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## The Use of Damage Maps to Identify Building Defects: A Systematic Review



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### ABSTRACT

Damage maps consist of graphic documents capable of synthesizing information about the state of conservation of a building, illustrating and discriminating the building defects, making it possible to record the evolution of problems. In this sense, the article aims to search for papers that used the damage map technique to verify and evaluate building defects in any elements of buildings, especially façades, to analyze their usability with other techniques, pointing out their positive aspects and negative. The methodology followed the guidelines of the Preferred Report Items for Systematic Reviews and Meta-Analysis (PRISMA) using some keywords, such as: "damage map", "map of damage", "mapping damage", "façade", "building façade", "pathologies", "defects" and "construction". Results show that 93% of the research had façades as their object of study and 46% were historic buildings. The combination of techniques used by the researchers, in addition to the damage maps, aimed at guaranteeing a more reliable proposal for the treatment of anomalies stands out. Still, there is a need for legal standardization to guarantee the quality and understanding of damage maps and projects for better execution and service of repairs and restorations. It is concluded that the technique is essential for taking actions concerning maintenance and rehabilitation interventions in buildings. It emphasizes the importance of other professionals and researchers in the area sharing their experiences, to compose the collection so that guiding guidelines for the use of this instrument can be obtained.



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## INTRODUCTION

Among the various elements in a building, the façades stand out. According to Santos *et al.* [1], having cultural and socioeconomic characteristics, they are the first visual contact of an enterprise. Façades play an important role in protection against harmful circumstances and aggressive environmental agents, such as rain, winds, and the sun. Besides, the façades are a complex system for their design, construction, and maintenance, considering that they have an essential function in the performance of buildings and, therefore, must have a minimum useful life [2, 3].

Useful life is, according to the ABNT NBR 15.575 Standard [4], the duration interval that an enterprise, its systems, elements, and components, are available to the activities for which they were designed and built. In this way, it can be inferred that the agents present in the environment can cause a decrease in the useful life of enterprises, given the probability of the appearance of building defects that can impair their performance. Such manifestations are the symptoms that a building presents, that is, resulting from a degradation mechanism.

It is known that building defects derive from failures that have occurred in the phases that follow civil construction, whether resulting from phases of design or execution. In general, the building defects appear on an evolutionary scale, which allows the distinction of different causes of the problem; however, the sooner the fault is identified, the easier the problem becomes. Rocha *et al.* [5] conclude that once identified, the diagnosis of the failures must be corrected based on critical and investigative analysis of the origin of the problem, aiming at the most effective treatment. It is important to note that such circumstances can present themselves internally and externally, as is the case with façades. Still, according to some authors, the main building defects that can arise during the life of an enterprise are cracks, chemical and physical attacks on the structure, corrosion of armatures, and defects due to the construction, design, and detailing of the project [6, 7, 8].

In this sense, the damage map tool emerges as an instrument that assists in maintenance and restoration work. Damage maps consist of graphic documents capable of synthesizing information about the conservation of construction, with building defects illustrated [9]. Also, it is possible to record the evolution of problems related to the state of conservation, facilitating future examinations, preventive actions, and maintenance interventions in buildings. It is

important to highlight that this tool does not yet have norms and, therefore, there is no standard to be followed for graphic representations.

Given the above, this study aims to investigate research that used the damage map technique for the verification and evaluation of building defects in any elements of buildings - especially the façades - to analyze their usability with other techniques, pointing out their positive and negative aspects for maintenance interventions.

#### **MATERIALS AND METHOD:**

The systematic review is important because it details the literature on the subject. Furthermore, the review aims to summarize evidence to reach reliable conclusions, illustrating objectivity and transparency to readers [10]. Table 1 was elaborated, consisting of the research protocol.



