Methodology to assess microbiological colonization on ETICS façades

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I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the *Universidade de Lisboa*.

To...

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Abstract

This thesis describes a methodology to identify and characterize types of anomalies, especially the microbiological growth. Micro-organisms are playing an important role in the biodegradation of ETICS (External Thermal Insulation Composite Systems) in combination with biotic and abiotic factors. The development of microbiological growth causes stains and biofilms formation on the cladding surface. Based on a proposed methodology consisting of a visual assessment and diagnosis methods, a case study was developed. The visual assessment consisted of observing 56 façades or approximately 22 000 m² of ETICS. The observations were limited due to the fact that it is difficult to identify types of biological colonization. It was possible to distinguish types of stains, such as the uniform and differential stains. This kind of stains have an impact on the aesthetic of façades. The diagnosis methods had to further reveal whether it was indeed possible to identify biological colonization. These methods consist of several phases, starting with a simple test in order to move on to more detailed tests, with a more specific result. The sequence was as follows: the magnifying glass, the digital microscope, bleach test and the scanning electron microscope (SEM). After these tests, it was found that it is still difficult to distinguish between types of biological colonization. The combination of all the tests of the proposed methodology reduce the uncertainty of the diagnosis. Further research, such as DNA, could lead to identification.

Keywords

ETICS, Microbiological growth, Type of stain, Visual assessment, Diagnosis method

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ETICS	External Thermal Insulation Composite system(s)
EPS	Polystyrene
MW	Mineral wool
ICB	Insulated cork board
VOCs	Volatile organic compounds
ETAG004	Guideline for European technical approval of External Thermal Insulation Composite Systems (ETICS) with rendering
ASTM	American Society for Testing and Materials
SEM	Scanning Electron Microscope
DGGE	Denaturing gradient gel electrophoresis
DNA	Desoxyribo Nucleic Acid
rDNA	Ribsomal Desoxyribo Nucleic Acid
PCM	Phase change materials
IR	Infrared radiation
Lot No. 11-18	Area 1
Lot No. 19-26	Area 2
Lot No. 63-76	Area 3
Sample 2	Area 1
Sample 3	Area 1
Sample 6	Area 3

μ	[-]	Water vapour diffusion resistance factor
E	[MPa or N/mm²]	Modulus of elasticity
d	[mm]	Insulation thickness

1 Introduction

1.1 Problems and objective

This study was developed within the 'Project WGB Shield – Shielding buildings' façades on cities revitalization. Triple-resistance to water, graffiti and biocolonization of external thermal insulation composite systems' (PTDC/ECI-EGC/30681/2017), financed by FCT – *Fundação para a Ciência e a Tecnologia* (Foundation for Science and Technology, Portugal). The dissertation is about the pathology of ETICS (External Thermal Insulation Composite Systems) in Portugal. Pathology is the science that studies anomalies, especially to determine the cause, the mechanisms of development and the consequences of the problems. ETICS is an acronym for Exterior Thermal Insulation Composite Systems. It is a nonload bearing façade system that consists of a combination of different materials in several layers with specific requirements and application methods. Since the 70's, ETICS are the most widely used in Europe, both for new construction and renovation projects (Sulakatkoa et al., 2017). Over the years, much more attention has been paid to both the installation and the problems associated with it. Many studies have lead to a better knowledge of the whole system, in order to limit or even avoid such anomalies in the future. A construction project consists of activities ensuring that the building meets the necessary specific construction requirements, including requirements in terms of time, costs and resources used (Hadji Rezaia et al., 2015).

In addition to the many advantages of the system, there is also a negative side. The cladding surface is exposed to the outside conditions, which leads to various anomalies such as material failure and different type of stains. But the main type is the microbiological growth, it is a major culprit in an ETICS. First of all, attention is paid to the origin and growth of these anomalies. The insulation has a high thermal resistance, with the result that moisture problems occur on the cladding surface or even deeper in the system. This gives rise to the growth of various types of biological colonization (Saraiva et al., 2014). In order to deal with biological deterioration, the types of micro-organism need to be identified and well characterized.

1.2 Methodology of the thesis

The main objective of this dissertation is to identify the current anomalies that occur on ETICS. Based on the literature review, a methodology will be proposed to reach the objective. The occurrence of anomalies can be analysed in the first instance by direct visual observation of the façade. Depending on the characteristics (specific pattern) each anomaly can be identified. The anomalies are organized and classified in a list of 19, divided into three groups: material failure, stains and microbiological growth.

By the limitation of the visual assessment, there will be further investigation on samples. These are the diagnosis methods, the next steps of the proposed methodology. Tests can be done in-situ and/or in the lab. The aim of these methods is to distinguish and characterize types of biological colonization. The application of the methodology will be through a case study.

1.3 Structure of the dissertation

The dissertation is structured in 6 chapters.

The first chapter is an introduction which defines the problem of the subject, the methodology and presents the structure of the dissertation.

The next two chapters are the literature review about ETICS in general and the microbiological growth. Chapter 2 defines the construction technology and the performance requirements according to ETAG004. A schematic overview of the anomalies with their possible causes is given later in this chapter. Chapter 3 is fully dedicated to microbiological growth on the façades. This problem and the different steps, such as visual assessment and diagnosis methods, to identify biological colonization are explained. These two chapters give a good background information that can be used in the next chapters. In chapter 4 the methodology is proposed, in which the entire process of the investigation, the construction of the inspection sheet and the samples are discussed.

In chapter 5, the results of the investigation by following the proposed methodology are presented and discussed, starting with an overview of the visual assessment. All the current anomalies on the façades will be analysed. Because of the microbiological growth is a major culprit in an ETICS, attention is paid on the influence of the orientation and the finishing coating. After the visual assessment, the next step of the methodology is the diagnosis methods, to identify and characterize the biological colonization.

Chapter 6 gives the main conclusion of the dissertation and further developments.

Finally, this thesis contains references and the attachments of the results.

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2 ETICS

2.1 General aspects

ETICS is an excellent solution for buildings with insufficient thermal insulation (leakage problems) because a large part of the heating and cooling energy is wasted by leakage through insulation. ETICS is advantageous for energy savings and reduces energy losses due to the additional insulation (Saraiva et al., 2014). The system consists of insulation panels that are attached to a substrate using an adhesive mortar and mechanical anchors. In contrast, there is a reinforcement layer, a key coating and finally a finishing coating. With regard to thermal properties and moisture control, ETICS is today one of the best performing façade cladding systems. The system complies best with the imposed building regulations, in which energy saving is an important point of attention. Through a continuous insulation layer and air barrier, the impact on the environment is limited and energy savings are promoted (EIMA, 2019).

Next, the ETICS is discussed more in detail and it is mentioned why it can be an essential system for both new constructions and renovation. Afterwards, all the components, the performance of the system, the requirements and the deterioration of the ETICS are discussed. The anomalies and causes are identified based on visual observations, in situ tests and laboratory tests. The possible causes of deterioration occur due to poor design, inappropriate use of building materials and imperfections in the materials. After identification, solution methods will be searched for to treat the system.

2.2 The importance of ETICS

A building should be comfortable, healthy, efficient and sustainable. A high-performance assessment and the studies of the problems that occur make it possible to give a better picture of the overall performance of the buildings. The thermal performance of buildings was often inadequate and did not always meet the standards imposed. In the 70's, there were no EITC-systems in place in Belgium and between 2008-2010 an estimated 0.7 million m²/year of ETICS were installed (Dirkx I. , 2010). In Portugal the use of the system has risen from 200 000 m² in 2006 to 2 400 000 m² in 2010 (Amaro et al., 2013). ETICS were initially not considered efficient because of the many problems involved (Dirkx & Grégoire, 2012), (Saraiva et al., 2014). In Portugal, ETICS are nowadays most commonly used to comply with the Regulations on Thermal Behaviour of Buildings (REH) or thermal code, to cover the energy consumption in buildings and to determine the design rules for all new residential buildings (Amaro et al., 2013). The system is more to be found in the north because it is cooler there. In 2011, Porto (in the north) had 19 400 m² of ETICS while Lisbon (more to the south) had 11 780 m². The centre

of the country has only 5 250 m² (Saraiva et al., 2014), (Amaro et al., 2013). ETICS reduce thermal bridges and global heat losses through continuous insulation around the building envelope (Figure 2.1). As a result, both energy consumption and condensation on the inside of the wall is reduced. Partly due to a higher interior thermal inertia, a better thermal comfort is present in the building. During the cold season there is a reduction in heat losses, during the hot season the building is kept at the right temperature which leads to a reduction in ventilation (Freitas & Barreira, 2014). The largest loss-making materials in a building are the outer walls however the additional wall insulation reduces energy losses. The air infiltration in a building can also be reduced by about 55%. Due to the energy efficiency of an ETICS, installations (heating and ventilation) can be selected with a lower power output. In terms of moisture content, ETICS is a water-resistant system but, as with all coverings, detailed installation is required. Incorrect installation can lead to moisture problems and damage. Window openings, doorways, roofs and all other exterior wall openings are the most sensitive areas (EIMA, 2019).

If the system is used in a new building, larger effective inner surfaces can be obtained, for example. The system makes it possible to provide thinner walls instead of cavity walls. The outer walls are additionally insulated, which leads to a reduction of heat loss in the winter (Freitas & Barreira, 2014). The system is very flexible, making it less susceptible to cracking and if the substrate expands due to fluctuations in temperature, it is resilient to handle the resulting movements. It can contain all possible colours, has a great variety of textures and can be built up in any possible form (EIMA, 2019).

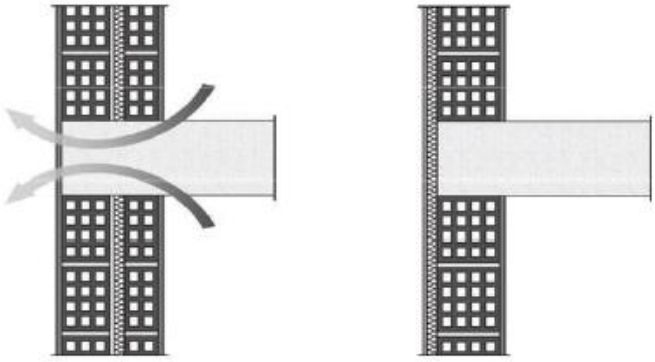
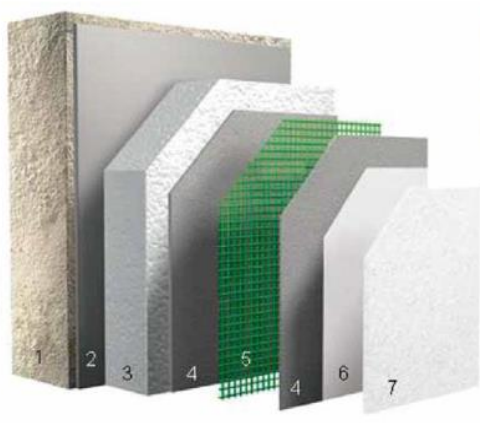


Figure 2.1: Reduction of heat losses due to the continuous thermal insulation (Freitas & Barreira, 2014)

2.3 Technology of ETICS

The installation of an ETICS requires a great deal of knowledge and must be carried out accurately. Construction details are important components that will have a major impact on performances in the future. The popularity of the technology was growing as it showed better properties compared to other insulation techniques. When renovating non-insulated walls, the exterior insulation is preferred over all other post-insulation systems, such as interior wall insulation etc. (Verhaeghe, 2016). The installation of

the system must not cause any nuisance to residents. It is intented that the system is implemented in a sustainable way in terms of lower consumption. ETICS consist of prefabricated insulation panels that are glued and mechanically fixed to the outer wall. On the insulation panels, a key coating with a mesh is applied. The finishing coating can consist of one or more layers and is applied directly to the insulation (Figure 2.2). All the different system components must be coordinated in order to form a complete unit (Freitas & Barreira, 2014). Prior to the work, the necessary provisions must be made to ensure that building moisture and other influencing factors do not adversely affect the system. For each project, a critical inspection must be carried out in advance to prevent problems and damage to the system in the future (EOTA, 2011).



1. Substrate
2. Adhesive
3. Insulation
4. Reinforcement Layer
5. Mesh
6. Key coating
7. Finishing coating

Figure 2.2: Construction technology (IVP, 2011)

2.3.1 Substrate

The substrate is the outer wall and this is the basis of the whole system. The outer wall is airtight and resists static and dynamic loads. It must have enough bearing capacity to support this system. If the substrate is not strong enough, additional fixings can be provided (EOTA, 2011), (Sulakatkoa et al., 2017). The quality of the wall determines the durability and behaviour of the system. Therefore, absolutely no moisture may penetrate the wall. In this way the façade system becomes moist and this leads to the loss of performance of the thermal insulation layer. The moisture present in the substrate has the possibility to migrate to the outside. In order to maintain the performance, the wall must be dry but clean and flat as well. The surface condition of the layers affects the adhesion between the applied and existing materials. In order to obtain enough adhesion properties, the imperfections of the substrate must be treated (IVP, 2011), (Verhaeghe, 2016). Finally, a minimum adhesion strength is also required to withstand wind, natural weight, hygrothermal loads and internal movements of the structure (Sulakatkoa et al., 2017). The substrate can be a masonry or concrete wall (EOTA, 2011).

2.3.2 Adhesive

The insulation panels are fixed to the substrate using an adhesive mortar. It can also be combined with

additional mechanical fixings (avoid the risk of detachment). The mechanical fixings provide temporary, additional stability until the adhesive has dried up (EOTA, 2011). Again, additional adhesives can also be used for mechanical fasteners to ensure the flatness of the ETICS. Installing an ETICS reduces the temperature gradients in the substrate because the main temperature gradient is in the insulation panel. This explains the strength created in the adhesive (Sulakatkoa et al., 2017).

