Detection of anomalies in concrete structures based in image processing – the case Study of the Pavilhão do Conhecimento, in Lisboa

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1. Introduction

Over the past decades, new technologies have begun to play an increasingly central important role in most research areas. There are multiple advantages to applying those new methods and Civil Engineering is no exception to the benefits that result from the growing use of new technologies. Image processing in order to improve the process of identification of anomalies in concrete buildings is one of the examples of the application of such technologies.

The present study sought to explore the possibility of using an image processing method in the identification of anomalies in the façades of visible reinforced concrete buildings, in order to reduce the time associated with such process, as well as, to reduce the risk of human eye error.

The proposed method, based in image classification will be able to: 1) Locate the critical areas in concrete building surfaces; 2) Identify the present anomalies; 3) mapping them, at pixel level.

The outcome will be analysed by comparing with the results of a classification based on a visual analysis. The main goal is to analyse the improved effectiveness of image processing study, although, it shows limitations when trying to identify anomalies with similarities in their visible spectrum. Besides those limitations, the algorithm allows the location of anomalies, at pixel level, and its effectiveness is proved when the location and mapping of regions without anomalies shows the best results.

2. Methodology

The methodology adopted in this dissertation involves the development two parallel methods. The main one, *SC-Anom,* will be applied in the detection and mapping of all anomalies, while, the other one, allows the detection of, only, the exposed reinforcement.

The method *SC-Anom* explores a semi-automatic detection of anomalies in reinforced concrete buildings' façades. The process is developed through clustering according to a number of clusters selected and to the physical characteristics of the anomalies under study, more specifically their respective code RGB. After this, the critical areas of the façade are identified. The process comprises 5 steps: 1) image acquisition; 2) pre-processing of the images; 3) clustering and application of SuperCluster method; 4) post-processing and identification of the critical regions according to the type of anomaly; 5) comparison of the results with the visual inspection results – *Ground Thruth*.

Simultaneously, two other processes occur. The first is a visual inspection of the critical areas presented in the façade. The objective is to compare the number of critical areas detected, after the SuperCluster-Anomaly (*SC-Amon*) procedure, with the results originated by the visual inspection. The second process allows mapping, at pixel level, the location of exposed reinforcement in all studied images, as well as, the location of critical regions that includes this anomaly. Figure 1 shows a diagram of the adopted methodology.

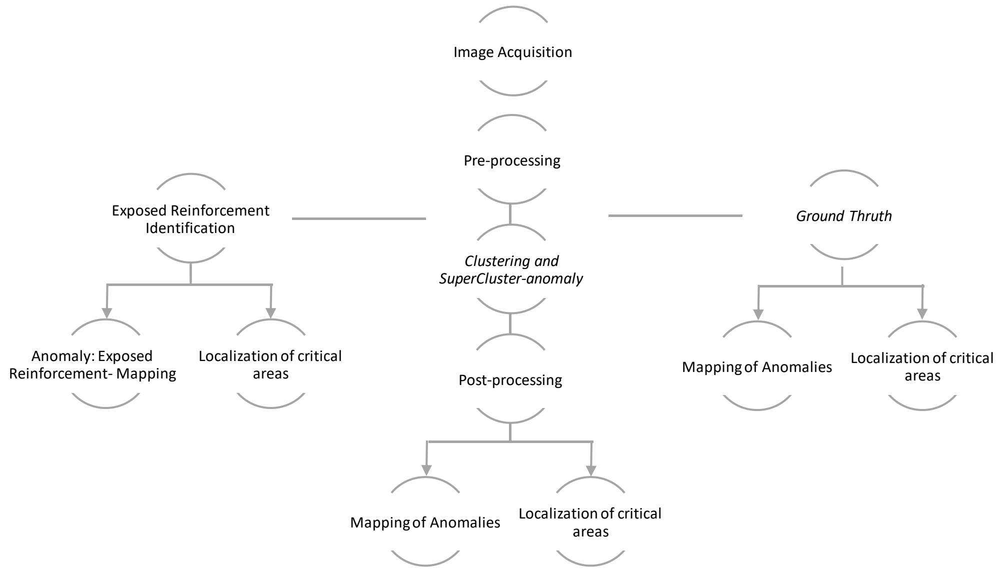


Figure 1 - Scheme of the adopted methodology.

