Identification and Detection in Building Images of Biological Growths – Prevent a Health Issue

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Abstract. Building rehabilitation is a reality, and all phases of rehabilitation work need to be efficiently sustainable and promote healthy places to live in. Current procedures for assessing construction conditions are time-consuming, laborious and expensive and pose threats to the health and safety of engineers, especially when inspecting locations that are not easy to access. In the initial step, a survey of the condition of the building is carried out, which subsequently implies the elaboration of a report on existing pathologies, intervention solutions, and associated costs. This survey involves an inspection of the site (through photographs and videos). Also, biological growth can threaten the humans inhabiting the houses. The World Health Organization states that the most important effects are increased prevalences of respiratory symptoms, allergies and asthma, as well as perturbation of the immunological system. This work aims to alert to this fact and contribute to detecting and locating biological growth (BG) defects automatically in images of the facade of buildings. To make this possible, we need a dataset of images of building components with and without biological growths. At this moment, that database doesn't exist. So, we need to construct that dataset to use deep learning models in the future. This paper also identifies the steps to do that work and presents some real cases of building façades with BG and solutions to repair those defects. The conclusions and the future works are identified.

Keyword: Sickness prevention · Biological growths · Deep Learning

1 Introduction

Building rehabilitation is already a reality. Moreover, it is an excellent way to improve the construction sector's sustainability and indoor air quality [1–3]. International policy frameworks propose measures that include innovation, digitalisation, lower carbon emissions, and the fight against climate change as the main goals to be achieved in the search for sustainable development [3]. So, betting on solutions that facilitate all the tasks of a rehabilitation process is welcome. The traditional methods for this work commonly include engaging building surveyors to undertake a pathology report that involves a laborious site inspection. That results in a description of the physical conditions of the

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building elements with the use of images, note-taking, drawings and information provided by the owner. The data collected is then analysed to produce a report. The report summarises the condition of the building, its elements [4], possible causes, and ways to repair the damages. This information also creates renewal, repair, and maintenance price estimates. Current assessment pathology report procedures are time-consuming and laborious and sometimes put the surveyor's health and safety at stake, particularly at height and roof levels that are usually not easy to access for those inspections [5].

Image analysis techniques for detecting defects have been proposed as an alternative to manual on-site inspection methods. In recent years, researchers have experimented with applying several soft computing and machine learning-based detection techniques to increase the automation of asset condition inspection. Whilst the latter is time-consuming and unsuitable for quantitative analysis, image analysis-based detection techniques, on the other hand, can be pretty challenging and entirely dependent on the quality of images taken under different real-world situations (e.g., light, shadow and noise) [5–13].

This paper proposes a deep learning methodology to detect and locate biological growth defects in images of facade walls of buildings. It is organised as follows: first, a brief discussion of selecting the most common defects that arise from biological growth in building façades is presented. This discussion is followed by a brief overview of deep learning methods used to solve fundamental computer vision problems. This quick overview provides the theoretical basis of the work that will be undertaken in the future. It follows the presentation of the deep learning-based detection and localisation model using transfer learning utilising the VGG-16 model for feature extraction and classification. It presents some real cases of building façades with BG and solutions to repair those defects. The images taken so far will contribute to constructing a dataset of images with and without BG to make the use of the methodology proposed possible. Finally, conclusions and future work are presented.

2 State of the Art

2.1 Biological Growths in Building Facades

Fungi, algae, mosses, and lichens are the biological agents that most affect building facades [14]. The growth of fungi and algae is usually caused by the absence of fungicidal and/or algicidal additives in the construction process. Stains resulting from biological colonisations can be caused by algae, fungi, lichens or parasitic vegetation, that is, microorganisms of animal or vegetable origin. In the presence of organic material, microorganisms of animal origin, such as fungi, grow in dark environments with little ventilation. Those of plant origin, such as algae, develop in hot environments with sun exposure in the presence of carbon dioxide [15].

Biological growths (BG) are the primary type of stone pathology that develops most quickly under usual conditions [16].

World Health Organization (WHO) concludes that the most critical effects of biological growths are increased prevalences of respiratory symptoms, allergies and asthma, and perturbation of the immunological system [3].