**Table No. 1: Research protocol**

Item	Content
<b>Objectives</b>	To gather research that verified and evaluated building defects through the damage maps.
<b>Results</b>	Obtain information about the usability of the damage maps along with other techniques, their positive and negative aspects.
<b>Keywords</b>	“Damage map”, “Map of damage”, “Mapping damage”, “Façade”, “Building façade”, “Pathologies”, “Defects” e “Construction”.
<b>Idioms</b>	English and Portuguese
<b>Database</b>	Scopus, CAPES, Web of Science, and Google Scholar.
<b>Inclusion criteria</b>	Languages: English, Portuguese; Knowledge areas: Civil Construction; Approach: Use of the Damage Map to assess building defects in any element of a building
<b>Exclusion criteria</b>	Approach: Publications that addressed the Damage Map as a result of thermographic images, and those focused on the area of geology, whose objective was related to identifying widespread damage that occurred from natural phenomena.
<b>Research questions</b>	* What are the difficulties and limitations of using the damage mapping technique? * How can the damage map technique contribute to maintenance and restoration works?

This paper follows the guidelines of the PRISMA method [10]. The research includes SCOPUS, CAPES, Web of Science, and Google Scholar databases to search for articles. Also, to include other publications relevant to the study, an analysis of the references from the found articles was carried out. The keywords in the search were: “damage map”, “map of damage”, “mapping damage”, “façade”, “building façade”, “pathologies”, “defects”, and “construction”.

As inclusion criteria, the selection included articles in English and Portuguese, which addressed the use of the Damage Map to assess building defects in any element of buildings. As exclusion criteria, publications that addressed the Damage Map as a result of thermographic images were excluded, as well as those focused on the area of geology, whose objective was related to identifying widespread damage to large areas.

A flowchart illustrates the research process. The articles included in the review were analyzed quantitatively concerning the year of publication, country of publication, and nationality of the authors; as well as qualitatively, where we examined the methods and techniques used, the pathologies found, the types of the evaluation carried out, and the object and relevance of each study.

## **RESULTS AND DISCUSSION**

### **RESULTS:**

From the searches, only 136 articles were found in the databases and the references of the articles selected for analysis. This number evidences the scarcity of the topic. Therefore, filtering by year of publication was not used so that searches were not limited. However, to continue the selection process, the authors applied the criteria of language (Portuguese and English) and area (civil engineering); the number of articles was reduced to 51. Then, the selection was carried out based on the reading of titles and abstracts (21 excluded), and later, by complete reading for inclusion of studies (16 excluded). Finally, with the criteria adopted, 14 articles were included for the analysis of this review. The selection process can be seen in the flowchart in Table 2.

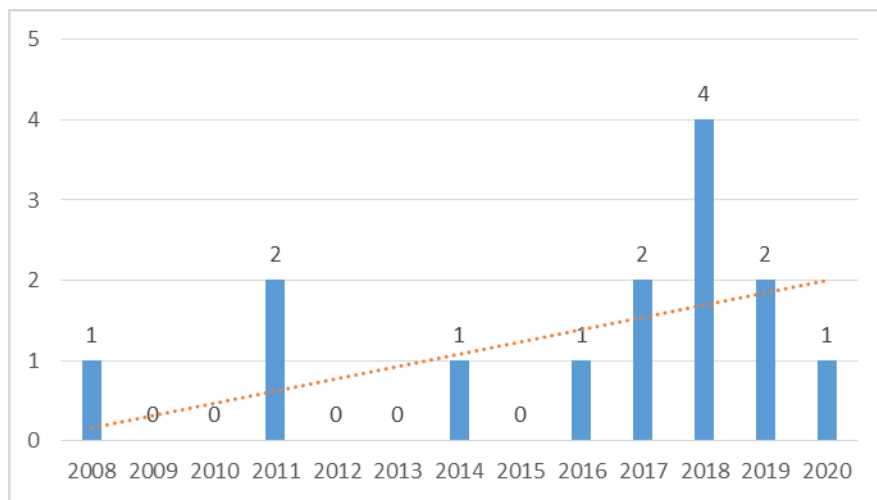


**Table No. 2: Research flowchart**

<b>Identification</b>	Articles identified through the search on the databases and thorough screening of references of included articles (N = 136)	
<b>Selection</b>	Articles selected by language and area (N = 51)	Articles excluded by language and area criteria (N = 85)
	Articles selected by title and abstract (N = 30)	Articles excluded by title and abstract (N = 21)
<b>Eligibility</b>	Full article text assessed for eligibility (N = 30)	Full article text excluded (N = 16)
<b>Included</b>	Number of articles included in the qualitative summary of this review (N = 14)	