2.3.3 Insulation

A first point of attention when installing the insulation is to avoid thermal bridges. Because the insulation is placed on the outside of the wall, the substrate does not suffer from large temperature differences and is less susceptible to cracking due to thermal gradients. The insulation influences the thermal conductivity of the façade (IVP, 2011). The most commonly used insulation materials are expanded polystyrene (EPS), mineral wool (MW) (Verhaeghe, 2016) and ICB- cork (Figure 2.3). If the insulation material gets wet during storage or during the execution of the works, the moisture will be trapped in the system for a certain period of time. Each insulation material has a vapour diffusion resistance, which determines the drying time of the material. The vapour diffusion resistance or µ-value indicates to what extent a material allows water vapour to pass through. Drying time after installation of EPS can take up to two years and that of mineral wool is about six months (Sulakatkoa et al., 2017).

Figure 2.3: ETICS with cork insulation (Amorim Isolamentos, 2014)

2.3.1 Render

2.3.1.1 Reinforcement layer

The next layer in the system is the reinforcement layer, which consists of a layer of mortar containing a mesh. The tensions present in the system are transferred to the reinforcement layer. This layer distributes the tensions and ensures the mechanical strength (Sulakatkoa et al., 2017). First, a layer of mortar is applied directly to the insulation, this can be done in one or more layers. Afterwards, the mesh is pressed into the mortar (Figure 2.4). It is important that there is always enough overlap of the meshes. Because the largest thermal tensions occur at the level of wall openings, extra reinforcement must be

provided at those places to prevent cracking. This must be done before the general reinforcement layer is applied and must be placed diagonally (Figure 2.5) (IVP, 2011).

Figure 2.4: Reinforcement layer (Guimarães et al., 2015)

Figure 2.5: Extra diagonal reinforcement (IVP, 2011)

As mesh, a glass fibre mesh, a metal batten, a plastic mesh reinforcement or fibres can be used to improve the mechanical properties. In the case of fibreglass mesh, a distinction can be made between a standard mesh and a reinforced mesh. A standard mesh is provided over the entire surface with enough overlap. A reinforced mesh is used as an addition to a standard mesh. The advantage of the reinforcement layer in connection with crack formation is that the growth of macro cracks is delayed and that the behaviour after a crack is optimally improved (EOTA, 2011).

2.3.1.2 Finishing coating

After placing the reinforcement layer, a key coating is applied, which serves as an aid for the final finishing layer. The finishing layer contributes to the mechanical strength and is therefore resistant to weather influences (wind, rain, polluted substances, temperature, humidity and solar radiation) (Sulakatkoa et al., 2017). The coating has a major influence on the durability of the façade. This layer also contributes to the decorative part of the system. A coating or a paint layer can be chosen as the finishing layer (EOTA, 2011) (Freitas & Barreira, 2014) (Verhaeghe, 2016). The finishing coating consists of an acrylic dispersion, silicone resin, silicate, ceramic or mineral bonded coating (IVP, 2011).

2.4 Performance

The energy performance of buildings is becoming increasingly important and many different factors need to be taken into consideration. Buildings are assessed in terms of overall performance, not just energy or economic performance. Shortcomings can lead to the loss of technical performance during the lifetime of the façade and have an economic and social impact (Sulakatkoa et al., 2017). A

construction project consists of activities ensuring that the building meets the necessary specific construction requirements, including requirements in terms of time, costs and resources used. But the needs of the users must also be met, such as in terms of comfort, function and use (Hadji Rezaia et al., 2015).

The building systems implemented must comply with European standards. The general requirements for construction works are (EOTA, 2011) (EU, 2011):

i. The mechanical resistance and stability

It is important to ensure that the system does not experience any problems when exposed to mechanical loads. The design must be chosen in such a way that the properties are retained during use, by a normal, accidental, intentional or unintentional effect (EAE, 2011) (EOTA, 2011). The loads must therefore not lead to collapse, unacceptable deformations, damage to building components or to equipment as a result of deformations and damage caused by an event disproportionate to the original cause (EU, 2011).

ii. Safety in case of fire

- The design of the building must limit the generation, spread of fire and smoke
- The load-bearing capacity of the building can be maintained for a certain period of time
- The occupants can leave the building and take into consideration the safety of the rescue teams (EAE, 2011) (EOTA, 2011) (EU, 2011).

iii. Hygiene, health and environment

A building must be designed and built in such a way that during its life cycle it does not endanger or have a significant impact on the hygiene or health and safety of workers, occupants or neighbours, on the environmental quality or on the climate during construction, use and demolition, as a result of (EU, 2011):

iv. Releasing toxic gases

- Emission of dangerous substances, volatile organic compounds (VOCs), greenhouse gases or dangerous particles into indoor or outdoor air.
- Emission of dangerous radiation.
- Release of dangerous substances into ground water, sea water, surface water or soil.
- Release of dangerous substances into drinking water or substances having a negative impact on drinking water.
- Incorrect discharge of wastewater, emission of flue gases or incorrect disposal of solid or liquid waste.
- Humidity in parts of the building or on surfaces inside the building (EU, 2011). There are several things that must certainly be taken into consideration related to the humidity of the exterior walls. The water vapour diffusion from outside and moisture from the ground must certainly not penetrate the building. It speaks for itself that the outer walls are resistant to rain and snow, and

neither of them penetrates the walls. If the walls do not meet this requirement there is a high risk of damage (EOTA, 2011).

It is important that moisture is prevented in an ETICS. A point of attention is the choice of the material and a suitable design. Additional precautionary measures are necessary to prevent moisture as much as possible (EOTA, 2011).

v. Safety and accessibility in use

An ETICS should always be able to withstand tensions due to weight, temperature, humidity and shrinkage, as well as movements of the main structure and wind forces (suction) (EOTA, 2011). The building must not present unacceptable risks of accidents or damage such as slipping, falling, collision, burns, electrocution, injury from explosions and burglaries. Accessibility and use for the disabled persons should also be taken into consideration (EU, 2011).

vi. Protection against noise

The building must be designed and constructed in such a way that any noise perceived by the occupants or persons nearby is kept at a level that does not endanger their health, enables them to sleep, rest and work satisfactorily. (EU, 2011).

vii. Energy, economy and heat retention

The aim is to have as little energy loss as possible, which is why the thermal bridges should be avoided. Therefore, in the ETICS some properties of all components must be known, such as thermal conductivity/resistance, water vapour permeability and water absorption (EAE, 2011) (EOTA, 2011). Also heating, cooling, lighting and ventilation installations should be designed and installed in such a way that the amount of energy during use is low. Construction shall also be energy efficient and use as little energy as possible during construction and disassembly (EU, 2011).

viii. Sustainable use of natural resources

The building must be designed, built and demolished in such a way that the use of natural resources is sustainable and ensure the reuse or recyclability of the construction works, their materials and components after demolition, the durability of the works and the use of environmentally friendly raw and secondary materials in the building (EU, 2011).

The above requirements are for constructions in general, ETAG004 contains specific requirements for the ETIC system. Table 2.1 lists the requirements for an ETIC system.

Table 2.1: ETAG004 requirements for an ETICS (EOTA, 2011)

Properties		**Requirements**
Reaction to fire		If no performance is determined, the products fall in class F without testing.
Water absorption		If the water absorption of the reinforced base coat after 1 hour ≥ 1 kg/m², the water absorption after 1 hour of each rendering system shall <1 kg/m²
Water tightness	Hygrothermal behaviour	Based on the assessment of water absorption, 6.1.3.1 and Annex B, the performance of the chosen ETICS is assessed from testing on the rig. The following defects shall neither occur during, nor at the end of the test programme: - blistering or peeling of any finishing coat - failure or cracking associated with joints between insulation product boards or profiles fitted with ETICS - detachment of the render coat - cracking allowing water penetration into the insulating layer (normally ≤ 0,2 mm)
	Freeze/thaw behaviour	Rendering systems have a water absorption ≥ 0,5 kg/m² after 24 hours
Impact resistance		Category I, II or III (6.1.3.3)
Water vapour permeability		Not available, Table 7 p. 66/143 (no performance determined, 6.1.3.4.)

Table 2.1: ETAG004 requirements for an ETICS (EOTA, 2011) (continued)

Properties		**Requirements**
Release of dangerous substances		- Submit the chemical constitution and composition of the materials and components to the Approval Body which will observe strict rules of confidentiality - The use of recycled materials shall always be indicated
Bond strength between	Base coat and insulation product	0,08 N/mm² (MPa)
	Adhesive and substrate	In dry condition: 0,25 N/mm² (MPa) After effect of water: - 0,08 N/mm² after 2 hours removed from the water - 0,25 N/mm² after 7 days removed from the water
	Adhesive and insulation product	In dry condition: 0,25 N/mm² (MPa) After effect of water: - 0,03 N/mm² after 2 hours removed from the water - 0,08 N/mm² after 7 days removed from the water
	Foam adhesives	≥ 0,08 N/mm² (MPa)
Bond strength after ageing		The minimum failure resistance value ≥ 0,08 N/mm²
		Failure shall occur in the insulation product if failure resistance < 0,08 N/mm² (MPa)
Fixing strength		Bonded surface > 20% E x d < 50000 N/mm (E: modulus of elasticity of the base coat without mesh and d: insulation thickness base coat (min > 120mm))

Table 2.1: ETAG004 requirements for an ETICS (EOTA, 2011) (continued)

Properties	**Requirements**	
Wind load resistance	Pull-through tests of fixings	5.1.4.3.1
	Static foam block test	5.1.4.3.2
	Dynamic wind uplift test	5.1.4.3.3
Airborne sound insulation	The acoustic performance of an ETICS shall be determined based on laboratory tests carried out in accordance with the standards EN ISO 10140-1, EN ISO 10140-2, EN ISO 10140-4 and EN ISO 10140-5.	
Thermal resistance	>1 m² K/W	

During the design several points of attention are taken into consideration. The characteristics of such a system must also be able to withstand for a long period of time, it must be sustainable (EOTA, 2011). According to ETAG004, the assumed working life for an ETIC system is 25 years if the system is properly used and maintained (EOTA, 2011). Sufficient knowledge and experience are required to achieve the assumed working life. In recent years, more attention has been paid to determining the durability, the lifetime of materials, components, installations, structures and buildings. This is based on two important aspects: environmental problems and economic problems. Predicting durability is subjective, there are so many variables that influence it and therefore it is not an exact science (Hovde, 2004). Testing methods are used to study the durability of an ETICS and to achieve objectives. Specifically, for the system there are measurements in terms of performance loss (hygrothermal behaviour) and the evolution of degradation. With these measurements, qualitative degradation models and suggestions for technological improvements are drawn up. Test methods will improve because information from different measurement techniques will be compared with each other (Daniotti, 2006). During the laboratory tests, the properties are examined under laboratory conditions over a short period of time. Under the natural climber factors, the deterioration of the materials will be much slower. Laboratory conditions should be as close as possible to natural, but it is not easy to simulate climatic conditions. If the conditions are known, the durability can be estimated. In this way, the mechanisms of deterioration, effects and the severity of the damage can be determined (Griciutė et al., 2013). However, the evaluation techniques used to determine a full performance-over-time, will not test all performance. Because there are several variables that do not occur at the same time, under the same conditions (Daniotti, 2006).

2.5 Types of Anomalies

As mentioned earlier, ETICS are increasingly being used in Europe, despite their thermal advantages, low cost and simple implementation, this system still faces serious problems. Problems that have a major impact on the system and damage the cladding (Amaro et al., 2013). Due to the increasing interest in this technology, the durability, pathology and degradation of an ETICS are important issues. As soon as construction has started, the process of decay starts. Periodic inspections are relevant to identify shortcomings in a timely manner. The deterioration of materials in the system has a major impact on sustainability. It is never homogeneous and differs from building to building and can therefore occur in different ways. The common problems in an ETICS increase the risk of early deterioration of materials, which negatively affects the performance of the structure. It is still difficult to identify the exact reasons and mechanisms of the anomalies (Silva et al., 2015) (Amaro & Brito, 2015). Below is an overview of the most common anomalies, Table 2.2 gives the material failure and Table 2.3 gives different types of stains. Stains as a result of microbiological growth is discussed in chapter 3 implementation.