Humidity is a fundamental factor for biological growth. When exposed facades are at high-temperature levels, whether due to water infiltration or condensation, an environment conducive to developing fungi, algae and lichens is created. Shaded areas with little ventilation tend to retain more moisture, favouring biological growth.

Although biological growth can occur in shady areas, exposure to sunlight plays an important role. Direct sunlight and ultraviolet (UV) radiation can negatively affect biological growth, inhibiting its spread. However, areas with prolonged shade or indirect light can facilitate BG growth.

Temperature conditions also influence biological growth. Some organisms can develop in various temperatures, while others are more sensitive and prefer specific climates. Mild and humid temperatures, especially in regions with mild winters and summers, can favour biological growth on facades.

Atmospheric pollution, including gases and particles in the air, can affect biological growth on facades. Some pollutants can provide nutrients that promote BC development, while others can be toxic and inhibit their growth. Air quality can also influence the availability of nutrients and the ability of organisms to establish themselves on facade surfaces.

Some construction materials, such as bricks, concrete, stone and wood, can provide favourable substrates for biological growth. Porous, irregular surfaces or surfaces with accumulation of dust and debris are more likely to harbour organisms. Furthermore, the type of coating applied to facades can affect the surface's ability to retain moisture and, consequently, influence BG growth if the facade is exposed to high humidity conditions, whether due to humid weather conditions, lack of adequate ventilation or drainage problems, this can create a favourable environment for the growth of biological organisms. Areas of the facade that receive little direct sunlight and are in shadow for long periods are prone to biological growth. The lack of the sun reduces the rate of moisture evaporation, creating wetter conditions favourable to the development of moss, fungi and lichens.

Certain building materials, such as mortar, concrete, bricks and porous stone, can absorb and retain moisture for longer, providing an environment conducive to biological growth. These porous materials can provide enough nutrients and moisture to support the development of biological organisms.

2.1.1 Fungi

Fungi are the primary agents of degradation of facade surface coatings, considering that they are highly adaptable to environments with low humidity, sudden temperature variations and a minimum amount of nutrients for their nutrition [17, 18].

Fungi are organisms that need organic matter, dead or alive, for their development, which is why they establish themselves in places where it is deposited by other living beings or by the action of the wind [19].

According to [20], most fungi are aerobic, as they require oxygen at least in one phase of their life cycle. An optimal pH is also crucial for the metabolism of fungi. Most of them grow at optimum pH values between 4 and 6. However, many species can grow between 2 and 9 [20].

According to [21], the stains resulting from the accumulation of filamentous fungi on any substrate can be scientifically designated as mould. These microorganisms cause the appearance of dark spots with black, brown or greenish tones, which not only affect the visual quality of the facades but also gradually deteriorate the coverings and the support itself. In Figs. 1a and b, it is possible to see an example of the presence of fungi on a facade.

The consequences caused by the presence of fungi are worrying, as they feed, above all, on organic materials attached to facades, some dirt, and carbon monoxide. They can also feed on some components present in surface coating resins, such as paints and varnishes. These materials have a high concentration of organic material in their composition so that fungi can damage the paint film [14].

a) Façade with the presence of BG b) Detail of fungus in the façade

Fig. 1. Presence of BG in a building façade.

Algae

According to [18] algae are photosynthetic organisms. That is, they use sunlight to produce their food. Therefore, they do not depend on the constituents of the material they adhere to develop. Like vegetables, algae need water and light, favouring their growth, especially in external environments.

Mosses

Mosses are bryophytes that preferably live in damp and shady walls, on which their reproduction depends. The humidity may be due to infiltrations or ineffective waterproofing. Figure 2 shows an example of mosses on facades.

This pathology begins from a seed, seedling or spore that reaches the facade of the building. The main ways are through the wind and bird faeces. Light, water (humidity) and nutrients are needed for germination or seedling development. The proliferation of mosses (bryophytes) in cracks or very porous concrete is mistakenly confused with fungi.