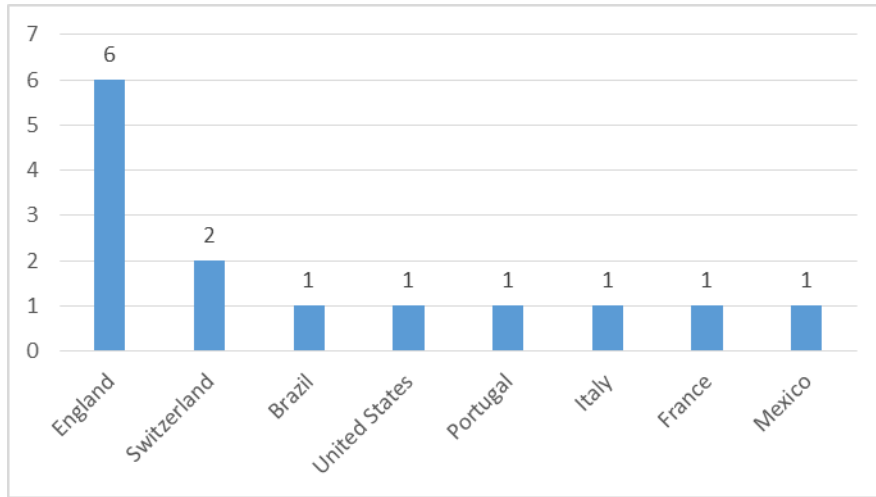
### Quantitative analysis

Four parameters that characterized the developed research were investigated: categorization of articles by year of publication, country of publication, nationality of the authors, and the recurrence of keywords. Such parameters aim to inform the reader about the frequency of publication on the subject, the places that most refer to it. It is possible to relate the nationality of the authors, making it clearer where the works can be retrieved from. Figure 1 shows the number of publications per year, according to the inclusion criteria.



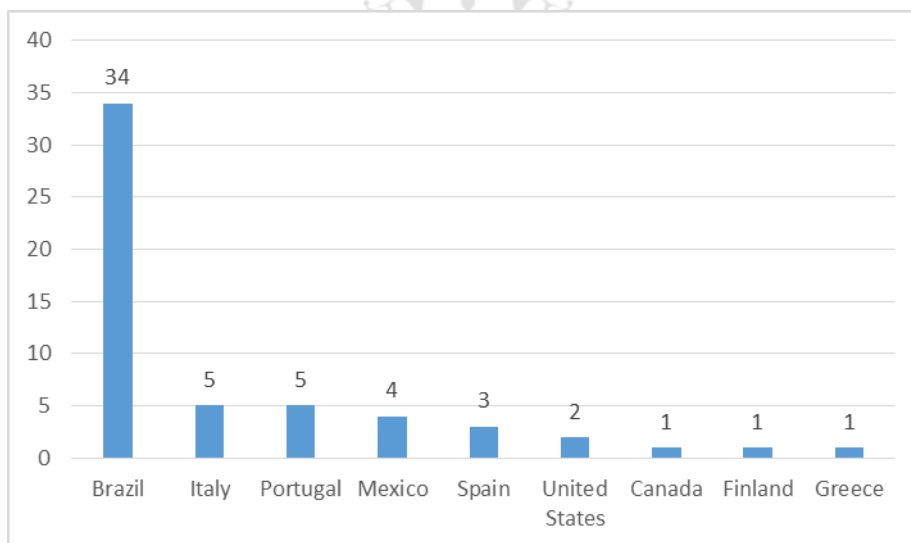
**Figure No. 1: Number of publications per year**