2.1. Image Acquisition

The image acquisition is a process that has to be done always considering the object of study. First, the method will be applied in a façade of a 30 meters tall building. To have images with high resolution is required a subdivision of the surface in several parts. There is a method to subdivide it because, after taking the photographs, it must be possible to generate a photomosaic. The equipment used was a robotic equipment with a panoramic head called Gigapan Pro V with a Nikon D810 camera. The focal length of camera lens was between 20 and 300 mm.

2.2. Preliminary Visual Inspection and Construction of Ground Thruth

The main objective is to analyse the images and visually detect the areas with most anomalies due to either a high number of detections just in one place or the size of the anomaly. This step is important because it helps developing a critical sense when analysing the results of the SuperCluster-Anomaly method.

Taking into consideration the ideas exposed, the Ground Truth maps are created with the objective of: 1) Identifying the critical regions; 2) Mapping each anomaly and image.

2.3. SuperCluster-Anomaly

2.3.1. Pre-Processing

The pre-processing involves the stitching of the images in a final photomosaic that represents all the surface of the façade, in *.png format. The matrix Homography (H) is also calculated in this step. The H matrix allow to correct the orientation of the image analysed based on rotations and translations, always trying to make it parallel with the camera's sensor plane. The calculation method relies on choosing 4 coplanars, but their coordinates must be known and the distance between them must be measured. ´

2.3.2.Clustering and SuperCluster-Anomaly

The SuperCluster-Anomaly method consists in a process developed in the RGB colour space, where R stands to Red, B to Blue and G to Green. Pre-processing images allow knowing RGB coordinates of all its constituent pixels which the clustering program will use when running.

The number of clusters used will determine the level of detail of the results. The higher the number, the higher the detail because it implies using more groups of colours in the analysis. The perfect equilibrium is reached when the number of clusters is low enough to achieve good enough results, but sufficiently high to not lose important information. To initiate SuperCluster two variables are needed: a centre and a radius.

The centre admits an RGB coordinate and the radius is called threshold, th. The base of the SuperCluster-Anomaly method is to detect clusters that have some characteristics chosen by the user. By detecting the clusters, one can place the region(s) of interest in the image, i.e. the anomalies.

2.3.3.Post-Processing

The last step of the proposed method is the post-processing of the results obtained with the SC-Anom algorithm. The mathematic morphology will be applied with simple operations between the matrixes that represent the images. The SC-Anom was applied in visible reinforced concrete surfaces and buildings whose execution implies the use of joints in concrete. This is an example of an information present in images obtained from photographs of concrete façades which can distort the results.

However, as part of the post-processing method the joints can be successfully erased from the images. The joints present a fixed width and it's possible to mark them with a line with the same width of the joint. Finally, the information of the joints in this mask can be subtracted in the matrixes that represent the images that include this information.

2.4. Exposed Reinforcement Detection

One of the alternatives to the main method is the execution of an algorithm that only detects the exposed reinforcement, setting out clearly where exists traces of corrosion or visible reinforcement.

It is important to locate regions with traces of corrosion, because the presence of corrosion in a structure, depending on the level, can compromise the structural safety of the building.

When collecting the RGB codes of the different anomalies, it was observed that the difference between the anomaly traces of corrosion and the anomaly visible reinforcement in itself is that, in the first case, the B is always higher than R, as shown in Figure 2.

