Ishikawa Diagram is used to analyze the failure method (cause and effect) in which all possible reasons are considered in the investigation of a problem.

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

- 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).

Table 2. Causes of pathologies in construction.

Origin	Causes
Ignorance	– Incompetence of those responsible for the project, construction or inspection; – Supervision by bosses or foremen without the minimum qualifications; – Hiring of maintenance by men without the minimum qualifications; – Men without the minimum technical qualifications making assumptions of vital responsibility that should be the responsibility of their respective foremen; – Competition without supervision; – Occurrence of situations without previous precedents; – Insufficient preliminary information.
Carelessness	– On the part of engineers and architects who, because of their self-confidence, relegate important points of the job to the background; – The entrepreneur or the supervisor who takes a chance knowing that he is taking a risk; – From the designer for not making a correct coordination in the production of the projects.
Greed/Economy	– Cost reduction at the expense of aspects such as safety and quality; – Maintenance relegated to a second plan.

Source: [14].

– Mother Nature (Environment): possible faults referring to interferences caused by rain, humidity, heat, and sun.
– Manpower: possible causes referring to problems caused by the task performers: mistakes, haste, imprudence, which are caused by the employee contradicting/ignoring/not understanding superior guidance.
– Method: possible causes referring to problems caused by procedures, routines, or techniques used, determined in the project, or through superior orders.
– Machine: possible causes referring to problems caused by machinery or tools.

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

For this research five buildings in the city of Belo Horizonte were considered, all under the same environmental conditions. According to Sales [16], their characteristics are diverse:

Building 1 (Figure 2) with three floors, was built in 2000, with a steel structure (non-parallel laminated profiles). The external vertical closure is in perforated ceramic brick, and the internal one is in precast reinforced concrete panels. The slabs between floors are made of precast reinforced concrete panels. The labor was contracted for that project. The company needs a staff training program or a systematic plan to introduce new technologies on site.

Building 2 (Figure 3), with nineteen floors, was built in 1998, with a steel structure (welded profiles, not visible). 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 construction assembly.

Building 3 (Figure 4), with three floors, was built in 2000, with a steel structure (light profiles, not visible). The external vertical closure is in reinforced concrete panels with an expanded polystyrene

Source: The authors.

Figure 2. Building 1.

Source: The authors.

Figure 3. Building 2.

Source: The authors.

Figure 4. Building 3.

core, and the internal closure was executed with plasterboard panels. The slabs are steel, with embedded formwork. The company does not have a permanent team of employees and does not have a training program; thus, the work has been carried out under contract.

Building 4 (Figure 5), with ten floors, was built in 1997 in a steel structure (welded profiles, not visible). The external vertical closures are in cellular concrete masonry, and the internal ones are in gypsum plasterboard panels. The company does not have a permanent staff and does not have a training program.

Building 5 (Figure 6), with nine floors, was built in 2000 with a steel structure (welded profiles, not visible). The exterior vertical enclosure is made of autoclave-treated cellular concrete panels and the masonry of cellular concrete blocks. The internal vertical enclosure comprises gypsum panels, and the floor slabs are in-situ concrete. The site labor was, almost in its totality, hired by service companies that sold the respective construction component systems to the construction company, which took on the role of coordinating the process.

Source: The authors.

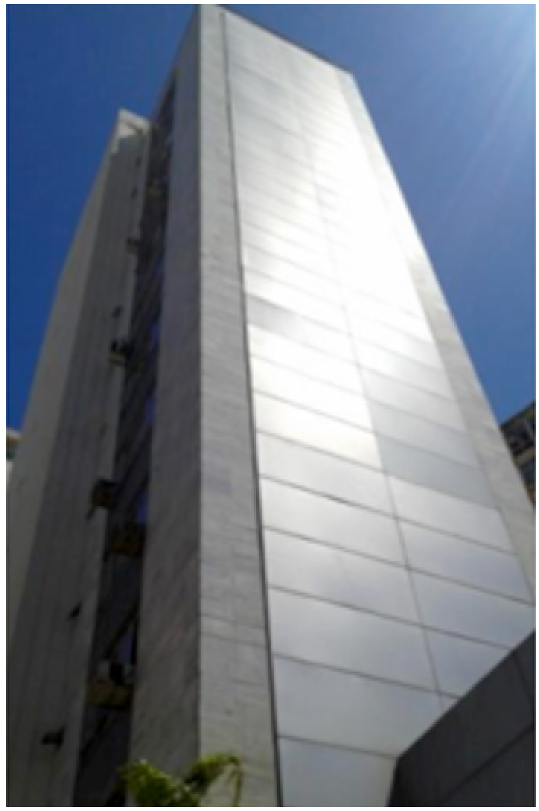

Figure 5. Building 4.