It is noted that in the period from 2008 to 2020, the years 2009, 2010, 2012, 2013, and 2015 did not have publications, evidencing once again the scarcity of works. On the other hand, there is an increase in research from 2016 to 2018, with 2018 being the period of greatest production, with 28.5% of publications. In the following years, 2019 and 2020, there was a drop in research, representing, respectively, 14.3% and 7.2% of the total. Despite the drop in recent years, there is a gradual growth in research. Figure 2 exposes the origin country of the journals.



**Figure No. 2: Number of publications by country**

According to Figure 2, England was the country with the largest number of articles, representing about 43% of the total. Second is Switzerland, which represented approximately 14% of the total. Brazil and the other countries (United States, Portugal, Italy, France, and Mexico) corresponded to approximately 7% each. Figure 3 shows the origin country of the institutions to which the authors are linked.



**Figure No. 3: Origin country of the institutions to which the authors are linked**

It appears that approximately 73.2% of the authors are linked to American institutions. In addition, the European continent represented 26.8% of the total. No authors linked to institutions from other continents were identified. Finally, in the quantitative analysis, a word cloud was generated (Figure 4).





Table No. 3: Characterization of research for the qualitative analysis

Number	Author (year)	Object of Study	Analysis	Methodological Procedures	Main Defects	Relevance
1	BAUER <i>et al.</i> (2014)	Residential Building Façade	Quantitative and Qualitative	Visual inspections, damage map, calculation to assess the level of façade degradation (ODL)	Detachment, grout failure, cracks, efflorescence, sealing failures	Damage map facilitates visualization for calculating the level of degradation. Older buildings have a level of progressive degradation
2	LERMA <i>et al.</i> (2011)	Front façade of Historic Building	Qualitative	Visual inspections, Thermography, thermal image processing and moisture damage map	Moisture	The approach presented with multitemporal imagery can be used successfully to help construction technicians determine the areas affected by moisture
3	SOUZA <i>et al.</i> (2016)	Residential Building Façade	Quantitative and Qualitative	Visual inspections, Degradation measurement (DMM), Damage map	Ceramic detachment, grouting failure, cracking, efflorescence and sealing failure	The degradation calculation is obtained from a superimposed mesh on the damage map. The biggest points of degradation are the continuous walls, transition between floors, and roof
4	PACHECO <i>et al.</i> (2018)	Historic Building Façades	Qualitative	Visual inspection, Damage map	Detachment of paint, rising humidity, vegetation, fungi, cracks, biodeterioration, peeling plaster	Maps are easy to understand instruments, allowing the visualization of the location where the pathologies are most centered and the extent they occupy

Number	Author (year)	Object of Study	Analysis	Methodological Procedures	Main Defects	Relevance
5	SOUSA <i>et al.</i> , (2017)	Façades of a wooden warehouse	Qualitative	Visual inspections, moisture content, impact penetration test and damage map	Moisture stains, cracks, surface deterioration by fungi, biological colonization, broken elements, column deformations	Visual inspection must be complemented with other non-destructive testings to qualitatively assess the level of conservation within and between the elements, thus allowing to identify and characterize different critical sections on a damage map
6	PUY-ALQUIZA <i>et al.</i> (2019)	Historic Building Façades	Quantitative and Qualitative	Survey and characterization of the type of material, quantification of weathering and degree of damage through Damage Map and image processing	Material loss, discoloration, broken blocks, efflorescence, fissures, biological colonization	The combination of maps and image processing allowed to quantify the extent of weathering and the degree of damage, in addition to facilitating the interpretation and assessment of pathologies
7	BERSCH <i>et al.</i> (2020)	Historic Building Façades	Quantitative and Qualitative	Documentary investigation, visual survey, percussion and thermography tests, damage map, characterization of coatings.	Cracks, detachments, disintegrated surfaces, vesicles, biodeterioration, dirt stains, moisture stains, manifestations in the painting	Documentary research allows identifying interventions made after construction. Combination of techniques allows better understanding of the causes and consequences of damage