Table 2.2: Material failure (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013)

Material failure	**Photo**	**Causes**
Cracks	 (Silva et al., 2015)	- No reinforcement - Inadequate/incorrect application method - Substrate settlements - Mechanical anchors too tight - Insufficient supervising and quality control

Table 2.2: Material failure (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013) (continued)

Material failure	Photo	Causes
Blistering	 [W1]	- Excessive moisture - Extreme temperature - Inadequate/incorrect application method - Disregard of the dry off period between coats - Application during adverse environmental conditions
Detachment of the finishing coat	 (Amaro et al., 2013)	- Contaminated materials or ones having fabric defects - Insufficient thickness of the base coat - Inadequate/incorrect application method - Action and direction of the predominant winds, rain, damp - Insufficient maintenance
Material gap	 (Amaro et al., 2013)	- Absence of reinforcement cantilever - Human action - Impacts - Undue intervention

Table 2.2: Material failure (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013) (continued)

Material failure	Photo	Causes
Craters	 (Amaro & Brito, 2015)	- Manufacturing/storage defects - Inadequate/incorrect application method - Incorrect product formulation or component mixture - Negligence of the substrate conditions - Incorrect/omitted prescription of the environmental conditions for application
Peeling	 (Silva et al., 2015)	- Manufacturing/storage defects - Inadequate/incorrect application method - Insufficient supervising and quality control - Erosion - Human actions - Natural ageing

Table 2.3: Types of stains (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013) (Büchli & Roland, 2003) (Johansson et al., 2005)

Stains	Colour	Photo	Causes
Differential stains (Soiling)	Dark	 (Silva et al., 2015)	- Poor construction details - Rain, damp - Splattering at the bottom of the walls - Natural ageing - Friction actions due to usage, orientation - The building location
Uniform stains (Soiling)	Dark		- Superficial condensation - Orientation - Building location - The thickness of external rendering
Oxidation stains	Yellow Orange	 (Silva et al., 2015)	- Deficient detailing - Preparation and state of the background - Human action - Continuous or alternate humidification (wet/dry cycles) - Atmospheric pollution or other particles in the air - Metal elements with no protection against corrosion - Orientation

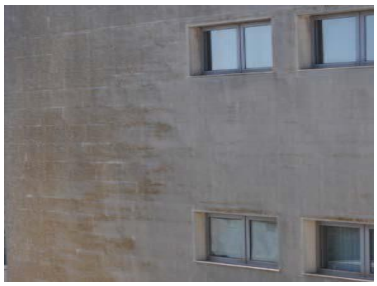
Table 2.3: Types of stains (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013) (Büchli & Roland, 2003) (Johansson et al., 2005) (continued)

Stains	Colour	Photo	Causes
Efflorescence	White	 (Silva et al., 2015)	- Manufacturing/storage defects - Negligence of the substrate conditions - Disregard of specifications/unconformity between design and execution - Solar radiation, orientation - Internal humidty - Rain, damp - Insufficient wall's ventilation - The building location - Crystalization of salts due to moisture
Parasitic vegetation	Green Yellow Orange Blue	 (Silva et al., 2015)	- Deficient detailing - Façade geometry - Characteristics of the cladding's surface - Action and direction of the wind - Continuous or alternate humidification (wet/dry cycles) - Atmospheric pollution or other particles in the air - Immediate surroundings

Table 2.3: Types of stains (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013) (Büchli & Roland, 2003) (Johansson et al., 2005) (continued)

Stains	Colour	Photo	Causes
Carbonation stains	White	 (CIB, 2013)	- Characteristics of the cladding's surface - Continuous or alternate humidification (wet/dry cycles) - Action and direction of the predominant winds - Atmospheric pollution or other particles in the air (salts) - Preparation and state of the background
White dots	White	 (Johansson et al., 2005)	- At the place of the white dot there is no microbiological growth - White dots are located where the mechanical fixings are - Lower relative humidity at these mechanical fixings
Graffiti	Various Colours	 (Amaro et al., 2013)	- Human actions

Table 2.3: Types of stains (Amaro et al., 2013) (EAE, 2011) (Flores-Colen et al., 2006) (Amaro & Brito, 2015) (Silva et al., 2015) (CIB, 2013) (Büchli & Roland, 2003) (Johansson et al., 2005) (continued)

Stains	Colour	Photo	Causes
Visible joints between panels due to dirt or fungi	Various colours	 (Silva et al., 2015)	- Insufficient dimensional stability of the insulation material - Inadequate protection against micro-organisms of the finishing biocide - Insufficient thickness of the base coat

2.6 Conclusion of the chapter

ETICS consist of insulation panels that are attached to a substrate using an adhesive mortar and/or mechanical anchors. In contrast, there is a reinforcement layer, a key coating and finally a finishing coating. The installation of an ETICS requires a great deal of knowledge and must be carried out accurately. Construction details are important components that will have a major impact on performance in the future. ETAG004 has more detailed requirements and these are only applied to the ETICS. Due to the fact that the system is struggling with many problems, a list of anomalies is made schematically so that later during the investigation more efficient work can be done. In the next chapter the microbial growth will be discussed, because it is a very important and common anomaly. First, the origin of moisture in the system will be explained, followed by a list of the different types of biological colonization. Next, different diagnosis techniques will be discussed and finally there is a small section on solutions to prevent and to treat the façades.

3 Microbiological growth

3.1 General aspects

In this chapter microbiological growth on an ETICS will be discussed. The microbiological growth is a major culprit in an ETICS. First of all, attention is paid to the origin and growth of these anomalies. Superficial condensation is the phenomenon that leads to an amount of moisture in the system and causes the growth of biological colonization. After the cause of the growth, the biological deterioration is discussed in which an overview of all the different types of biological colonization are given. Finally, the visual observations and the additional diagnosis methods are discussed. These methods are carried out to identify all anomalies and to provide appropriate repair methods.

In 2014, a study showed that microbiological growth is the most common anomaly and Figure 3.1 explains this finding. The code A-M is the group of Material failure, A-C are Colour/Aesthetic anomalies and A-P are the Flatness anomalies. On a number of 146 façades examined, 55,5% was affected with microbiological growth (A-C5). These results allow us to conclude that this anomaly requires extra attention (Saraiva et al., 2014). An ETICS has a low resistance to compressive strength, these strengths not only have an aesthetic impact but, due to the damage, they reduce the protection against rain and water vapour due to condensation (Sulakatkoa et al., 2017). The amount of moisture in the system is due to a combination of surface condensation (which mainly occurs at night), rain, drying process and the properties of the finishing coating. The thermal and mechanical performance does not change, the microbial growth has mainly aesthetic consequences (IVP, 2011) (Sulakatkoa et al., 2017) (Saraiva et al., 2014).

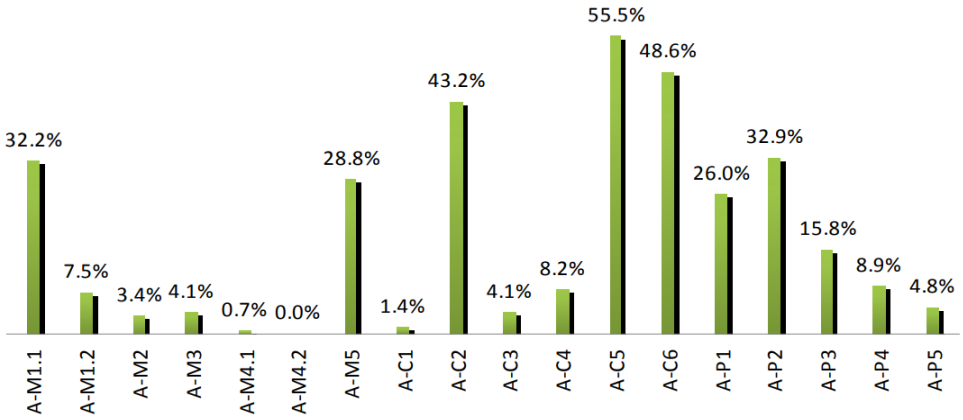


Figure 3.1: Percentage of different anomalies, 55,5% of the façades consist microbiological growth (A-C5) (Saraiva et al., 2014)

3.1.1 Superficial condensation

Façades with discolouration as a result of microbial growth are becoming increasingly important. More and more attention is being paid to this phenomenon. Microbial growth is a complex phenomenon caused by a combination of biotic and abiotic factors. The biotic factors are organic food and other organisms, while temperature, relative humidity and pH are the abiotic factors (Johansson et al., 2005). Buildings equipped with an ETICS are most likely to discolour. This is because the low thermal mass of the outer coating combined with a high thermal resistance of the insulation layer leads to overcooling of the coating surface by exchanging long wave radiation from the air. The hygrothermal behaviour of an ETICS is a determining factor for the service life and damage behaviour. The growth is caused by the moisture from the nocturnal conditions on the outer surface of highly insulated façades. Layers on the cold side of the insulation with a low thermal mass are particularly vulnerable (Sedlbauer et al., 2011). Air contains a concentration of moisture, called water vapour (relative humidity). The relative humidity is related to the air temperature. The higher the air temperature the higher the relative humidity, the more water vapour the air will contain (Freitas & Barreira, 2014). As mentioned earlier, the long wave radiation causes overcooling at night (Figure 3.2). The long wave radiation from the surface of the façade to the outside air will lead to a lower surface temperature of the outer layers. At night, the temperature of the outer surface will drop until it reaches the dew point temperature of the outer air. From the dew point temperature, the water vapour in the air will be converted to water and this will settle on the surface, called superficial condensation (relative humidity 100%) (Sedlbauer et al., 2011) (Büchli & Roland, 2003).

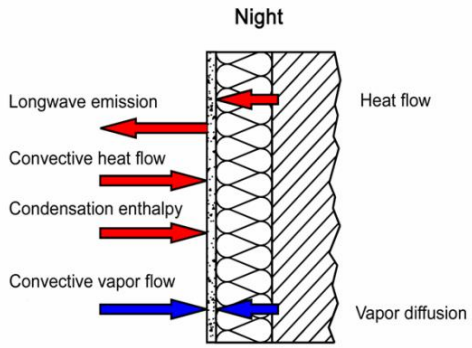


Figure 3.2: Overcooling at night (Künzel, n.d.)

In other words, if the water vapour partial pressure of the air is higher than the water vapour saturation pressure at the surface, condensation occurs. The amount of long wave radiation emitted by the outer surface is determined by the emissivity (radiant power). The greater the radiant power the more radiation the outer surface will emit and the greater the drop-in surface temperature. During a clear night, the radiation emitted by the outer surface will be greater than the radiation reaching the surface. In this way a loss of radiation to the sky occurs (Freitas & Barreira, 2014).

The heat storage capacity has a major influence on the temperature gradients in this process. ETICS

have a low heat storage capacity, which means that only a small part of the solar radiation can be stored during the day. The graph on the left of Figure 3.3 is the result of measurements on an ETICS directed to the south. The curve of the surface temperature from 18h to about 9h the next day is below the dew point temperature of the outside air. The low heat storage capacity of the finishing coating is clearly visible due to the strong rise (morning) and fall (evening) of the surface temperature. The relative humidity on the surface will be higher and increase the risk of the superficial condensation. The graph on the right of Figure 3.3 is the result of measurements made on thermal insulating masonry, also directed to the south. The thermal energy stored in the masonry compensates for the night-time radiation losses. The surface temperature in the early morning will be equal to the temperature of the outside air and is above the dew point temperature because it is lower than the air temperature. This phenomenon only occurs if enough heat can be stored during the day. In the north, heat storage will depend entirely on the difference between the air- and surface temperature, because of the lack of solar radiation (Johansson et al., 2005) (Freitas & Barreira, 2014).

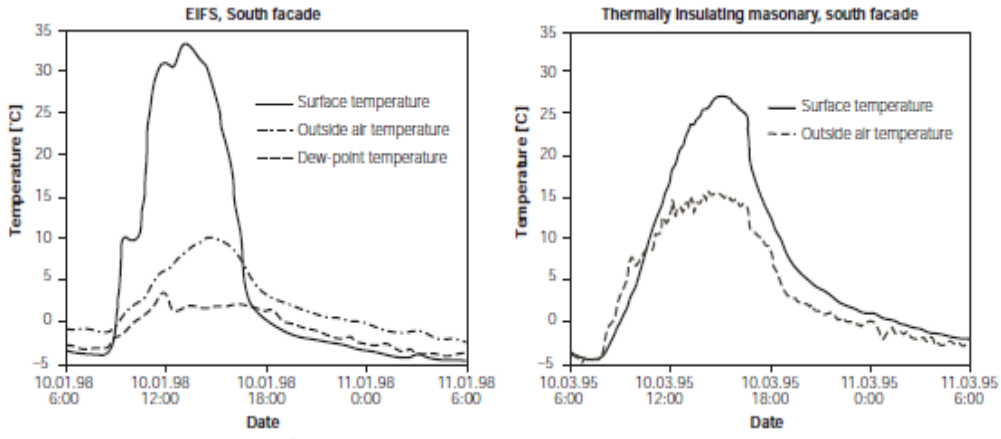


Figure 3.3: Temperature range for ETICS on the left and thermal insulating masonry on the right (Büchli & Roland, 2003)

The thickness of external rendering will determine the amount of condensation. Thin coating on insulation generally has lower temperatures at night than thicker ones. The heat capacity of a thin coating is low and this leads to a higher relative humidity. The thickness of the thermal insulation also influences the surface temperature. Thicker thermal insulation reduces the heat flow through the wall (Figure 3.2), so higher thermal insulation is worse for condensation risk (Johansson et al., 2005).

Porous materials that come into contact with water vapour molecules from outside air have a tendency to absorb and store the water vapour. As the materials absorb more water vapour molecules, the moisture content will increase. The increase in moisture content in materials therefore depends on the relative humidity of the outside air. This characteristic of materials is called hygroscopic (Verhaeghe, 2016).

3.1.2 Drying process

After surface condensation has taken place, all the moisture present on the outer surface will be evaporated during the drying process. If the saturation pressure at the surface is greater than the vapour pressure of the outside air, evaporation occurs. The presence of moisture in the system leads to various problems and damage. The appearance and durability are affected but it also leads to unhealthy comfort for the occupants. The drying process is important to avoid the risk of microbial growth (Verhaeghe, 2016) (IVP, 2011). The orientation, local climate and absorption of shortwave radiation are parameters that influence the drying process. The sun emits shortwave radiation (visible light) and contains a lot of energy. When the solar radiation reaches the atmosphere, a cladding surface will absorb the radiation. During the day, the process depends on the amount of solar radiation on the façades. In Portugal, the drying process will be faster in the south and slower in the north but the amount of condensation will be the same for both façades (Freitas & Barreira, 2014). In the Master dissertation of Ilse Verhaeghe about Hygrothermal behaviour of ETICS for timber frame construction, tests were carried out in Belgium. The result therefore indicates that the drying process for façades to the south is the most optimal (Verhaeghe, 2016).