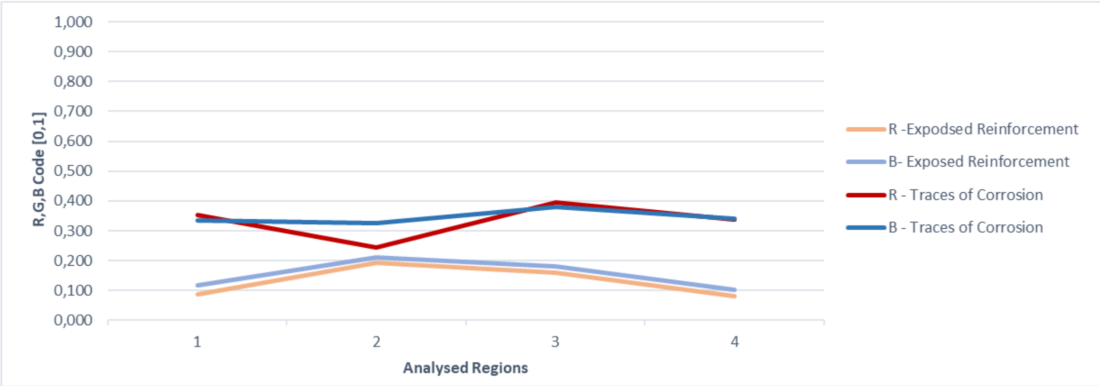


Figure 2 - Graph with results collected from the RGB codes of the pixels that correspond to anomalies traces of corrosion and visible reinforcement.

2.5. Map of Results

After the post-processing, the final file is obtained, and it should represent all the anomalies present in the images. the accuracy of the results is studied by comparing the results of the SC- Anom with the Ground Truth. Based on this evaluation some parameters can be drawn that give the user a value for accuracy. Those parameters are TP (true positive), FP (false positive), TN (True Negative) and FN (False Negative). The first one, TP, identifies the number of matrixes elements identified by the algorithm that coincide with the ones identified by the user. The false positive parameter indicates the pixels that the algorithm identifies but not the user. The third parameter (TN) is the number of matrix elements that are not identified neither by the user nor the program, while the FN parameter indicates the number of pixels that should be identified by the computer and weren't. All these values originate the F1 parameter that give the user a final value for accuracy.

3. Case Study: Pavilhão do Conhecimento

3.1. Anomaly Characterization

The most frequent and critical anomalies observed are disaggregation of concrete and exposed reinforcement. To guarantee the right application of the algorithm, it is necessary to define the physical characteristics that distinguish all the identified anomalies. The table 1 presents a summary of this work.

Table 1 - Physical characteristics of different anomalies;

Anomaly Identification	Example	Characteristics	RGB Code
Exposed Reinforcement		○ Dark Brown colour ○ Linear shape ○ Mostly horizontal and vertical orientation ○ Constant space between anomalies	0.14 0.14 0.16
Signs of corrosion		○ Brown colour ○ Run-off indicators ○ Shape undefined ○ Usually, near exposed reinforcement or concrete zones with porosity	0.27 0.32 0.36
Concrete Delamination		○ Non-linear shape but have horizontal orientation	0.36 0.33 0.33
Concrete Disaggregation		○ Most part between concreting joint or joints between panels ○ Porous appearence and rugosity ○ Lack of concrete ○ Gray colour, darker than concrete ○ Coarse aggregates	0.31 0.28 0.26
Biological Colonization		○ Dark Colour ○ Zone with water accumulation ○ In joints between panels ○ Linear Shape ○ Horizontal Orientation	0.27 0.27 0.27

3.2. Ground Truth Maps: process

This step involves two phases: Critical zones identification and mapping of anomalies in each image. The identification of critical zones can be originated by the presence of different anomalies in each of the 48 photographs taken. As an example, in the next figure, it's possible to analyse the method used to identify the critical zones using visual inspection.

Figure 3 - Identification of critical zones in panel 13;

Each anomaly was equally mapped in order to build the Ground Truth. The Ground Truth is a binary mask, manually executed by the user with a Matlab script. It includes the information about the areas of image where the anomalies where visually detected. For each panel, the Ground Truth was built for each included anomaly, individually. Figure 4 is an example of the visible reinforcement anomaly's Ground Truth in panel 13.

a) b)