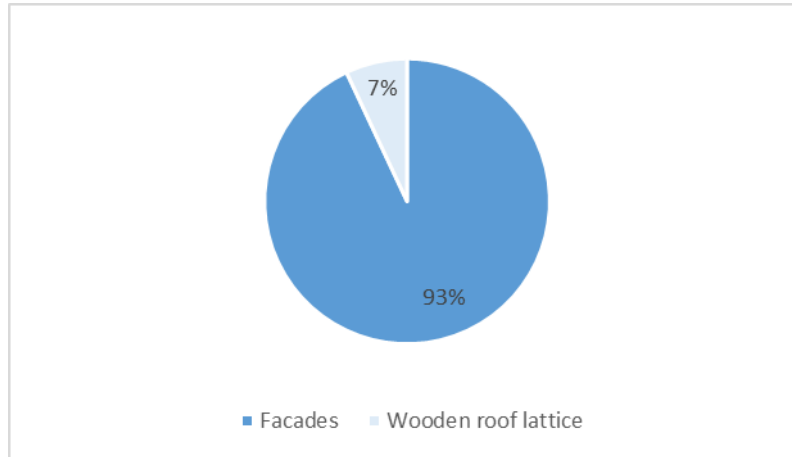
Number	Author (year)	Object of Study	Analysis	Methodological Procedures	Main Defects	Relevance
8	SAARI (2008)	Residential Building Façades	Qualitative	Documentary investigation, development and testing of reform procedure, visual inspection, damage map	Cracks, plaster detachment, no adhesion between plaster and masonry	A complete and objective analysis of the state and functioning of the structures is essential to determine a precise renovation procedure
9	ROCHA <i>et al.</i> (2018)	Historic Building Façades	Qualitative	Visual inspection, documentary inspection, damage record and identification, damage map	Plaster deburring, moisture stains, biodegradation, dirt, efflorescence, cracks, loss of section, wood degradation, granular breakdown, pitting	The combination of techniques provides subsidies that facilitate the analysis of symptoms and the correct diagnosis of pathologies, guaranteeing a more reliable proposal for the treatment of anomalies
10	MELO JÚNIOR <i>et al.</i> (2018)	Public Building Façade	Quantitative and Qualitative	UAV, DSM technique, photogrammetry, Tyche program, damage map	Dark stains on the façade	The use of UAV is important for visual inspections of façades at great heights. The use of combined techniques supports inspections and monitoring of building defects

Number	Author (year)	Object of Study	Analysis	Methodological Procedures	Main Defects	Relevance
11	BAUER <i>et al.</i> (2011)	Façades of Residential Buildings	Quantitative and Qualitative	Visual inspection, damage map, tensile adhesion tests, material characteristics tests, defect index.	Loss of ceramic adhesion and detachment, problems with mortar, cracks, efflorescence, sealing failure	The most recurrent failures in old buildings are due to the gradual deterioration of materials, and in new buildings, constructive failures
12	CAVALAGLI <i>et al.</i> (2019)	East façade of Historic Building	Quantitative and Qualitative	Documentary investigation, visual inspection, survey and damage classification, risk assessment table, climate monitoring, environmental vibration test	Black crust, scaling, incrustation, biological colonization, corrosion stains, residual discoloration, cracks, moisture	The map was useful to anticipate and prioritize the necessary modernization actions, including remediation and preventive conservation strategies
13	CHOI <i>et al.</i> (2018)	Abandoned Building Façade	Quantitative and Qualitative	UAV for visual inspection of the façade, to produce orthophoto that serve as a damage map of the regions of interest	The use of the technique allows to detect cracks, cracks, broken frames and others	A single orthophoto is sufficient to make the best use of the technique, if the façade is flat. If there are objects in the vicinity, collecting additional points of view is necessary, making the job more difficult