Source: The authors.

Figure 6. Building 5.

ANALYSIS AND INTERPRETATION OF RESULTS

The main pathologies identified by building users in Bastos [17] survey and their quantification are presented in Table 3:

Table 3. 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: [17].

Table 1 shows the possible causes of the pathologies described, and the origin of the possible causes of each pathology is presented in analyses 1 to 10. The relationship with the fact of being a steel structure building is also considered, expressed in parentheses.

ANALYSIS 1 - List of possible causes for the "Infiltration" pathology:

Material:
– Use of low-quality asphalt blanket [19] - (No).
– Material unsuitable for weathering [19] - (No).

Measurement:
– Asphalt blanket with an inadequate thickness [19] - (No).

Mother Nature (Environment):
– Non-waterproofing of elements in contact with the ground [20] - (No).
– Non-waterproofing of slabs [19] - (No).

Manpower:
– Unskilled labor [16] - (Yes).

Method:
– Water ingress through poorly installed window frame [21] - (No).
– Lack of ruffles and dripping [19] - (No).
– Interface with masonry poorly defined in the design, in the case of steel structure [22] - (Yes).
– Professional failure when specifying material [14] - (Yes).

Machine:
– No applicable parameters.

The structure/masonry interface is a constant source of pathologies and is very common in concrete structures [23]. The three possible causes of the "Infiltration" pathology are unfamiliarity with the material. Regarding the cause and effect diagram, they are linked to artistry and method.

ANALYSIS 2 - Relationships of possible causes for the "Cracks" pathology:

Material:
– Low-quality material [14] - (No).
– Presence of expansive clay minerals in the aggregate [14] - (No).
– Mortar shrinkage [24] - (No).

Measurement:
– Horizontal joints with insufficient width between masonry elements [25] - (No).
– Actuation of localized overloads [26] - (No).

Mother nature (Environment)*:*
– Temperature and humidity variations [19] - (No).
– Cracking in masonry due to slab expansion by the heat of the sun (top floor) [27] - (No).
– Chemical attacks [24] - (No).

Workforce:
– Unprepared labor [16] - (No).
– Faulty execution [16] - (No).

Method:
– Crushing of construction elements [23] - (Yes)
– Incorrect storage of materials during construction [28] - (No).
– Poor curing of concrete [19] - (No).

- Arrow in the beam causing masonry crushing [23] - (Yes).
- Masonry connected to structure, working together but with different dilatations[23] - (Yes).
- Structural settlements [28] - (No).
- Masonry-column encounter: water percolation [23] - (No).
- Differential settlement of the foundation [28] - (No).
- Absence of expansion joints [29, 30] - (No).
- Poorly cured roughcast [23] - (No).
- Absence/inefficiency of the lintel [23] - (No).
- Failure in the dimensioning of the structure [31] - (No).
- Failure to place mesh near door and window openings in case of EPS panel [32] - (No).

Machine:
- No applicable parameters

It can be seen from the data shown in Table 6 that the possible causes of the "cracks" pathology are mainly linked to the culture of performing vertical closure with ceramic bricks and are linked to the method within the cause and effect diagram.

ANALYSIS 3 - List of possible causes for the pathology "Sound transmission through walls":

Material:
- Defect in the product in quality and geometry [33] - (No).

Measurement:
- No applicable parameters.

Mother nature (Environment)*:*
- No applicable parameters.

Workforce
- Unprepared labor [14] - (No).

Method:
- Non-use of a double sheet [34] - (No).
- Non-existence, at the moment, of norms about plaster walls [16] - (No).
- Lack of insulation material in plaster walls [35] - (No).
- Insufficient amount of filler for treatment of joints between plasterboards [35] - (No).
- Cracked interface allowing sound passage [35] - (No).

Machine:
- No applicable parameters.

Although 40.7% of the buildings present the pathology "Transmission of sound through walls", the occurrence of this problem does not depend on the fact of being a steel-structured building.

ANALYSIS 4 - List of possible causes for the pathology "Sound transmission through slabs or vertical installations":

Material:
- No applicable parameters.