Lichens

Uemoto, K. et al. [18] clarifies that lichens are particular living organisms developed due to symbiosis (mutualistic relationship between two organisms where there are advantages

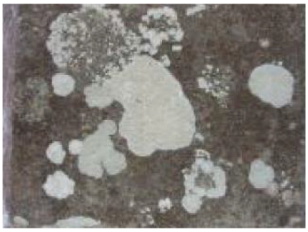
Fig. 2. Detail of a building façade with mosses.

for both individuals) between algae and fungi. Honda, N. K. et al. [22] defines lichen more precisely as a symbiotic organism composed of a fungus and one or more algae. In this symbiotic relationship, the algae produce organic food and photosynthesis. The fungus, on the other hand, guarantees protection and a suitable environment for the development of the algae. Therefore, it is concluded that for lichens to exist, fungi and algae must exist together.

Lichens are more frequent on rocky substrates Fig. 3a) and b) [20].

According to [21], like algae, lichens are photosynthetic and do not depend on the constituents of the materials to which they are attached. The damage that lichens cause to surfaces is similar to that of algae and fungi. They grow more slowly than algae and are generally not found on new surfaces until the algae and fungi have become established. They are usually found embedded in masonry, forming a thin layer firmly adhered to the substrate, or in the form of flat sheets, forming rosettes and poorly adhered to the base. In the initial stage, lichens can be easily confused with fungi and algae.

a) Yellow lichens



b) White lichens

Fig. 3. Lichen in a rocky substrat [20].

Prevention, Control and Repair Methods

Prevention and control of biological growths generally involve cleaning strategies, adequate maintenance, chemical treatments, selection of resistant materials and environmental control measures. Great care must be taken when deciding whether or not to carry out an intervention. When choosing the best method, evaluating the different aspects involved in the problem is necessary.

Initially, it is recommended that a preliminary project be carried out, defining proper procedures for greater effectiveness. On very degraded substrates, preliminary consolidation must be carried out to avoid further deterioration of the state of conservation, and the stone must be partially dried to improve the treatments' [20].

Afterwards, the most appropriate method for treatment must be chosen. The selection of the mechanical, physical or chemical treatment method depends on the type of organism present, the type of substrate to be treated, the state of conservation, and the costs involved.

Mechanical methods involve physically removing biological material with manual instruments such as scalpels, brushes, spatulas, scrapers, etc. These methods are widely used due to their simplicity and immediate results.

Physical interventions have no preventive power. They only eliminate living organisms. Examples of physical interventions include ultraviolet radiation and washing using water jets, which can also be used to remove biological growths.

In the chemical method, chemicals are responsible for eliminating macro and microorganisms, although some products also have preventive action on biological growth. The effectiveness of any chemical depends on the type of substrate, the type of organism or organisms involved, and the application method. In addition to chemicals, there are also biocides. The term biocide refers collectively to bactericides, algaecides, fungicides, and herbicides, distinguished by the specific organism to attack: bacteria, algae, fungi, lichens and plants, respectively [16].

2.2 Deep Learning Methods

Deep learning has increased in different research fields, with the potential to overcome the most challenging and laborious problems by using various layers of information processing in deep architectures for pattern recognition or classification [11, 22]. Convolutional Neural Networks (CNNs) dominate computer vision tasks and image processing, where the input data is usually 2D. CNN recognises visual patterns directly from the image using multiple-layer neurons and uses shared weights in each convolutional layer [11, 23]. CNNs are usually composed of layers organised according to their functionalities designed to learn spatial hierarchies of features automatically and adaptively, from low to high-level patterns. There are three main layers: convolutional, pooling and fully connected, where the first two perform feature extraction and the third maps the extracted features into the final output classification [23].

VGG16 is an example of a CNN model proposed by K. Simonyan and A. Zisserman from Oxford University. The model achieves 92.7% top-5 test accuracy in ImageNet, a dataset of over 14 million images belonging to 1000 classes. It improves AlexNet by replacing large kernel-sized filters with multiple 3×3 kernel-sized filters one after another [24].

Transfer learning appears to optimise and minimise the error through weight initialising the convolutional layers using pre-trained CNN weights with the same architecture to avoid training a CNN from scratch. The exception is the layer whose nodes depend on the number of classes. The early layers learn low-level features, and the late layers learn high-level features specific to the problem in the study [25, 26]. After the weight initialisation in the last fully connected layer, the network can be fine-tuned, starting with only the previous layer tuning and then the remaining layers, incrementally including more layers in the update process until the desired performance.