Number	Author (year)	Object of Study	Analysis	Methodological Procedures	Main Defects	Relevance
14	BRANCO <i>et al.</i> , (2017)	Roof trusses of an old building	Quantitative and Qualitative	Visual inspection, puncture resistance test, ultrasound test, pin penetration test	Cracking, rotation, and displacement of the wood	The combination of tests with visual inspection allows the identification of fragile sections, making it possible to highlight critical sections through damage maps

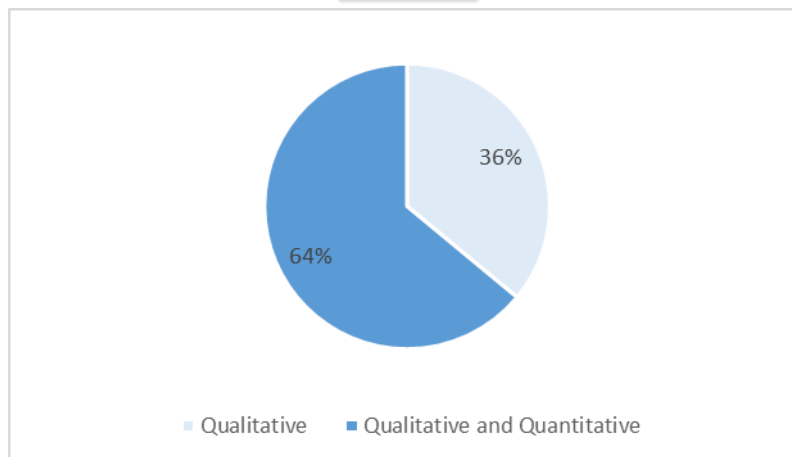


From the analyzed articles, it was found that 93% of the research was concentrated on building façades, whether in historic, public, or residential buildings. Only 7% of the surveys did not have the façades as an object of study (Figure 5).



**Figure No. 5: Research object of study**

It was also observed that 36% of the studies carried out the qualitative analysis and 64% of the researchers used both analyzes (Figure 6). Quantitative nature analysis was not addressed in any review article.



**Figure No. 6: Research type of analysis**

When it comes to the methodological procedures of the research, it is worth noting, in addition to the use of damage maps, the use of visual inspections in comparison to other techniques, since they allow the detection of damage to structures in a simple way. It is known that when visual

inspections are combined with damage maps, non-destructive tests, and other techniques, there is better efficiency in the diagnosis of pathologies found in the structures.

Among the building defects addressed, it can be said that the most frequent ones were mainly related to cracks, efflorescence, biodeteriorations, dirt, and moisture stains. On the other hand, the relevance of the studies was determined from aspects related to the applicability of the damage maps and some other techniques for the identification, evaluation, and possible conservation strategies of the enterprises.

## **DISCUSSION:**

When properly used, the damage map technique can provide data to correct diagnoses of pathologies. The technique also records the evolution of problems related to the state of conservation and is a facilitating agent for building exams, preventive actions, and maintenance interventions.

Research has shown that damage maps can be applied to various elements of a building. However, the tool was mainly applied to façades of enterprises in 93% of the articles. Such fact may be related to a greater need to preserve the architecture, since 46% of the objects of study were historic buildings [5, 12, 14, 16, 17, 21].

Also, graphs showed scarcity on the theme in the period from 2008 to 2015. In the following years, there was an increase in works on this subject, which may be linked to the increase in discussions about the preservation of welfares in the world. Studies show that the first use of the damage map appeared in Italy, in the 1960s, and later in Brazil, in the 1970s [24]. However, even with the increasing number of articles, the use of damage maps is not often addressed.