Measurement:
- Slab with small thickness [36] - (No).

Mother nature (Environment)*:*
- Cracks caused by poor slab curing and structural factors [28] - (No).
- Cracks caused by time (non-maintenance) [37] - (No).

Workforce:
- Unprepared labor [14] - (No).
- Failure in the execution of the slab [28] - (No).

Method:
- Non-compatibilization of projects, especially in case of steel structure [38] - (Yes).
- Installation boxes of two adjacent environments placed in coincident opposite positions [39] - (No).
- Lack of insulation material on the walls [34] - (No).
- No use of acoustic insulation material on the floor [36] - (No).
- Non-existence, at the time of construction, of standards on plaster walls [16] - (No).
- Non-use of double sheet [16] - (No).

Machine:
- No applicable parameters.

The lack of project compatibility characterizes lack of planning, a behavior that conflicts with steel construction, which must be previously analyzed and thought out before being executed. Project compatibility is linked to the method, within the cause and effect diagram.

ANALYSIS 5 - List of possible causes for the pathology "Leaks in the slabs between floors":

Material:
– Low-quality blanket [14] - (No).

Measurement:
– Excessive weight on the slab causing cracks [26] - (No).

Mother nature (Environment)*:*
– Cracks caused by poor slab curing [28] - (No).
– Broken tile on the roof [40] - (No).
– Cracks caused by time (non-maintenance) [37] - (No).

Workforce:
– Unprepared labor [14] - (No).
– Non-maintenance in waterproofing [37] - (No).

Method:
– Infiltration caused by downpipe [40] - (No)
– Water passing through ceramic floor tiles - lack of grouting [24] - (No).
– Infiltration caused by water accumulation in ceramic tiles loosening on external coating [29] - (No).
– Concrete/steel detachment [14] - (Yes).
– Infiltration in the walls reaching the slab, caused by settlement and cracks in the walls [24] - (No).
– Lack of waterproofing on the slab [28] - (No).
– Entry of rainwater through a window reaching the upper floor slab [34] - (No).
– No maintenance on the gutters [40] - (No).

Machine:
– No applicable parameters.

Considering that most Brazilian constructions are executed in concrete, the possible causes for this problem are pertinent to any construction work, except, exactly, the only one referring to steel construction: the use of steel forms filled with concrete (steel deck). In the cause and effect diagram, this problem is related to the method.

ANALYSIS 6 - List of possible causes for the "floor detachment" pathology:

Material:
– Low-quality ceramics [14] - (No).
– Improper mortar [30] - (No).

Measurement:
– Large mortar thickness [25] - (No).

Mother nature (Environment)*:*
– Exposure to high temperatures [30] - (No).
– Expansion by humidity [19] - (No).
– Excess moisture [19] - (No).

Workforce:
– Unprepared labor [14] - (No).
– Use of mortar after expired open time [29] - (No).

Method:
– Absence of expansion or deformation joints [19] - (No).
– Positioning of joints in improper location [29] - (No).
– Absence or insufficiency of expansion, settlement, or desolidarization joints [19] - (No).
– Project flaws [30] - (No).
– Incorrect specification of laying or grouting material [30] - (No).
– Absence of a screed layer [19] - (No).
– Deficiency in base preparation [30] - (No).
– Lack of cord kneading [30] - (No).
– Placement of grout shortly after laying [30] - (No).

Machine:
– Problematic use of toothed straightener [29] - (No).

The fact that it is a steel-framed building is not a possible cause of this problem.

ANALYSIS 7 - List of possible causes for the "unevenness of the floor slab" pathology:

Material:
– Inadequate concrete consistency [41] - (No).

Measurement:
– No applicable parameters.

Mother nature (Environment)*:*
– No applicable parameters.

Manpower:
– Unprepared labor [14] - (No).
– Error when defining the level of each slab [41] - (No).
– Structure built unevenly [14] - (No).

Method:
– Design incompatibility [38] - (No).

Machine:
– No applicable parameters.

No possible cause for the incidence of the "unevenness of the floor slab" pathology is linked to the fact that it is a steel structured construction.

ANALYSIS 8: List of possible causes for the pathology "Detachment of coating from wet areas":

Material:
– Low-quality material [14] - (No).

Measurement:
– Stresses from base movement [28] - (No).

Mother nature (Environment)*:*
– Excessive moisture [19] - (No).