3.2 Biological colonization

The most important points of interest that give rise to microbiological growth are the hygrothermal behaviour of the façade and the emissivity between the external surface and the sky. Longwave radiation between the outer surface and the sky causes overcooling. If the drying process does not run smoothly and moisture remains on and in the outer surface for a long period of time, the chance of microbiological growth increases (Freitas & Barreira, 2014). The development of microbiological growth on surfaces is called a biofilm. Biofilm formation usually starts with phototrophic organisms (algae and cyanobacteria) that use carbon dioxide and sunlight as energy sources (Büchli & Roland, 2003). The biofilms almost always consist of a combination of bacteria, fungi, algae and other micro-organisms (Simpson, 2013). Table 3.1 gives an overview of all the different types of microbiological growth.

Phototrophic micro-organisms (algae, cyanobacteria) cause decay on a surface in a short period of time (Simpson, 2013). These micro-organisms have the greatest influence on biological deterioration and do not need organic matter, resist solar radiation and are able to survive some drying processes. There are many cyanobacteria, their presence depends on the climate area (Büchli & Roland, 2003). Algae are most common where the humidity is high or the outer surface moist. Algae (green) and the cyanobacteria (blue algae) form a mucus layer on the surface and cause discolouration. Red algae can be yellow, orange or red-brown and cause serious deterioration and mechanical damage (Simpson, 2013). Algae are washed out by the rain and spread along the water path that runs over the façade, that makes the typical elongated pattern (Büchli & Roland, 2003).

Fungi will quickly spread and colonize causing deformation and discolouration (Simpson, 2013). This type of colonization develops on porous surfaces and especially if these surfaces contain sufficient nutrients, due to the surface temperature and humidity. So the growth increases if the above factors occur or are present for a long time. Fungi are dependent on a quantity of organic material (Barberoussea et al., 2007). The colonization is strongly dependent on the roughness of the surface, the higher the roughness the faster the colonization (Ferrari et al., 2015), (Büchli & Roland, 2003).

Mosses usually occur in damp and shady places. Mosses are most active during the winter because there is little sunlight and the temperature is much lower. The nutrients present also lead to growth of mosses, but mosses do not cause direct damage to a cladding surface. Lichen consists of a combination of a fungi with an algae or cyanobacteria but usually contain green algae. About 90% of all lichen contain green algae, i.e. the Chlorophytes (green) or the Xanthophyta (yellow-green). The algae or cyanobacteria will produce nutrients to feed themselves and the fungi. Lichen, in turn, can survive well at high temperatures and during long periods of drought (Simpson, 2013). Biocorrosion also occurs on the façades of buildings and this leads to cracks, detachment and stains. Biological agents will deposit on façades, which make them sensitive to the development of biological corrosion. Biocorrosion refers to façades of new and old buildings, façades with insulation and the ones with thin-layer plasters. By the photosynthesis processes and respiration of the micro-organisms, acidic substances are excreted and thus biodegradation occurs. The most influential factor is moisture because this leads to the growth and multiplication of micro-organisms. The development of biological corrosion therefore depends on the climatic conditions (temperature and humidity), wind speed and direction, sun and the vegetation in the environment that leads to increased pollution. (Piontek et al., 2016).

Table 3.1: Types of microbiological growth (Amaro et al., 2013) (Simpson, 2013) (Flores-Colen et al., 2006) (Barberoussea et al., 2007) (CIB, 2013) (YL Chew & Pay Phing, 2003)

Types	**Photo**	**Characteristics**
Algae	 (Johansson et al., 2005)	- Green - Grow best where sun, moisture and nutrients are - Close to windowsills - Rendered surfaces that are highly absorbent and textured

Table 3.1: Types of microbiological growth (Amaro et al., 2013) (Simpson, 2013) (Flores-Colen et al., 2006) (Barberoussea et al., 2007) (CIB, 2013) (YL Chew & Pay Phing, 2003) (continued)

Types	Photo	Characteristics
Red algae	 (Simpson, 2013)	- Red-brown/orange/yellow - Grow best where sun, moisture and nutrients are - Close to windowsills - Rendered surfaces that are highly absorbent and textured
Fungi	 (Simpson, 2013)	- Colourless but may become blackish if they are active - Grow best in the shade and high humidity level - The colonization dependent on the surface roughness (high roughness better for fungi)
Mosses	 [W2]	- Green - Patches of small, matforming plants - Appears in humid areas that retain moisture and dirt

Table 3.1: Types of microbiological growth (Amaro et al., 2013) (Simpson, 2013) (Flores-Colen et al., 2006) (Barberoussea et al., 2007) (CIB, 2013) (YL Chew & Pay Phing, 2003) (continued)

Types	Photo	Characteristics
Lichen	 [W3]	- Green/yellow/grey/brown/black - Places where algae and fungi cannot survive on their own - Nearly on every terrestrial substrate
Biocorrosion	 (Piontek et al., 2016)	- Green - Caused by micro-organisms - Areas with a lot of moisture - Leads to cracks, detachment and stains

3.3 Assessment methods

3.3.1 Visual observation

The first step is the visual observation of the surface in order to identify all anomalies. During the observations, an inspection sheet is filled in which contains a list of the different anomalies, but also general information such as the location of the building, the age of the building, the structure of the investigated system, the locations of the stains, % affected area, etc. (Silva et al., 2015) (de Freitas et al., 2008). The observations are usually made on the ground floor and are therefore sometimes limited because not all façades are always easily accessible. It is impossible to gather all the necessary information during visual observation, that is why further research is required (Amaro & Brito, 2015). No problem arises without a cause, so all possible causes that give rise to anomalies must be identified. In many cases, a correlation matrix is made to create a clear overview. The matrix contains the list of all anomalies in the y-direction and a list of the causes in the x-direction. In most articles microbiological

growth is used in general and no separation of the different types is made (Amaro & Brito, 2015) (de Freitas et al., 2008) (Silva et al., 2015).

3.3.2 Diagnosis methods

To identify, register and classify the anomalies and define the causes, it may be necessary to use auxiliary methods, in-situ and laboratory tests (in this type of assessment, samples are collected on site) to clarify the origin, characteristics and level of development (CIB, 2013) (Flores-Colen, de Brito, & Freitas, 2010). The next step after the visual observation are the diagnosis methods to further characterize the degradation patterns and the properties of the anomalies. The methods make it possible to study an identified anomaly, to help determine the causes and to draw up a conclusion. The absence or inadequacy of the diagnosis may lead to new anomalies under real exposure conditions.

The diagnosis allows precise observations of material characteristics, both quantitatively and qualitatively. Properties measured in-situ are the roughness, surface moisture, the surface temperature, absorption coefficient, water permeability at 48h, hardness of materials and adhesion strength (CIB, 2013) (Flores-Colen et al., 2006). Laboratory tests can be mineral petrographic and chemical analyses, physical tests of porosity, hydraulic tests and durability tests (Griciutė et al., 2013). The measurements on samples are the capillary coefficient, water content at 48h, initial velocity of drying, drying index, and the bulk density. Other parameters are the pH, conductivity, chloride-, nitrate- and the sulphate concentrations (CIB, 2013) (Flores-Colen et al., 2006). These parameters are in addition to those established by standards or technical provisions (in laboratory conditions with samples) (CIB, 2013). At the same time, the performance level of the render is also determined, whereby the performance delivered is compared with the required performance. The in-situ tests focus more on degradation and have no direct relation to the performance requirements.

Microbiological growth in and on the surface of paint films represents a major cause of discolouration or disfigurement of painted surfaces. Because of the dark pigmentation it is often difficult to notice for example the difference between algae, fungi and dirt. With a standard test method according to ASTM, the degree of disfigurement of a façade is evaluated. Specimens are compared with photographic reference standards which are used as a tool to determine the disfigurement. The photographic standards rate the degree of disfigurement from 0 to 10. A rating of 10 would indicate a specimen totally absent of disfigurement (ASTM(a), 2002). A standard guide of ASTM describes techniques used for determining the presence of fungal or algal growth on paint and related coatings. Bleach or Sodium hypochlorite (NaOCl) is used to perform the test, it is a household bleach with approximately 5% of water content. A drop of 5% of aqueous sodium hypochlorite solution is applied to a sample and if it is algae or fungi growth, discolouration will occur within 60s. If it is not discoloured, it is probably dirt. For further confirmation there are additional visual tests, which are carried out with other magnifications. (ASTM(b), 2017). The Scanning Electron Microscope (SEM) can be used to distinguish different types of biological colonization. The SEM has an electron beam whose wavelength is smaller than the visible light used in a light microscope. It is used due to the high magnification power, high resolution and

sharpness. On the images, the shape, size, (chemical) composition and distribution of particles can be observed. Because electric current flows through the electromagnetic lens, the solenoid will create an electromagnetic field. A high-energy electron beam is concentrated in an area and reaches the sample and generates signals on the surface. This results in the transmission of electrons that are spread back, and these are received by a detector, which consists of a photomultiplier and a scintillator. The scintillator will convert the signals emitted by the sample into electrical pulses, which in turn are amplified by the photomultiplier. Then, the signal from the detector will reach electronic circuits that control the image on the computer screen (Piontek et al., 2016). Figure 3.4 and Figure 3.5 are examples of images created by SEM. Sample A in Figure 3.4 has a 35x magnification and the arrows are directed towards unicellular cyanobacteria or algae. Sample B with 300x magnification indicates numerous colonies of spherical bacteria. The arrows on sample A, Figure 3.5 indicates Lichen and in sample B the thin arrow indicates dead mites and the thicker one to fungal hyphae. Figure 3.6 also indicates fungal hyphae, it is taken from a church. The preparation of the samples must be done carefully because errors can lead to incorrect images (Piontek et al., 2016). Adequate knowledge is of course required to correctly interpret the images (ASTM(b), 2017).

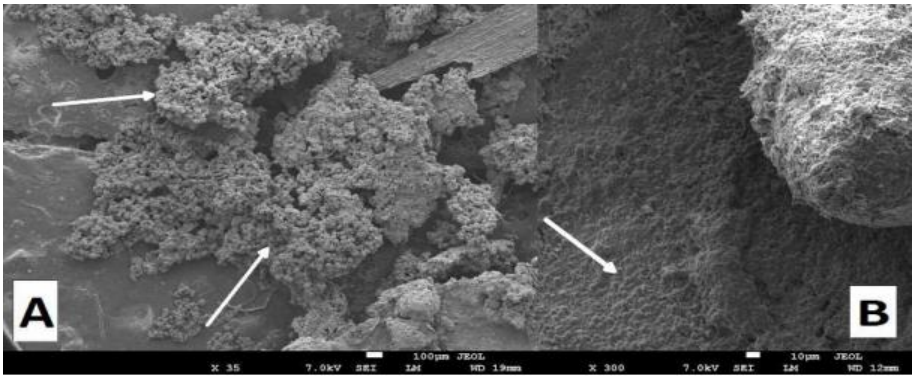


Figure 3.4: An example of a SEM image: sample A contains cyanobacteria or algae and sample B contains numerous spherical bacteria (Piontek et al., 2016)

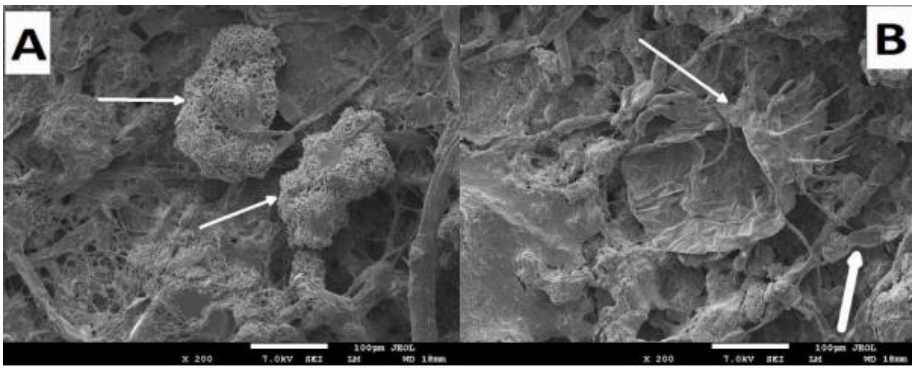


Figure 3.5: An example of a SEM image: Sample A contains Lichen and on sample B, the thinner arrow indicates dead mites and the thicker one indicates fungal hyphae (Piontek et al., 2016)

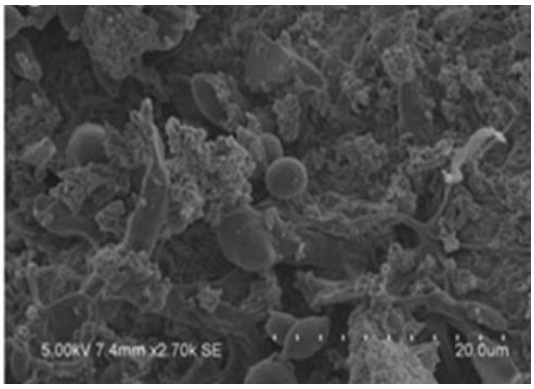


Figure 3.6: Fungal hyphae on a church (Rosado et al., 2013)

As mentioned before, it is important to know as much as possible about the biological colonization that is present on a façade. Further research will make it possible to better understand the phenomena that promote the degradation of façades. The use of techniques such as molecular approaches can determine the differentiation of micro-organisms. To obtain an even better view, molecular fingerprint techniques such as denaturing gradient gel electrophoresis (DGGE) can be applied. In this technique, the genetic diversity of the micro-organisms present on façades is determined and identified. The identification is based on small subunit ribosomal DNA (rDNA) genes. DGGE is a powerful technique for the observation of microbial organisms and population studies (Rosado et al., 2013).