About journals, those linked to England, which had the largest number of publications, stand out, compare to the other countries. However, most authors identified in the review are linked to Brazilian institutions. It may indicate interest in applying the damage mapping technique, combined with others or not. It also shows Brazil's concern with its cultural heritage. Cultural heritage can represent the memory, history, culture, architecture, and technical, aesthetic, and artistic expressions of a time in society, making it a heritage for generations to come. In Brazil,



for example, the Federal Constitution makes explicit the need to protect and prevent any degradation to buildings of historical, artistic, or cultural importance [25].

Regarding the methodological procedures, 86% of the surveys mention the use of visual inspections in addition to the use of maps. The participation of the professional/researcher as an observing agent promotes symptomatic analyzes for a reliable and correct treatment of anomalies. Also, 14% of the works carried out inspections through UAVs (unmanned aerial vehicles) generating damage maps for regions of interest through photogrammetry and subsequent treatment in computer software [19, 22]. However, there is a limitation in detecting building defects employing UAVs, considering that only dark spots on façades were found and represented on the maps, although it is also possible to perceive cracks and broken frames. On the other hand, inspection using the aforementioned technique has remarkable applicability at great heights.

In addition to visual inspections, documentary inspections are cited in 29% of the articles. The documentary research promoted the analysis of historical records as well as information that allowed the identification of design characteristics and different uses of the building. The documentation also covered architectural projects (including façades) and other projects related to changes in the projects and maintenances. In short, the documentary investigation allowed identification of interventions after the construction of the buildings to assist future maintenance actions and preparation of damage maps from the projects [5, 17, 18, 21].

Also, on the methodological procedures, 14% of the research addressed calculations of degradation indexes from damage maps, with meshes superimposed on the maps, and the degraded area obtained by counting the units of the grid, expressed in  $m^2$ . The authors state the measurement of degradation is a basic step to assess the useful life of the building and its elements. It is also possible to define the behaviors of anomalies regarding the prediction of useful life through monitoring [11, 13]. In this way, the damage maps facilitate visualization to perform calculations of the level and degradation. Therefore, relationships between building defects and architectural or environmental conditions can be established. They allow, consequently, making observations about the useful life of the building, its components, and its durability.

On the other hand, some negative points can be listed regarding the damage maps. Despite being an easy-to-understand instrument, the technique has limitations, considering that 100% of the researchers used other methods and additional techniques to achieve their objectives.

In 43% of the works, the authors reiterate that the use of combined techniques supports inspections and monitoring of building defects. It allows quantification of extent and degree of years, facilitating the interpretation of such manifestations. Also, from non-destructive tests, the causes and consequences of the damage can be better understood. The critical sections in the structure are identified, characterized, and represented on the maps [5, 15, 16, 17, 19, 23].

Finally, another negative point concerning the damage maps is related to the non-existence of a standard for representing the instrument. Therefore, there is no standard; it can be done in several ways. Filho and Achiamé [26] highlight the need for legal standardization in the elaboration of maps to guarantee quality and understanding. That would lead to better execution and repair as well as restoration service, with a feasible understanding of the real state of building conservation.

## **CONCLUSION:**

The use of the damage map technique for the identification and evaluation of building defects is essential for taking action, concerning maintenance and rehabilitation interventions in buildings. The damage maps are generally elaborated as a complement to other methods. They are not often used because of non-destructive tests and the visual inspection technique, which can detect building damage. On the other hand, damage maps allow the monitoring of preservation conditions and durability issues, highlighting the combination of methods. It facilitates the analysis of the symptoms and the correct diagnosis of pathologies, guaranteeing a more reliable proposal for anomaly treatments. The frequent non-use of the technique may be associated with the lack of knowledge on the part of professionals/researchers, because of the scarcity of articles on the subject, as well as the lack of standardization in its graphic representation. Thus, it is emphasized the importance that other professionals and researchers in the area share their experiences so that guiding guidelines for this instrument are obtained, taking into account that the first use of the map of damage was a long time ago.

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