Workforce:
– Use of mortar after the open time has expired [29] - (No).
– Unprepared labor [14] - (No).

Method:
– Insufficient mortar [30] - (No).
– Execution prior to standards [16] - (No).
– No maintenance or in disagreement with the owner's manual [29] (No).
– Inadequate grouting [30] (No).
– Conventional mortar in place of industrialized mortar [42] - (No).
– No expansion or deformation joints [28] - (No).
– Use of aggressive material in cleaning [30] - (No).

Machine:
– No applicable parameters

Although many possible causes are presented for the occurrence of the pathology "Detachment of the coating of wet areas," no possible cause for the incidence of the pathology is linked to the fact of being a steel-structured construction.

ANALYSIS 9: List of possible causes for the "Corrosion of apparent structural elements" pathology:

Material:
– Low-quality material [14] - (No).
– Material unsuitable to weathering exposure [19] - (Yes).

Measurement:
– Inexistence/insufficiency of drainage holes [43] - (Yes).

Mother nature (Environment)*:*
– Dust, gases or moisture [14] - (Yes).
– Chemical attacks [44] - (Yes).

Manpower:
– Non-specialized labor [14] - (No).

Method:
– Parts half-buried or in contact with the ground [20] - (Yes).
– Contact with aluminum or galvanized parts [21] - (Yes).
– Failure of the professional when specifying materials or forms [14] - (Yes).
– Error in detailing [45] - (Yes).
– Failure or absence of maintenance [14] - (No).
– Non-specification of paint, in case of exposed steel [46] - (Yes).
– Use of non-corrosion resistant steel [47] - (Yes).
– Water accumulation in arrow points [43] - (Yes).
– Non-use of heat treatment on parts [48] - (Yes).
– Consequence of work hardening, welding, loads [48] - (Yes).

Machine:
– Presence of sharp edges, burrs, recesses, cracks, or cavities [48] - (Yes).
– Grooves that provide accumulation of aqueous solution or dirt [21] - (Yes).

The possible, and many, causes for the "Corrosion" pathology are mostly related to the fact that it is a steel-structured building. Furthermore, in the cause and effect diagram, the problems are related to raw material, measurement, environment, method, and machine.

ANALYSIS 10 - List of possible causes for the "warping or wall movement" pathology:

Material:
– Gypsum sheets made prior to the standards [16] - (No).
– Use of paste and tape in disagreement with the manufacturer of the plate [30] - (No).

– Non-use of RU[1] type plates in humid environments [45] - (No).

Measurement:

– Failure to respect the steel profile size requirement of 5mm to 10 mm less than the ceiling height [34] - (No).
– Insufficient quantity of paste for joint treatment [34] - (No).
– Insufficient screws in the fixation [34] - (No).

Mother nature (Environment)*:*

– Excessive moisture in the environment [34] - (No).

Workforce:

– Unqualified labor [14] - (No).
– Inadequate storage of the profiles, causing them to warp [28] - (No).
– Improper fixing of the screws [49] - (No).

Method:

– Non-use of steel angle bracket for protection at corners [39] - (No).
– Galvanized steel profiles made in non-conformity with the standards [50] - (No).
– Irregularities in the floor slab [41] - (No).
– Execution prior to the standards [16] - (No).
– Use of paste plaster or putty in the treatment of joints [30] - (No).

Machine:

– No applicable parameters

No possible cause for the incidence of the pathology "Warping or wall movement" is linked to the fact that it is a steel structured construction.

Observing the data presented in Analyses 1 to 10, 134 possible causes are listed for the ten pathologies presented and indicated in the work of Bastos [17]. Of these causes, 16 are related to raw material, 19 are related to labor, 3 are related to machinery, 11 are related to measures, 17 are related to the environment, and 68 are related to the method.

It can be seen, therefore, that the way of construction or the resolutions contained in the project are responsible for the absolute majority of pathologies, representing 51% of the possible causes of pathologies in the surveyed buildings (Figure 7). The method can mean design determinations (or the lack of them) and the execution practice at the construction site. Some construction techniques may present themselves as insufficient in preventing pathology and will only present consequences in the future. Other times, some construction methods may have needed to be addressed due to sloppiness or economy. As stated by Castro [14], the presence of pathologies is explained by greed, ignorance, or carelessness.