3.4 Solutions to prevent and to treat the façades

To prevent growth, attention must be paid to the properties and texture of the outer surface. Properties such as capillary absorption, vapour diffusion behaviour, pH value, type of binder (mineral, synthetic) and the use of materials with a low emission value (Freitas & Barreira, 2014). The best way to prevent microbiological growth is to reduce the duration and intensity of the superficial condensation by limiting the periods of overcooling. To prevent the growth of fungi, algae and mosses, etc. a solution was searched to increase the thermal inertia of the exterior coating. There are two possible ways to achieve this:

- PCM (phase change materials)
- Low IR emissivity (Low-E) coatings

Microbiological growth is most common in autumn and spring. Using both solutions, including various factors such as insulation, layer thickness, orientation, etc., an attempt is made to design the best possible system. By adding PCM or by applying a paint with a shortwave increase absorption factor, more solar radiation will be stored. If more heat can be retained, the surface temperature at night will drop less quickly or will not drop below the dew point temperature. Figure 3.7 shows the differences in the duration of condensation of an ETICS without and with the PCM or IR (Sedlbauer et al., 2011).

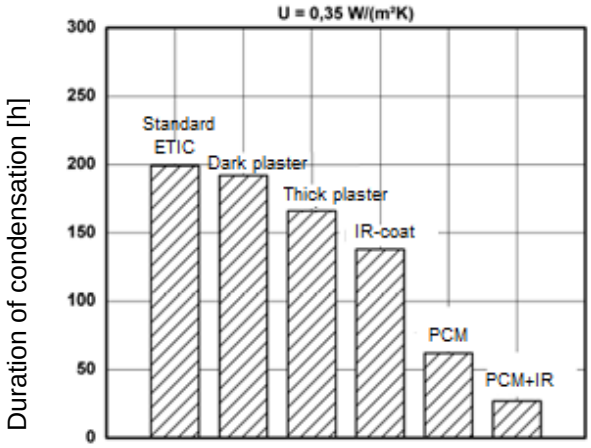


Figure 3.7: Duration of condensation for different types of coatings (Sedlbauer et al., 2011)

To prevent microbiological growth, additional agents may be used. The biocidal products are intended to reduce biological activity (De Muynck at al., 2009). Algicides and fungicides are applied to the façade, the place where microbiological growth is present. Algicides are used to inhibit algae, while fungicides resist the growth of fungi or mould. Biocides inflate the price of products and are harmful to the environment because water solubility is required for performance (Büchli & Roland, 2003). The durability of the biocides depends on the climate, material and construction properties. Biocides do offer a solution but for a limited period of time (Hofbauer et al., 2011). The focus is on refining the treatments to improve performance, considering the ecological risks (Büchli & Roland, 2003).

As mentioned earlier in the section on diagnosis methods, first of all there is an observation, then a diagnosis method is performed to obtain the best possible solution. Besides the treatment of the anomalies, the treatment of the cause must be taken into consideration. The repair alone cannot prevent that no new problems arise in the future (Flores-Colen et al., 2006). The removal of microbiological growth according to ASTM is as follows: first the surface is washed with a solution of water with 2% phosphate-free detergent. Washing means that the surface is scrubbed firmly. The product must remain on the surface for about 10 to 15 minutes. The second step is to rinse the surface with water in order to remove the detergent. The third step is to wash the surface with a solution of 1 part by volume of sodium hypochlorite 5 % aqueous solution and 3 parts by volume of water. The fourth step is to rinse the surface again with water and finally, if removal of the coating is necessary, to consult the manufacturer of the coating for the recommended drying time before applying a new coating (ASTM(b), 2017).

3.5 Conclusion of this chapter

With an ETICS, a building is extra insulated from the outside and the façade is therefore exposed to temperature fluctuations. The outer surface contains a low thermal mass, which will not be able to retain much solar radiation during the day. At night, the temperature will quickly drop below the dew point

temperature of the outside air and causes superficial condensation. This phenomenon leads to the growth of biological colonization. In Portugal, according to statistics made in 2014, microbiological growth is the most common anomaly. The first step was the visual observation of the surface in order to identify all the types of biological colonization. It is impossible to identify the types only due to a visual observation. In order to identify, register and classify the types, it may be necessary to use auxiliary methods, in-situ and laboratory tests (in this type of assessment, samples are collected on site) to clarify the origin, characteristics and level of development. Standard methods of ASTM can be used to determine the disfigurement of a façade and a distinction can be made between microbiological growth and dirt or soil with bleach. Further research is carried out using the Scanning Electron Microscope or SEM. The images can confirm the results of previous tests and may lead to additional information. Based on the identification, an appropriate repair method is searched for. According to a standard guide of ASTM, steps can be taken to remove microbiological growth. In the next chapter the methodology of investigation will be discussed. Step-by-step instructions will be given on how the investigation will proceed. During the field work, an inspection sheet is used, which ensures that all necessary information is collected, both about the anomalies and about the building itself. Finally, the way in which the samples are collected is considered.

4 Methodology of investigation

4.1 General considerations

The investigation will be carried out according to a proposed methodology, which is based on chapter 2 and 3. The objective of the proposed methodology will be explained in this chapter. The first part is the visual assessment, which was carried out on 56 façades in the centre of Lisbon (Bairro de Boavista). General information about the location and the buildings is clarified, including the use of the inspection sheet. The next part of the methodology is the diagnosis methods, divided into 5 steps. These methods are carried out on samples, which is why attention is paid to the collection of the samples.

4.2 Proposed methodology

The methodology will proceed according to a step-by-step plan, shown on Figure 4.1. It starts with the visual assessment (1), where the façades are inspected on the site. The anomalies are divided into three groups in chapter 2 and 3 and will help with recognition and identification. Limited accessibility and visibility of the façades may affect the outcome of the observations. Only with a visual assessment it is not possible to characterize and identify all anomalies, especially microbiological growth. The discolouration or disfigurement of façades is the result of microbiological growth. The stains often have a dark colour so that it is not easy to recognize specific types of biological colonization. The next steps of the methodology, the diagnosis methods (2), make it possible to distinguish and possibly identify types. The methods are in different levels, because each method will have a different objective and a more specific result. Further investigation will of course lead to more information. The first method is the magnifying glass (2.1), which can be used in-situ as well as in the lab. With this method a distinction will be made between the particles present in a stain or in a sample (collected during the visual assessment), by comparing the shape and colours. Next there are the digital microscope (2.2) and the bleach test (2.3). The objective of the digital microscope is also to make a distinction between particles based on shape and colours. The various magnification does lead to better results, with which a clear distinction can be made for the first time between different types of biological colonization. The bleach will determine whether the types belong to microbiological growth of dirt. A drop of 5% of aqueous sodium hypochlorite solution is applied to a sample and if it is algae or fungi growth, discolouration will occur within 60s (ASTM(b), 2017). Another level lower is the test with the Scanning Electron Microscope (SEM). This can be used to distinguish different types of biological colonization, due to the high magnification power, high resolution and sharpness. On the images, the shape, size, (chemical)

composition and distribution of particles can be observed. Each biological colonization has its own structure and the SEM makes it possible to distinguish them (Piontek et al., 2016). The last step is DNA-investigation, it was discussed in the previous chapter, but does not belong to the scope of the thesis. It is certainly mentioned because with this test there can be certain identification of a type of biological colonization and is under the research project WGB. The step-by-step implementation of the methodology will lead to distinction, identification and characterization of biological colonization. So the innovation of this proposal is, that there are easy steps to assess microbiological colonization on ETICS façades. Starting with a simple step and then going into more and more detail. However, detailed techniques are needed.

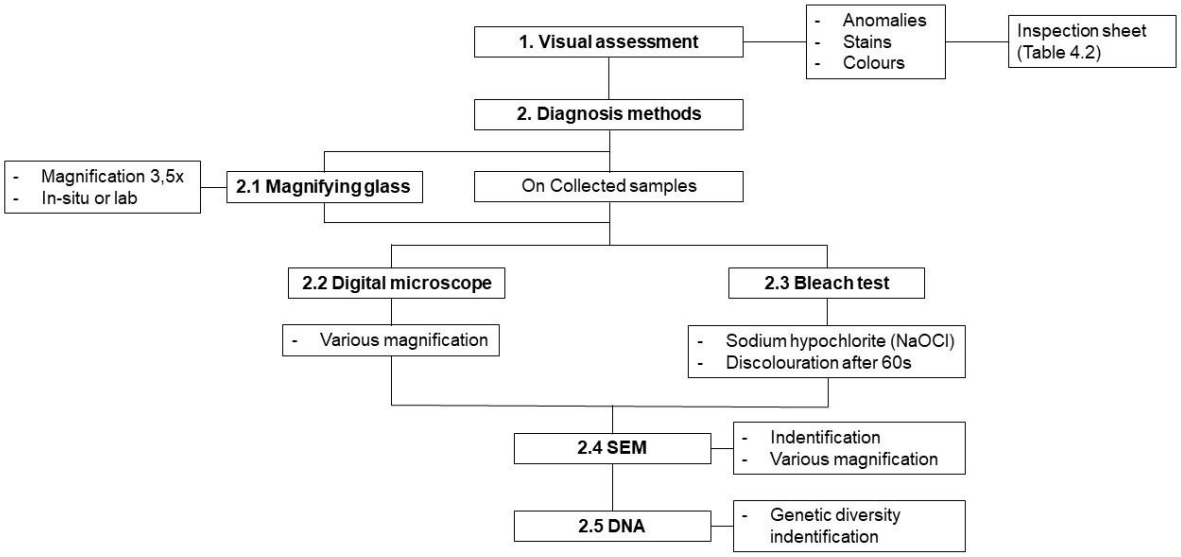


Figure 4.1: The proposed methodology

The visual assessment and the diagnosis methods were conducted during the last 2 months on social housing projects owned by Gebalis in Boavista (center of Lisbon). The aim of this company is to promote and manage common housing, including a policy of quality of life, neighbourhood management and heritage conservation. A first step was to understand everything about the ETICS and with this knowledge to start the practical implementation of the methodology. The practical part is the visual assessment and the diagnosis methods. The location of the Boavista district is indicated on the ground plan with the red dot (Figure 4.2). The district is located in an urban area and is ± 300m from the Monsanto forest. The first visual observation was spent with Prof. Inês Flores-Colen, Prof. Cristina Viegas (Institute for Bioengineering and Biosciences), the manager of Gebalis, Eng. Luis Brás and a co-student. The manager started with a general explanation of the entire district and gave us the necessary information. The district is divided into three different areas that consist of a number of buildings. The first area is shown in Figure 4.3 with the red box, the second area is shown with a blue box and lastly area 3 is shown with the yellow boxes. Figure 4.3 also shows directions that will be important during the

discussion of the results. The materials used in the ETICS are the same for the area 1 and 2, and the construction were carried out by the same contractor but by a different subcontractor. Buildings in area 3 only have an ETICS on the side-façades and are built with different materials. Table 4.1 shows a short overview with the Lot numbers investigated, the year of construction, the year of the last intervention (application of ETICS) and the constructive solution of the ETICS with the substrate. Figure 4.4 gives a plan view of the district with the indication of the Lot numbers and the area's, to understand Table 4.1 better.

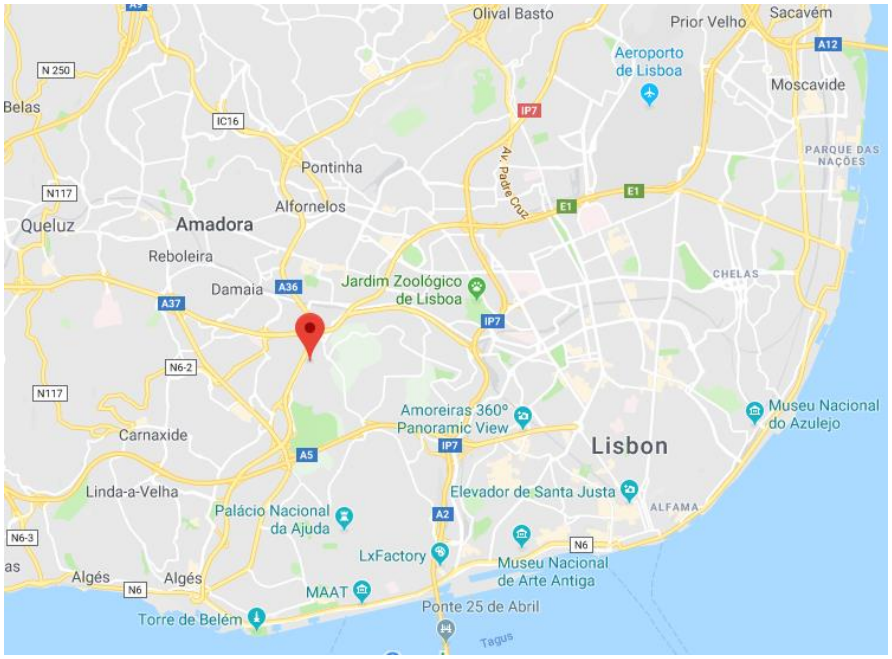


Figure 4.2 Location of Bairro de Boavista [W4]

Figure 4.3: Indication of the area's and directions. Area 1 is red; Area 2 is blue, and Area 3 is yellow [W5]

Table 4.1 Information of the three area's

Boavista	Area 1 (red box)	Area 2 (blue box)	Area 3 (yellow boxes)
Lot No.	11-18	19-26	63-76
Date of construction	1990	1990	1998
Last intervention (application of ETICS)	January 2014	January 2014	2015
Constructive solution ETICS + support	- Brick cavity wall (2 leaves of brick with an air cavity between) - ICB (cork) insulation 40 mm - Silicate paint with a mixed lime and resin coating layer		- Brick cavity wall - ICB 40 mm - Mortar cement-based with resin + Acrylic paint + pigment