3 Methodology

This research aims to develop a model that detects (the presence or absence of biological growths) in the facades of buildings.

The pipeline used for the automatic detection of biological growths is described in Fig. 4.

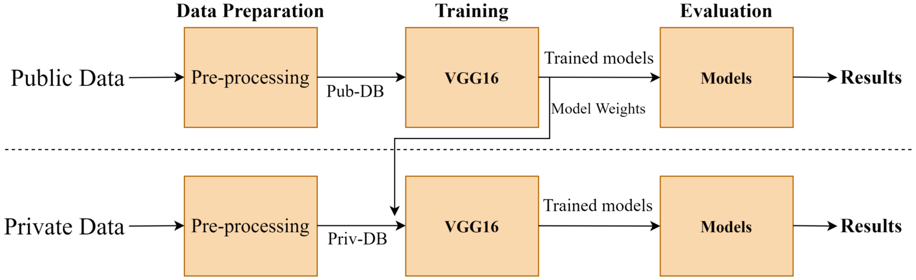


Fig. 4. Workflow of the research.

First, the data will be collected (from public and private databases) to be pre-processed and organised in datasets. The images of the private database will be collected and annotated by the authors. These datasets will train the deep learning model (VGG16) to classify images with or without biological growths. A model will be trained with public data, and then, with transfer learning methods using the weights of this model, a new one will be pre-train and fine-tuned on the private data. After the training, the models will be evaluated, and the results will be discussed in future work.

3.1 Data Preparation

A private database (Priv-DB) will be constructed. The dataset will be divided into 70% of the images for training, 15% for validation and 15% for testing the models.

3.2 Training

For the classify the images as with or without BG, a VGG16 pre-trained model will be used. The VGG16 is a state-of-the-art classification model with high-accuracy results, similar to the other available models, and for this reason, was the one chosen.

3.3 Evaluation

The standard metrics for model classification in machine learning were used for the model's evaluation. The accuracy (1) represents the fraction of predictions that the model hit.

$$\text{Accuracy} = (\text{TP} + \text{TN})/(\text{TP} + \text{TN} + \text{FP} + \text{FN}) \tag{1}$$

where TP is the true positive, TN is the true negative, FP is the false positive, and FN is the false negative. Sensitivity (2) measures the proportion of correctly identified positives, and specificity (3) measures the proportion of correctly identified negatives.

$$\text{Sensitivity} = \text{TP}/(\text{TP} + \text{FN}) \tag{2}$$

$$\text{Specificity} = \text{TN}/(\text{TN} + \text{FP}) \tag{3}$$

The area under the curve (AUC) represents the degree or measure of separability. It tells how much the model is capable of distinguishing classes. The higher the AUC, the better the model predicts the classes.

4 Results and Discussion

4.1 Vila Real Climatic Conditions

The city of Vila Real is located in the Northern Region of Portugal. Its geographical location is 41° 18' North latitude and 7° 44' West longitude, on a plateau at approximately 450 m altitude, on the promontory formed by the confluence of the Corgo and Cabril rivers, where its oldest part is located (Vila Velha).

The Serras do Marão and Alvão act as natural barriers for the region. Due to this geographical situation, it has a climate with some continentality compared to the Portuguese west coast. The climate of Vila Real is Mediterranean. The average annual relative humidity is 74%. The summer is moderately hot and dry but is already transitioning to a temperate maritime climate, given the average annual temperature of 13.3 °C and the accumulated yearly precipitation exceeding 1000 mm. Winter is relatively long, with temperatures occasionally reaching below 0 °C.

4.2 Biological Growths on Building Façades

Below are some photographs of biological growths on building facades in Vila Real, most of which are on buildings in the city's historic centre. Most of the facades where biological growth was detected are oriented to the North and West, and some are located on narrow streets that cause the main facade of the building to be shadowed for most of the day.