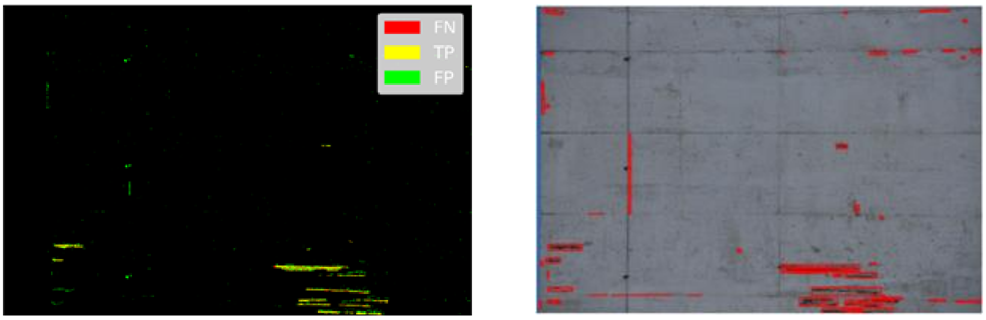
Figure 4 - Ground Truth (b) of panel 13 (a);

3.3. SuperCluster-Anomaly

Using a distribution of 30 clusters, the centre and the threshold values defined by the user for each anomaly, the SuperCluster method aims to locate the anomalies, map them and detect the critical areas of each panel. To illustrate the results, the panel 13 will be used as an application example.

3.3.1. Identification and mapping of Anomalies

The use of *SC-Anom* methodology successfully identifies the anomalies visible reinforcement, evidence of corrosion and disaggregation; the other anomalies have an insignificant expression in the sample images and in consequence cannot be considered relevant in the case study. As shown in Figure 5 a), the accuracy of the method, when applied on panel 13 to detect Visible Reinforcement, is higher than 50% and the parameter TP, i.e., the number of pixels identified by both the user and the algorithm, is close to 90%. The final result, after post-processing is very satisfying, since it clearly identifies the anomaly to detect and allows for the clearly mapping of this anomaly, as shown in figure 5 b).



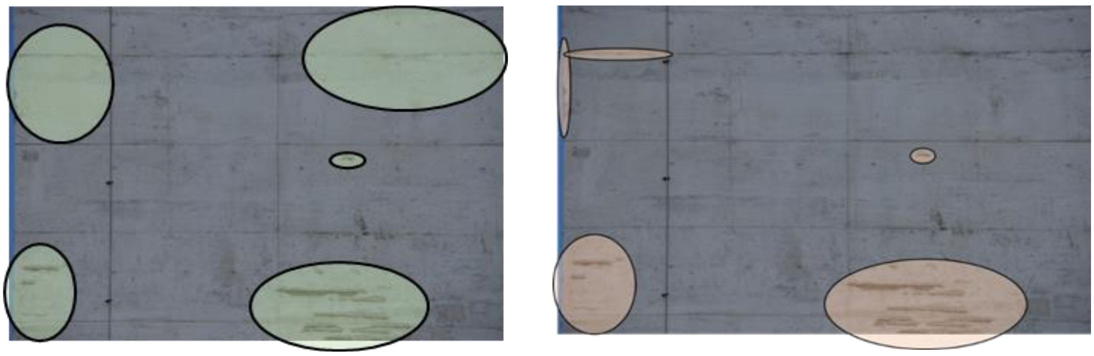
FN: $0{,}36\times10^{-4}$ **FP:** 0,75 **TN:** 0,10 **TP:** 0,89 **F1:**0,67

a) b)

Figure 5 – a) Result of *SC-Anom* for visible reinforcement anomaly; b)Result of critical areas detection based on *SC-Anom* method;

3.3.2.Identification of critical regions

To identify the critical regions of the images using *SC-Anom*, it is necessary to run the algorithm for each anomaly. The analysis of those results, by intersecting and overlapping some regions, will give the user the final number of critical regions, bearing in mind all anomalies studied.



a) b)

Figure 6 –Identification of critical using the SC-Anom results (a) and the visual detection results (b);

Comparing figure 6 a) and 6 b), it is possible to conclude that the results of *SC-Anom* identify all the critical regions previously tagged by the user when building the Ground Truth. As shown, the automated method actually identifies even more regions than those detected by the user, thanks to the higher accuracy and thoroughness of the method, which lists anomalies more conservatively.