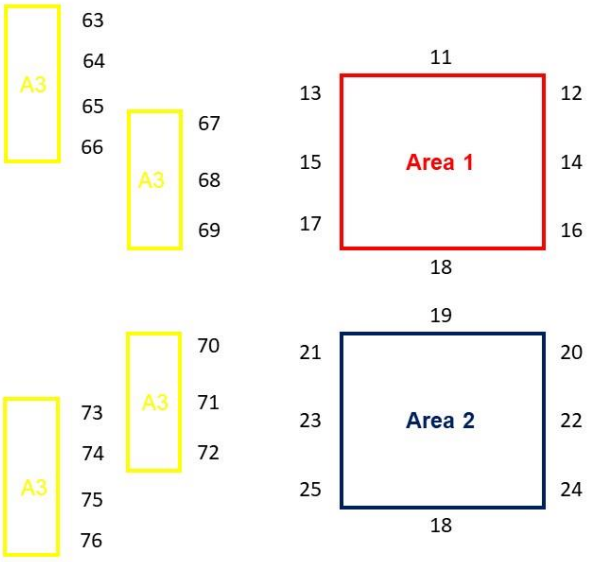


Figure 4.4: Plan view of the district with the Lot numbers and area's

4.3 Visual assessment

During the inspections, information about certain factors will be stored and filled in on the sheet. Table 4.2 is an example of a completed sheet to better visualize and understand it. First of all, there is the general information about the appointment and summary of all investigated façades, the address, the weather conditions during the inspections. The general information is followed by information about the buildings, such as the location, the construction technology, the year of last intervention, the age of the building, type of use, the distance from the sea and No. of floors above ground. The construction technology will have a strong influence during the results discussion, by building up materials with different properties, other anomalies can be obtained. The year of the last intervention gives more clarity about the performance and durability of the ETICS. The durability also depends on the distance to the sea: buildings more than 5 km from the sea are generally more durable than those less than 5 km away. Buildings close to the sea are exposed to strong winds that contain moisture and soluble salts. These soluble salts are weathering agents and chemical weathering occurs as a result of the exposure of the salts. This can lead to a shortening of the durability and degradation of the façade (Silva et al., 2015). Information about the façades are: the orientation, exposure to pollution, the type of façade and the type of surroundings. The orientation will also be a determining factor during the discussion of the results, because it will largely determine the amount of moisture present in the system, the exposure to pollutants, wind and rain. Façades facing north are more likely to have biological colonization, because they are more in the shade and thus become wetter and colder. Because of the lesser amount of shade,

the façades will dry out less quickly than façades facing south. But the façades to the south may be more susceptible to material damage and other stains due to the high exposure to solar radiation. The air contains an amount of pollutants due to heavy traffic on highways or other human activities. These pollutants can be deposited on façades either by the wind or by the rain and form stains (Freitas & Barreira, 2014) (Silva et al., 2015).

Table 4.2 contains 19 different anomalies divided into 3 groups in which a distinction is made between the shape of the anomalies. The first group is the material failure: cracks, blistering, detachment of the finishing coat, material gap, peeling and visible joints. The deterioration in the colour of the façade is grouped in two different group of stains. Group B contains differential stains, uniform stains, oxidation stains, efflorescence, carbonation, white dots and graffiti. Group C contains all types of microbiological growth: green algae, red algae, fungi, mosses, lichen, biocorrosion and parasitic vegetation. For each type of anomaly, the locations on the façades and the % affected area are determined during the observation or afterwards. This information can be useful if statistical comparisons are made. For example, façades in a certain orientation can contain a large amount of a certain type of stains, at a common location. The different possible locations are: Continuous wall (CW), Near ground (NG), Windows and opening (WO), Cornice or roof hangings (CR), Balconies (BA), Corner and edges (CE). The % of affected area is determined using scale patterns, where the façades are compared with the patterns to obtain a percentage (Flores-Colen(a), 2009). For each type of anomaly, a reference is made to the appropriate figure with the scale patterns (Figure 4.5-4.7)

Table 4.2: Example of a completed inspection sheet

No of Façade: Area 1 Lot No. 11 + 18			Date: 19/04/2019
Location: Rua Rainha Dona Catarina			
Air condition of the day: Dry/sun, Wind: 14 km/h			
Temperature (°C):	< 5 ☐	Beteen 5 and 15 ☒	>15 ☐
Humidity: 55%	Low☐	Medium ☒	High ☐

Table 4.2: Example of a completed inspection sheet (continued)

<table>
<tr><td colspan="6">Last intervention (application of ETICS): 2014 (January)</td></tr>
<tr><td>Age of building: 1990</td><td colspan="5">Technology of ETICS + Support</td></tr>
<tr><td>Orientation Façade:
NE (northeast)</td><td colspan="5" rowspan="4">- Brick cavity wall
- ICB (cork) insulation 40mm
- Lime-based coating + silicate paint

NOTE: Here are 4 samples collected
- Sample 1 (northeast)
- Sample 2 (northwest
- Sample 3 (northeast)
- Sample 4 (northeast)</td></tr>
<tr><td>Type of use: Housing</td></tr>
<tr><td>Distance from the sea: < 5km</td></tr>
<tr><td>No. Of floors above ground: 6</td></tr>
<tr><td>Exposure to pollution:</td><td>Nil ☐</td><td colspan="2">Low ☐</td><td>Medium ☒</td><td>High ☐</td></tr>
<tr><td>Type of Façade:</td><td>Front ☒No. 11</td><td colspan="2">Side ☐</td><td colspan="2">Back ☒No. 18</td></tr>
<tr><td>Type of surroundings:</td><td>Rural ☐</td><td>Urban ☒Near Monsanto</td><td colspan="2">Costal ☐</td><td>Other ☐</td></tr>
<tr><td colspan="6">Types of anomalies</td></tr>
<tr><td colspan="6">Location of anomaly: Continuous wall (CW), Near ground (NG), Windows and openings (WO), Cornice or roof hangings (CR), Balconies (BA), Corner and edges (CE)</td></tr>
<tr><td>Aesthetic impact on the façade:</td><td>Low ☐</td><td colspan="2">Medium ☐</td><td colspan="2">High ☒</td></tr>
<tr><td>Severity Level</td><td>0 ☐</td><td colspan="2">1 ☐</td><td colspan="2">2☒</td></tr>
<tr><td rowspan="10">Material failure (A)</td><td colspan="2">Type</td><td>% affected</td><td colspan="2">Location</td></tr>
<tr><td>Cracks</td><td>☐</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="5">Horizontal ☐, vertical ☐, diagonal ☐, mapped ☐</td></tr>
<tr><td>Blistering</td><td>☐</td><td></td><td colspan="2"></td></tr>
<tr><td>Detachment of the finishing coat</td><td>☐</td><td></td><td colspan="2"></td></tr>
<tr><td>Material gap</td><td>☐</td><td></td><td colspan="2"></td></tr>
<tr><td>Peeling</td><td>☒</td><td>1 to 5</td><td colspan="2">CW, CE</td></tr>
<tr><td>Other(s)</td><td>☐</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="5">Name of other(s):</td></tr>
</table>

Table 4.2: Example of a completed inspection sheet (continued)

Depth	Insulation ☐	Reinforcement ☐		Substrate ☐
Coats affected	Finishing coat ☐	Key coat ☐		Reinforcement ☐
Stains (B)	Type		% affected	Location
	Differential stains	☒	5 to 25	CW, WO and CE
	Uniform stains	☒		
	Oxidation stains	☐		
	Efflorescence	☐		
	Carbonation	☐		
	White dots	☐		
	Graffiti	☐		
	Visible joints	☐		
	Other(s)	☐		
	Name of other(s):			
Microbiological growth (C)	Microbiological growth			
	Colours		Yellow, black, grey	
	Location		CW, WO and CE	
	Area affected (%)		5 to 25	
	Stains		Uniform ☒	Differential ☒
	Green algae			☐
	Red algae			☐
	Fungi			☐
	Mosses			☐
	Lichen			☒
	Biocorrosion			☐
	Other(s)			☐

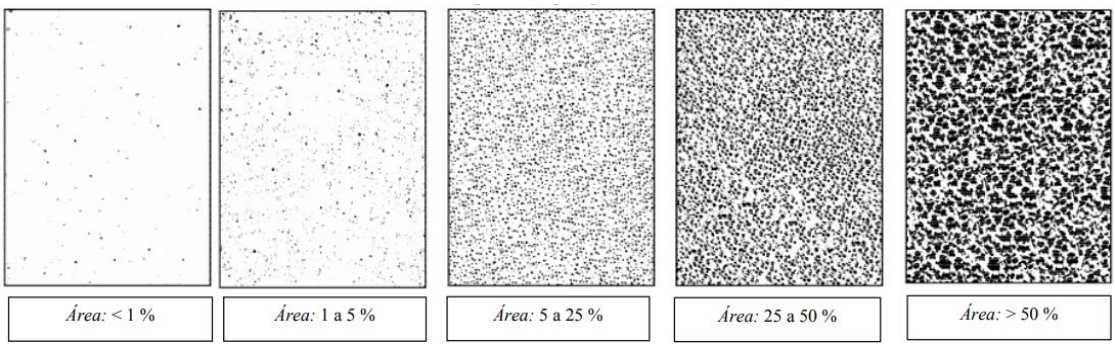


Figure 4.5: Soiling (uniform and differential stains) (Flores-Colen(a), 2009)

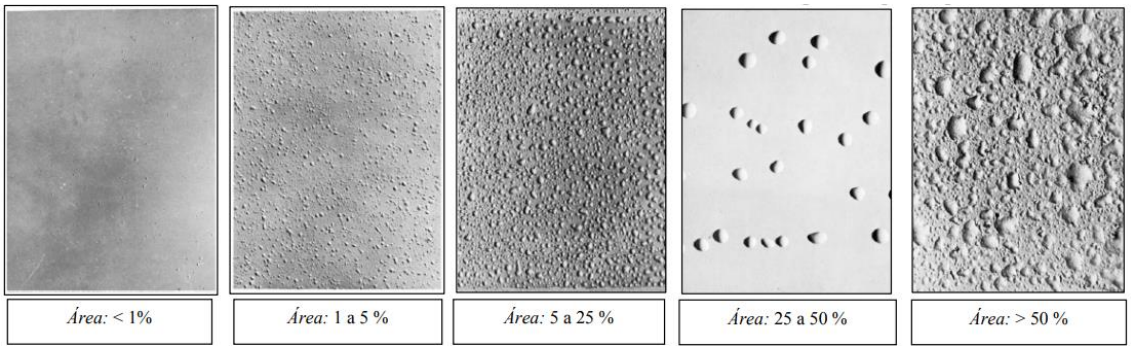


Figure 4.6: Blistering (Flores-Colen(a), 2009)

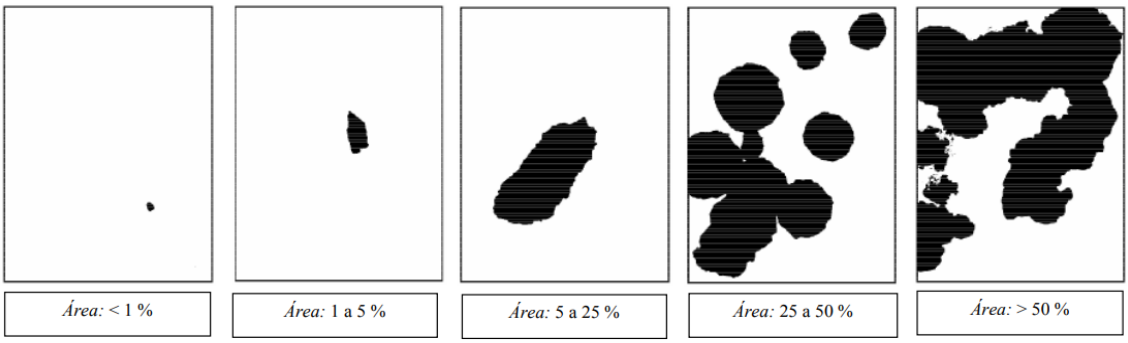


Figure 4.7: Occasionally spread defects in the coating (Detachment of finishing coat, material gap, peeling, visible joints, differential stains, uniform stains, oxidation stains, efflorescence and carbonation) (Flores-Colen(a), 2009)

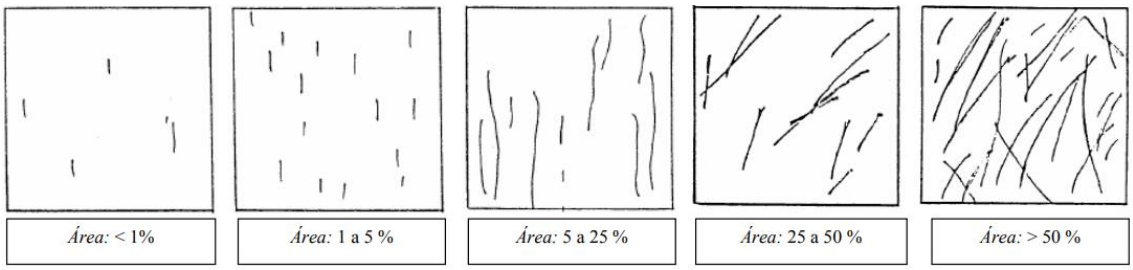


Figure 4.8: Cracks (Flores-Colen(a), 2009)