The biological growths found were fungi, algae, mosses, lichens and vegetation in yellow, black, white and various shades of green.

a) Shadowed façade b) Details of the mosses in the façade

Fig. 5. Shadowed building façade.

In Figs. 5a) and b), on a facade facing west, it is possible to observe that the growths are located on the rough stones and have a more significant protrusion, and for part of the day, they are under the shade of tree branches.

Broken tiles and leaks from downpipes are relatively common causes of biological growth. Leaks in downpipes can be due to broken pipes or insufficient sections to dispatch the volume of water from the gutters. Figure 6 (facade facing west) is an excellent example of the two situations mentioned, where it is possible to observe the presence of algae and vegetation growth.

Fig. 6. Vegetation and algae in building façade.

In Fig. 7a) and b), on a facade facing west, stains associated with biological colonisation (moss, lichens) are visible near the base of the walls in contact with the exterior floor of the house.

The presence of these biological colonisations is associated with frequent humidification of stone elements and lack of maintenance. The humidity on the facades may be due to rising dampness or rainwater that runs down, is absorbed by the facade, and accumulates at its base.

a) Lichens and mosses in façade b) Detail of yellow and white lichens

Fig. 7. Building façade with lichens and mosses.

The absence of a drip tray on the top of the facade to direct water leads to a constant presence of water in the same places, providing a favourable environment for microorganisms. In Fig. 8a) and b), the façade facing south is wholly filled with mosses of different colours.

a) Building wall with mosses b) Green and yellow mosses

Fig. 8. Building with a stone wall with the presence of mosses.

In the lower parts of buildings close to the pavement, it is common for rainwater to accumulate. Even if the water does not run down the facade, the rain splashes deposit residue and wet the surface of the materials. In the long term, this action provides a favourable environment for the growth of biological colonisation. Figures 9a) and b) show a facade facing North with a significant presence of mosses and fungi in the lower part.

The previously mentioned phenomenon also causes the appearance of algae, as shown in Fig. 10a) and b).

a) Building façade b) Detail with fungus and mosses

Fig. 9. Building façade with several types of BG.

a) Building façade b) Detail with algae and mosses

Fig. 10. Building façade with algae and mosses

4.3 Repair of Biological Growths

The first step to repairing biological growth is cleaning the facade to remove existing growth thoroughly. Depending on the type of growth (such as moss, fungi, lichens) and severity, appropriate cleaning methods may be used, such as washing with water and detergent, gentle brushing, low-pressure blasting, or using specific cleaning agents.

After cleaning, an antimicrobial treatment is recommended for the facade surface. This treatment will help prevent the future growth of biological organisms by inhibiting their proliferation.

It is necessary to check whether damage or cracks in the facade could allow moisture to enter and encourage biological growth. If present, it is crucial to carry out appropriate repairs, such as filling cracks with appropriate sealants, replacing damaged bricks or mortar, or any other action necessary to ensure the integrity of the facade.

Check that the facade has an adequate drainage system to direct water away from the surface. Excessive humidity can promote biological growth. It would help if it ensured that the gutters and drainage pipes were in good working order and the water was correctly directed away from the facade.

To prevent recurrent biological growth on the facade, a regular maintenance routine must be established. This maintenance may include periodic cleaning, visual inspections to identify problem areas, and preventive measures, such as removing leaves or debris that may accumulate moisture on the facade.

Depending on the conditions and history of biological growth on the facade, it may be helpful to consider applying specific protective coatings, such as anti-algae, anti-fungus or water-repellent coatings. These coatings help to create an additional barrier against biological growth and protect the facade.

5 Conclusions and Future Works

The appearance of biological growth is directly related to the building's solar orientation and the climatic conditions of its location, as well as shading and the rainwater drainage system from the roof, gutters, and downpipes. The most common types of CB were lichens, mosses, algae, and fungi found on facades facing north and west.

Finally, a periodic maintenance plan is essential. It must be programmed and followed, considering the growth rates of the species involved and the dynamics of recolonisation. This makes it possible to intervene in the initial phases of evolution or even prevent such a situation.

As a suggestion for future work, we intend to increase the database with the various types of biological growths in photographic records, apply deep learning models to this database, and obtain automatic detection results.

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