Source: The authors

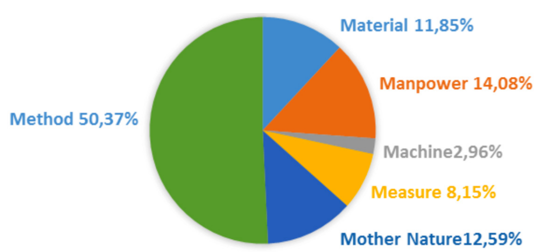

Figure 7. Percentage of 6M causes.

Table 4. Pathologies and quantification of related causes.

Pathology	Number of Causes	Results in %
Corrosion of apparent structural elements	15	68.18%
Cracks	3	13.63%
Infiltrations	2	9.09%
Leakage from slabs between floors	1	4.55%
Sound transmission through the slab or through electrical installations	1	4.55%
Sound transmission through walls	0	0%
Detachment of floor slab	0	0%
Unevenness of the floor slab	0	0%
Detachment of wet area coverings	0	0%
Warping and/or movement of internal walls	0	0%

Of all the identified pathologies, only a part is a consequence of the structural steel typology of the building (Analysis 1 to 10). The others are general problems that can occur in buildings, regardless of the structure's material. The demonstration of this incidence of pathologies as a function of the steel structure is shown in Table 4.

Submitting the pathologies presented to an analysis in the GUT Matrix, we obtain the higher or lower risk each pathology offers, Table 5.

The analyzed buildings present many pathologies. However, some of these pathologies could happen in any building, while others arose because it is a steel-structured building. The latter are:
- Infiltrations;
- Cracks;
- Sound transmitted between slabs and vertical installations;
- Leaks between floor slabs;
- Corrosion of structural elements.

Figure 8 shows the score obtained in the GUT Matrix for each pathology. In hatching, the pathologies are related to the fact that it is a steel-structured building.

CONCLUSIONS

The knowledge about the material and, the techniques and procedures for its use are of fundamental importance in obtaining a building free of pathologies. However, eventually, the emergence of problems occurs.

In planning or analyzing certain situations, Quality Management tools work as definers of solutions to

Table 5. GUT scores of each pathology.

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

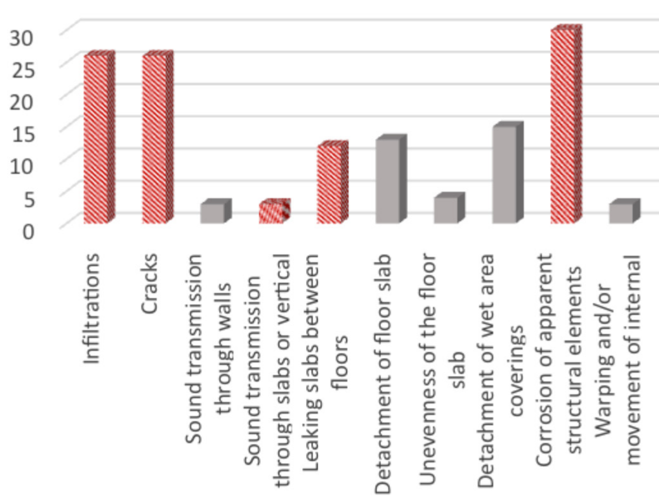

Figure 8. GUT scores of each pathology.

be adopted or, still, as tools in interpreting problems. In this work, they were used in the problem analysis. This analysis, at first, defined, among all the pathology-causing factors, which ones are related to the fact that it is a steel structure building and which ones are likely to happen in any building, regardless of the material of its structure. Finally, the analysis proved to be efficient and assertive in defining the pathologies that need quick intervention in steel structure buildings: mainly corrosion, followed by infiltrations, and then cracks or fissures.

Through the use of the Ishikawa diagram, it is possible to identify that the origin of the pathologies is related to the way of execution at the construction sites. Despite the quality of the workforce in Brazilian construction, these contingent follows procedures, routines, and techniques determined in the project or command from a higher hierarchy, which retains (or should retain) technical knowledge to issue such guidance. Therefore, one must consider the way of doing things (determined by a technical leader) as a major significant cause of pathologies, and the onus for the problems presented in the building is not on the low qualification of this workforce.

Therefore, the identification and prevention of pathologies arising from the structural steel system become highly relevant because, as observed, these pathologies are the ones that cause the most influential impact on the life of a building, with severe repercussions and even total collapse.

Knowledge of this origin will avoid repeating the procedure, especially since the risk it poses is demonstrated here.

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