3.4. Detection of Visible Reinforcement Anomaly method

3.4.1.Identification and mapping of Anomalies and critical areas detection

The identification and mapping of anomalies with the detection of Visible Reinforcement Anomaly method is a simple tool of getting satisfactory results but limited to this particular anomaly. Figure 7 shows the application of this method in panel 13.

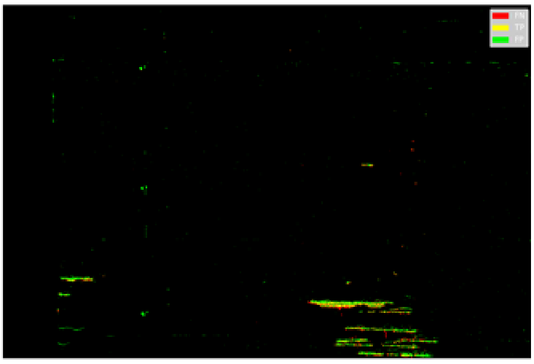


Figure 7 - Result of the visible reinforcement detection method;

This method can easily identify the pixels where the anomaly in study is present, so mapping the anomalies and detecting critical areas is simpler, because the detection of the anomaly directly implies the presence of a critical area.

3.5. Results

Figure 8 shows the results for critical areas detection using the Ground Truth versus using the Critical Regions Detection method.

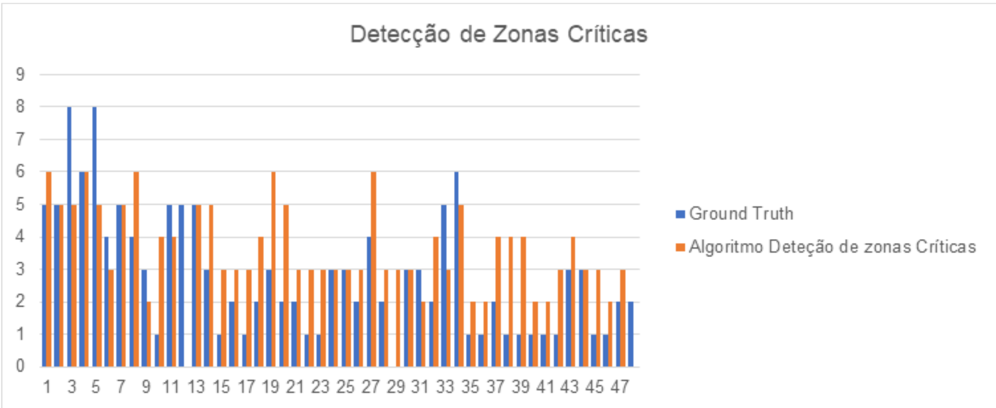
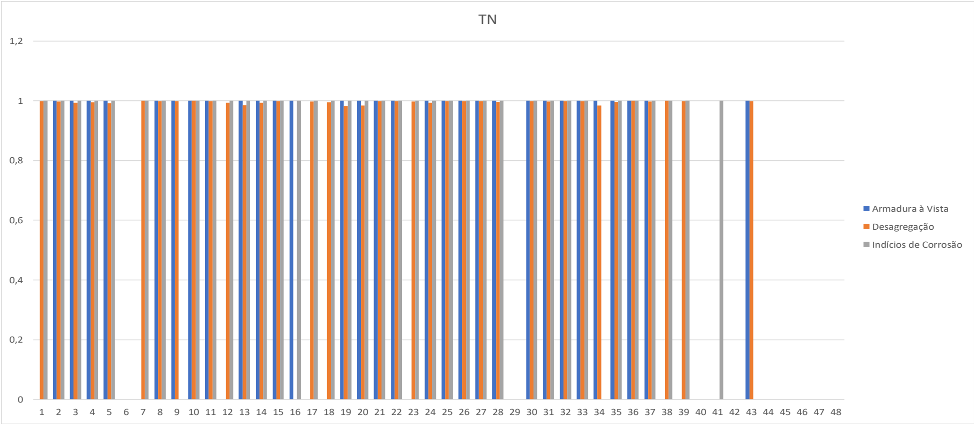
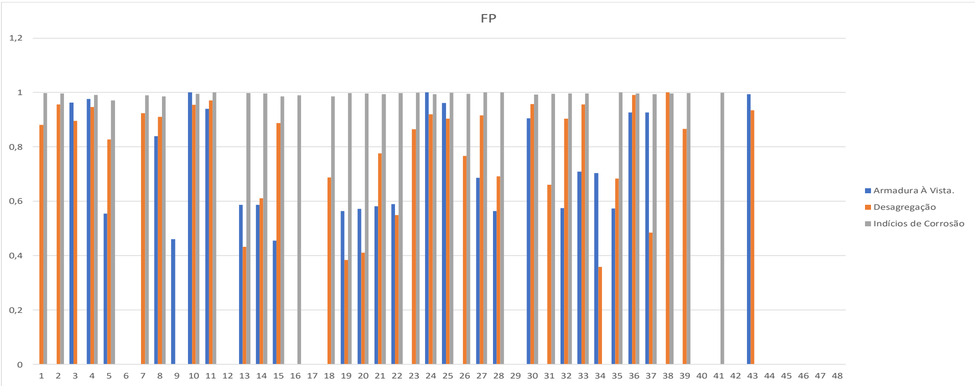