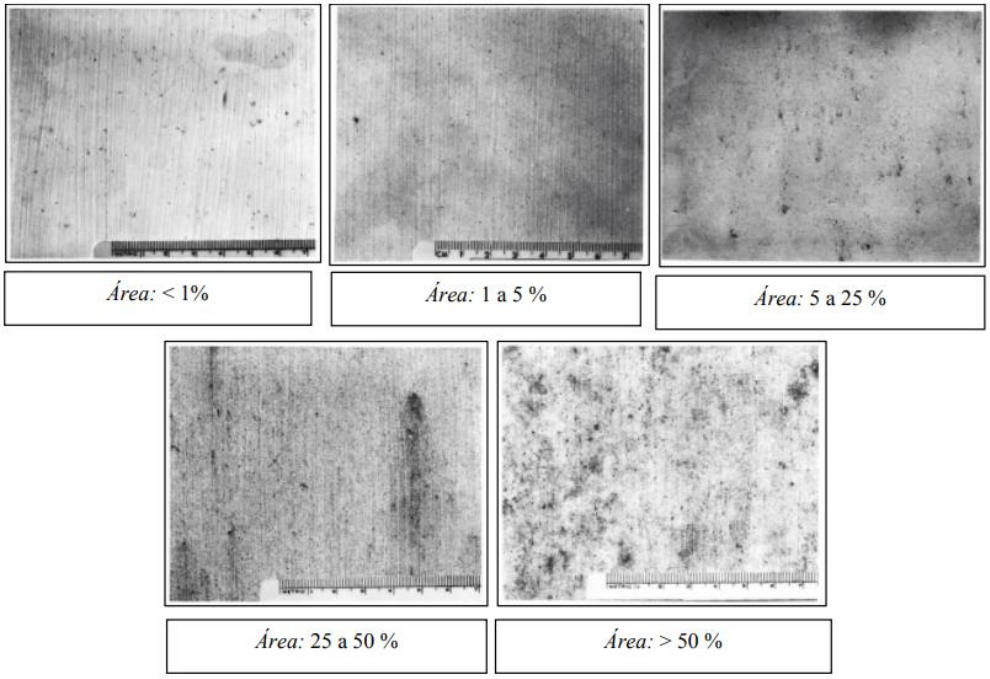


Figure 4.9: Microbiological growth (Flores-Colen(a), 2009)

4.4 Collecting samples

The diagnosis methods are performed on samples and these were collected on the roof under the guidance of Eng. Luis Brás. The required materials are sterile tweezers and a box or bag in which the sample could be stored. There are two possible options for the tweezers, either make the tweezers sterile with alcohol each time and wait until it is dry again or take sterile tweezers with you from the lab. The samples are collected by scraping on a stain, present on a façade (Figure 4.10). In this study, 6 samples were collected, of which 3 were investigated and the other 3 are used for other tests but is out of the scope of this thesis. Sample 2 (Figure 4.11) was taken at the front of Lot No. 11 (Area 1, northeast), Sample 3 (Figure 4.12) was taken at the side of Lot No. 11 (Area 1, northwest) and Sample 6 (Figure 4.13) was taken at the side of Lot No. 67 (Area 3, northeast). For each sample the orientation, the material of finishing coat or deeper layers is mentioned, because it can be interesting during the discussion of the results. The orientation determines the exposure to solar radiation, wind, rain and pollutants. The materials like the key and finishing coating have properties that influence growth and the type of biological colonization. Between the visual assessment and the diagnosis methods, the samples were stored in the refrigerator. So that the micro-organisms are no longer active and that no further development would take place. Step by step, according to the proposed methodology (Figure 4.1), diagnosis methods will be performed on the samples. The objectives of the different methods are mentioned in 4.2.

Figure 4.10: Collecting the samples by scraping on the stains with a tweezer

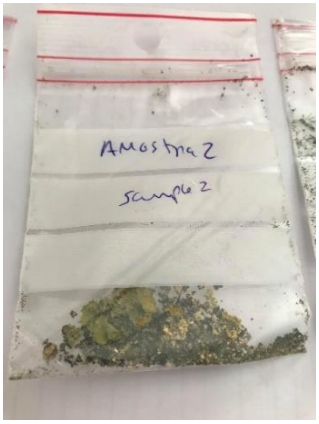


Figure 4.11: Sample 2 (area 1) northwest, front of Lot No. 11

Figure 4.12: Sample 3 (area 1) northeast, side of Lot No. 11

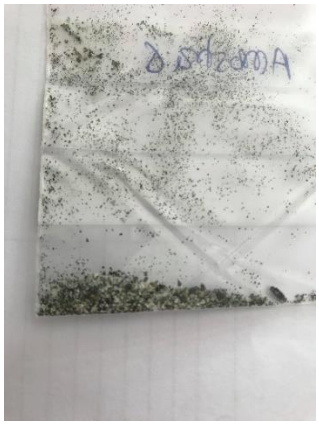


Figure 4.13: Sample 6 (area 3) northeast, side of Lot No. 67

4.5 Conclusion of this chapter

In this chapter, the methodology of the investigation was discussed. To begin with, there was the visual assessment that will be carried out on 56 façades or 22 000 m² of ETICS in Lisbon. The observations will be carried out using an inspection sheet, where all the anomalies (divided in three groups) are identified. Next, the diagnosis methods were explained, starting with the magnifying glass, in which particles are distinguished by the shape and colours of particles. The following methods are digital microscope that will also distinguish particles by shape and colour, but this device has a various magnification. The bleach test will show whether the particles are microbiological growth or dirt. Finally, the particles will be distinguished by analysing structures, with the scanning electron microscope. It was

also made clear that collecting samples is not always an easy task because of the inaccessibility of the façades. The next chapter contains the results of the application of the methodology. Each step of the methodology is discussed in order to make a conclusion.

5 Case study

5.1 General aspects

This chapter will discuss the application of the proposed methodology to a case study. First, there will be the results of the visual assessment, where current anomalies, colours and types of stains will be identified. The completed sheets will be clarified by means of figures and statistics, with some figures being shown to represent it visually. The following results are those of the diagnosis methods performed on the samples. The first method is with the magnifying glass, the second one is with the digital microscope, the third one is the bleach test and the fourth one is the scanning electron microscope. The results and analysis will make it possible to explain whether the various techniques are useful.

5.2 Results of the visual assessment

5.2.1 Anomalies

Via the visual assessment, all the current anomalies on site were identified and updated with the help of the inspection sheet. The observations were carried out at about 15 meters from the façades. In this part, the results of all collected sheets are displayed, in which a list is made of the different types. Table 5.1 shows the results of the anomalies that are identified on 56 façades or ± 22 000 m² and contains the frequency of each type. In Area 1 and 2: northwest contains 6550 m², northeast contains 3275 m², southeast contains 6650 m² and southwest contains 6650 m². In Area 3, northeast and southwest contain each 587,5 m². All the results and calculations are presented in Table A.1-1 to A.1-3. The microbiological growth is in a clear majority, with 100% façades affected with this anomaly. The other anomalies are peeling (25%), white stains (14,58%), oxidation stains (5,36%) and cracks (4,17%). The fact that microbiological growth is generally the biggest problem for ETICS, is confirmed by the results of this case study. Peeling of the finishing coating (Figure 5.1) is mainly present on the free surface and sometimes at corners and edges. The reason of peeling is due to an incorrect application method, or natural ageing. Natural ageing can also be a cause, but the façades were hard to reach. The white stains were mostly found on the façades facing south. Because of the wind, soluble salts together can cause moisture to settle on the surface. In combination with the solar radiation, the crystallization of the salts will cause whitish stains (Figure 5.2) to form. The orientation will therefore have some influence on the formation of the white stains. The oxidation stains (Figure 5.3) were only visible on the façades with an acrylic paint as finishing coating. The orientation certainly also affects this type of stains, because of

the atmospheric pollutions of other particles in the air. The stains are located on the free surface and were really small. Mechanical anchors that hold the insulation panels may be a reason for the oxidation stains. The size of the anchors is small and so are the stains, hence this estimation. The cracks (Figure 5.4) were only observed on façades facing southwest, both on the free surface and on the windowsills. There were several types of cracks, such as horizontal, vertical and mapped. The crack width, measured by a crack width gauge (Figure 5.5), are <0,5 mm. Due to the inaccessibility of the façades, the measurements could not be accurate enough. There is a difference between graffiti like art and grafitti like bombing. Figure 5.6 shows that it is indeed art, so it is not an anomaly.

Table 5.1: The identified anomalies on 56 façades

Anomalies	**Frequency of the anomalies on 56 façades**	
	In %	In No. of façades
Microbiological growth	100,00	56
Peeling	25,00	14
White stains	14,58	7
Oxidation stains	5,36	3
Cracks	4,17	2

Figure 5.1: Peeling on the back of Lot No. 18

Figure 5.2: White stains (near the window) on the back of Lot No. 1

Figure 5.3: Oxidation stain on the right of the window

Figure 5.4: Vertical crack on the back of Lot No. 11

Figure 5.5: Crack width gauge

Figure 5.6: Graffiti as art and not bombing

5.2.2 Biological colonization

Biological colonization leads to the creation of stains and is the result of the hygrothermal behaviour, the construction details and the not careful execution of the works. It is difficult to distinguish the types of biological colonization and dirt by observations alone. Due to insufficient experience and knowledge and because the façades are not always easy to reach, identification is more difficult. An attempt can be made to distinguish the types of stains. In the literature review (chapter 2, Table 2.3) the differential and uniform stains were placed in the group of stains. In the beginning it was assumed that it was dirt, but because of the visual inspections, it was assumed that the stains are mainly biological colonization. Without the visual assessment, it is difficult to pass judgement on this and to place it in a group with certainty. So the two major problems are the uniform and differential stains, whereby the uniform stains are the result of superficial condensation and the differential stains are the result of poor construction

details or deficient materials. Figure 5.7 is a good example to distinguish the types of stains, to start with the differential stains (red circles), at the location of the windowsills and at the height of the roof covering. The cause of this type is mainly the rain that accumulates due to poor construction details. The typical elongated stains caused by the rain, the rainwater that runs down the façades and forms an elongated pattern. The free surface also turns dark in many places, such as above the window, where there are clearly black stains (blue circles). The uniform stains at different locations can be different types of biological colonization.

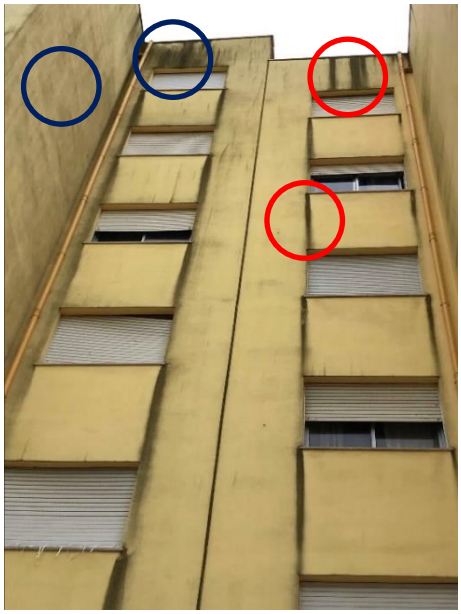


Figure 5.7: Façade (back of Lot No. 24) that is affected by different types of stains

Table 4.1 already mentioned that the buildings in area 1 and 2 contain a different constructive solution than the buildings in area 3. In 5.2.1 it soon became clear that microbiological growth is present in large quantities compared to other anomalies. There is no point in compiling statistics on how many façades have been affected. More interestingly, a graph should be drawn up showing a distribution by what percentage the façades have been affected by colonization. By means of the visual assessment, a percentage was determined using a scale pattern (**Error! Reference source not found.**). It is not easy t o compare it with the scale patterns, but an attempt can be made to distinguish between the different percentages. The calculation results are presented in Table A.1-4 and A.1-5. Figure 5.8 (left) shows the result of the buildings in area 1 and 2. Only 4,17% has between 1 and 5%, while 12,50% has more than 50% and the majority is between 5 and 25%. Based on these figures, it can be concluded that these façades are in a very bad state of conservation. The recurring types of stains show that the buildings have similar problems. On the right of Figure 5.8, the results of the buildings are shown in area 3. If both circular diagrams are compared with each other, a very large difference can be observed. 75% of the façades contain between 1 and 5% biological colonization, the remaining 25% is below 1%. There are no façades in area 3 that are affected with >5%.