Figure 8 - Results obtained for all the 48 panels in the detection of critical areas;

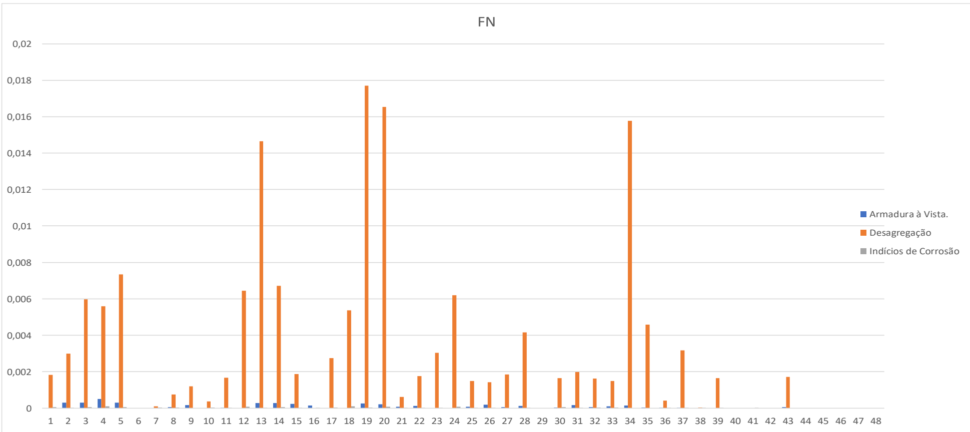
The identification by executing the *SC-Anom* method is higher than using Ground Truths. This is a positive result because by using the automated method the study is conducted more conservatively when compared with visual inspection. The analysis of the precision of *SC-Anom* in the identification of anomalies shows, for all panels, values over 90%. As expected, better results, close to 100%, are still achieved in the case of the exposed reinforcement anomaly. Figure 8 contains values for all three anomalies considered.


TN
Armadura à Vista
Desagregação
Indícios de Corrosão

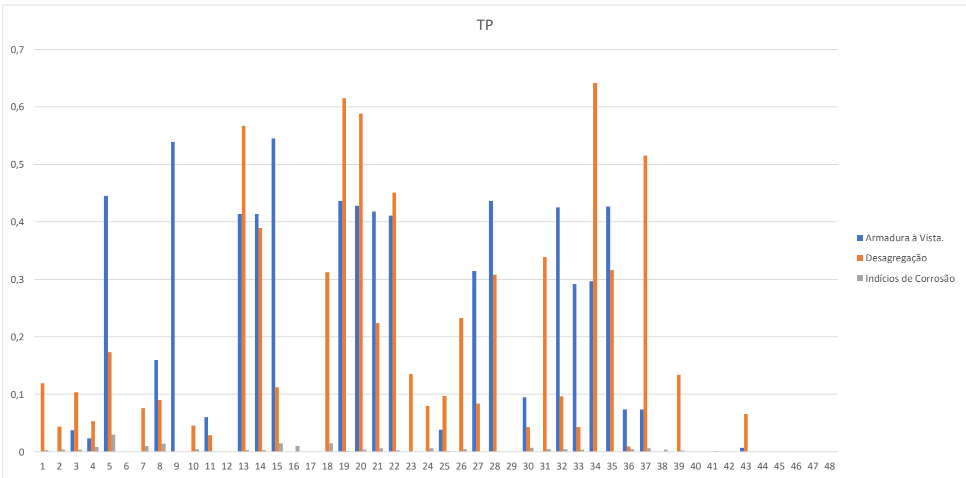
a)


FP
Armadura À Vista.
Desagregação
Indícios de Corrosão

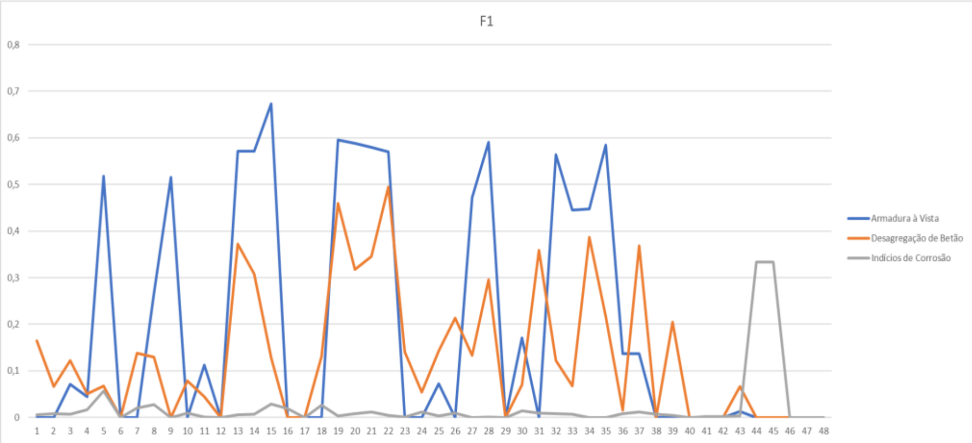
b)


FN
Armadura à Vista.
Desagregação
Indícios de Corrosão

c)


TP
Armadura à Vista.
Desagregação
Indícios de Corrosão

d)



e)

Figure 9 – Resuls obtained for all the panels of the façade: a) TN identifications b) FP identifications; c) False Negative Identifications; d) True Positive Identifications; e) F1 parameter;

The results of the 48 panels prove that the analysis can represent the conclusions drawn during the process. Figure 9 allows the next conclusions:

- Parameter TN assumes values near 100% in the detection of all anomalies, that represents the information considered false by the algorithm, is also considered like that by the user.
- The FP parameter assumes very high values for all anomalies, while FN identifications are near 0%, except in the case of disaggregation. These results are due to the identification of confusion zones by the algorithm.
- TP identifications are lower than expected. These values together with the other parameters, allows a positive conclusion, specially in the Exposed Reinforcement and Disaggregation cases.
- The last parameter, F1, presents a variation of the values along the panels. The Exposed Reinforcement anomaly is the case with the best results, as expected. However, disaggregation has good results, since the media of the values is near 50%.

3.6. Conclusions

The SC-Anom image processing method is the most useful and thorough when analysing all different anomalies. However, the Visible Reinforcement detection method is the most accurate when analysing specifically this anomaly. Efficiency increases in identifying this anomaly individually because confusion problems with other anomalies are reduced.

The efficiency of the critical areas identification method is directly connected with the results obtained from *SC-Anom*. Due to the overlapping zones between anomalies, it is not possible to distinguish each one clearly. This results in a more conservative, but also more redundant identification. On the other hand, since the analysis done at the pixel level it shows stronger results, allowing for obtaining more detailed information that traditional methods cannot provide.