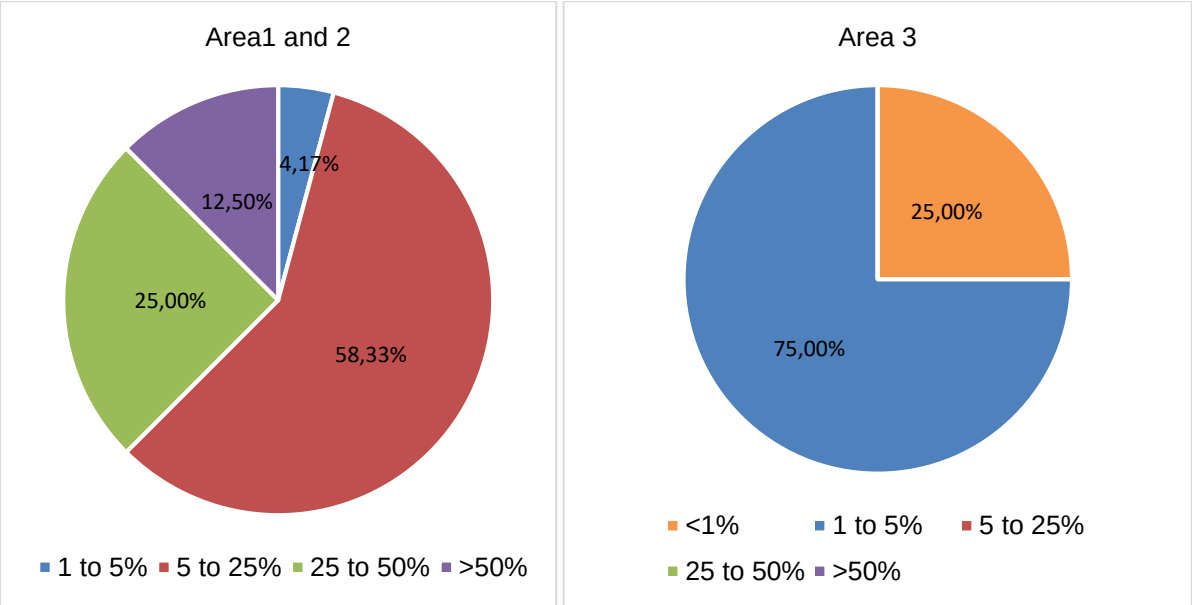


Figure 5.8: The percentage of affected area by biological colonization on façades

5.2.2.1 Influence of the finishing coating

A first cause that will influence the amount of biological colonization is the finishing coating. Table 4.1 shows that area 1 and 2 of the façades contains silicate paint and that area 3 acrylic paint as a finishing coat. The paint can have both a decorative and a protective function. The protective function of the paint is to prevent the development of microbiological growth, it contains a certain microroughness which makes it easier for water to flow over the surface. Together with Giovanni Borsoi we tried to discuss the influence of the finishing coating. It is difficult to distinguish which type is better, in terms of prevention of microbiological growth. The façades with silicate paint are much more severely affected than those with acrylic paint, the results on Figure 5.8 speak for itself. Silicate will be more negatively affected if there is a lot of moisture or heavy rainfall. This causes water stains on the coating as a result of the water absorption capacity. According to chapter 3, the growth of biological colonization is influenced by the amount of moisture present on the cladding surface. On the other hand, silicate has a high-water vapour permeability, which leads to a better breathability of the surface and a drier surface. The buildings were built about 30 years ago, the better breathability can be positive for an old masonry. Acrylic has almost no water absorption, so no formation of water stains on the façade, but has a low water vapour permeability. From the results it seems that the highwater absorption has the upper hand compared to the high permeability. The silicate paint contains a yellow colour (pigment) as shown on Figure 5.9. Usually, organic pigments are chosen over the inorganic ones because it is cheaper. The result is a less durable coating, which can promote biological colonization if there is an abundance of water. On the same figure it is also noticeable that the coating contains irregularities. To show the difference, Figure 5.10 contains a façade with an acrylic paint. Acrylic has a better adhesion than silicate, and this may explain why there was a certain detachment from the silicate. This detachment is partly caused by biological colonization. The question can also be asked whether the choice to combine the silicate paint

with the lime-resin coating was a good idea. It can also relate to the PVC (pigment volume concentration), if there is too much pigment and too little binder, then a critical pigment volume concentration can be achieved. This leads to blistering and, at a later stage, to biological colonization. One of the conclusions may also be that the quality of the silicate paint is deficient. In order to demonstrate a clear difference in quality, more research is required.

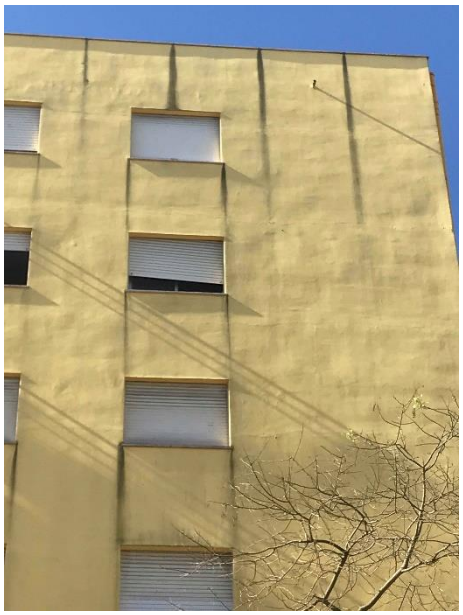


Figure 5.9: Lack of flatness of the surface (Front of Lot No. 19)

Figure 5.10: Side of Lot No 65, acrylic paint

5.2.2.2 Influence of the orientation

Another factor that influences the growth of biological colonization is the orientation. In Portugal, the drying process of the system will be faster in the south, as mentioned in 3.1.2, due to exposure to solar radiation. On an annual basis, the most dominant wind directions in Lisbon are north and northwest, followed by northeast (Figure 5.11). The wind directions will certainly have an impact on the façades, as both wind and rain carry pollutions. Because of the rain, the façades will also be much moister and will need more time for the drying process. The pollutions will settle on the façade surface and form stains. The results below will show by means of diagrams whether the effect of the orientation does indeed have an influence. Again, the results of the façades in area 1 and 2 will first be discussed and compared with the façades in area 3. Figure 5.12 shows the results of the 24 façades facing northwest and northeast. None of them are affected by less than 5% and the majority contain 25 to 50% of stains. Compared to the diagrams on Figure 5.13, the theory of orientation and wind direction can be applied. Most of the façades have an affected area of 5 to 25%, which is already better than the 25 to 50% of the previous diagrams. A minor contradiction is that in southeast 6,25% is more than 50% affected, mainly due to uniform stains. Based on the diagrams it can be concluded that the results are influenced by the orientation and the most dominant wind directions. Because the façades in the north are subject

to wind and rain and are less exposed to solar radiation, the results will be worse. In general, the stains are less present on the façades in southwest and southeast.

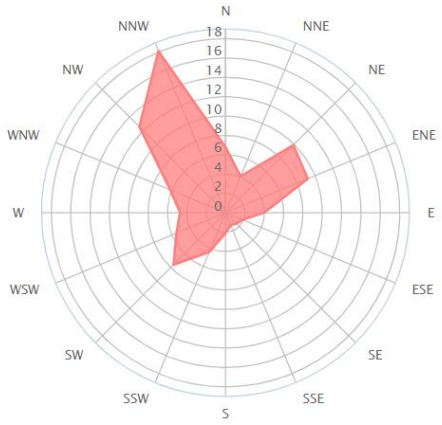


Figure 5.11: Wind direction distribution in Lisbon [W6]

A longer exposure to solar radiation will lead to a faster drying process, which will strongly reduce the uniform stains in particular. Figure 5.14 and 5.15 are pictures with a different orientation, to show the difference. The main difference is mainly in the visibility/presence of the uniform stains. Figure 5.14 contains no uniform stains under the windows and next to the windows, but it is difficult to explain the cause of this.

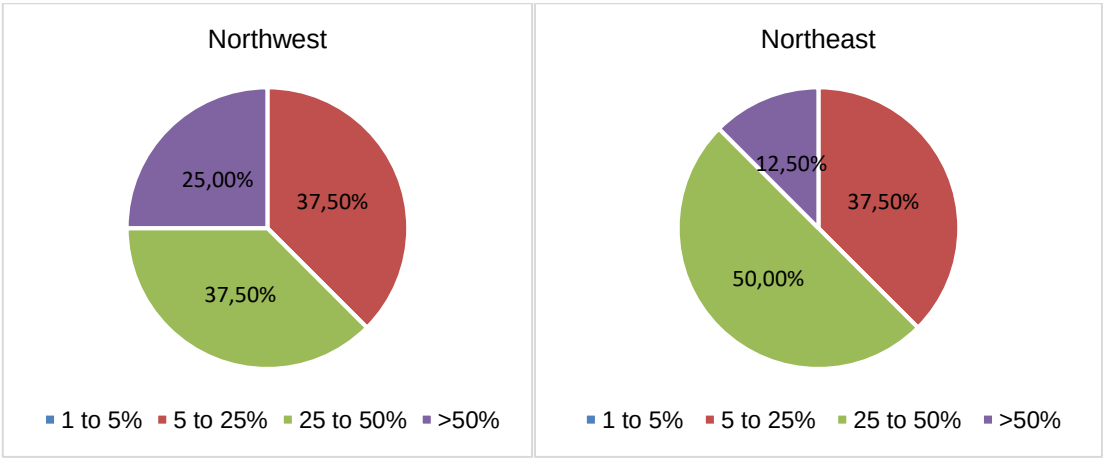


Figure 5.12: The percentage of affected area on façades oriented to northwest and northeast in area 1 and 2

The diagrams with the results of area 3 are shown on Figure 5.16. The buildings in area 3 only have an ETIC system on the side-façades (in northeast and southwest). On both sides, 75% of the façades are affected by stains with 1 to 5% and the remaining 25% is below 1%. Both orientations contain the same result, which makes it difficult to explain the influence here. Compared to Figure 5.10, the deterioration on Figure 5.14 is less noticeable. The difference will mainly be explained by materials used in the ETICS, as mentioned in 5.2.2.1. Silicate is more negatively affected if there is a lot of moisture or heavy rainfall. This causes water stains on the coating as a result of the water absorption capacity, but there's also a

chance that the quality of the paint was not sufficient. There are different types of silicate paints, with different characteristics. It can also be the choice to combine the silicate paint with the lime-resin coating.

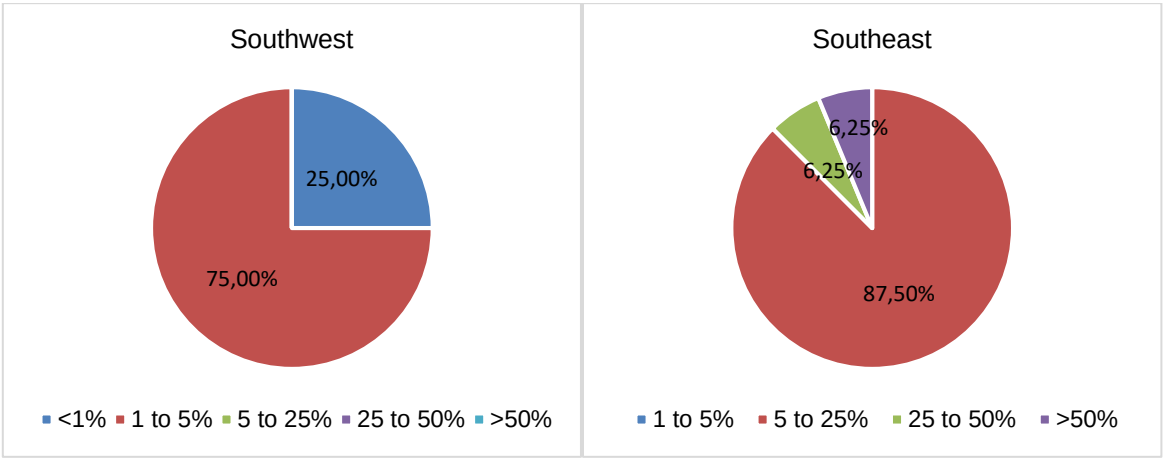


Figure 5.13: The percentage of affected area on façades oriented southwest and southeast in area 1 and 2

Figure 5.14: Front of Lot No. 21, northwest

Figure 5.15: back of Lot No. 23, southeast

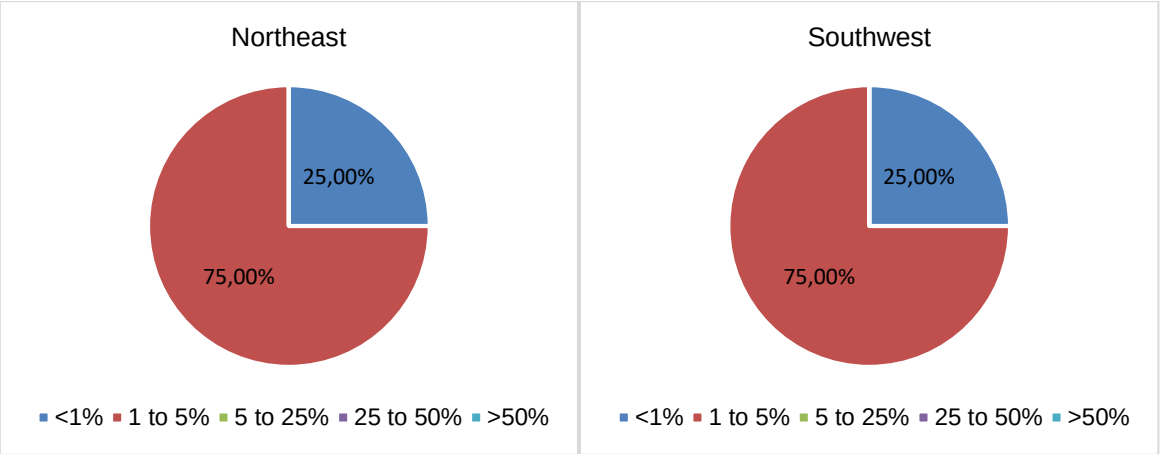


Figure 5.16: The percentage of affected area on façades oriented northeast and southwest in area 3

5.3 Results of the diagnosis methods

According to the proposed methodology, the results of the different steps (2.1 until 2.5 on Figure 4.1) will be discussed. It was not possible to get closer to the stains from the street, but it was possible to see them from the roof. Figure 5.17 shows a differential stain at the location of the roofing and is the result of poorly executed construction details or choice of material. The movement of rainwater on the façade will lead to deposits of stains at different locations. From below, the stains only appeared to have a dark colour, but from up close, several colours can be observed immediately. Sample 2 and 3 both have a yellow, grey, brown and black colour, where the yellow colour indicates lichen. The other parts can be dirt or other types of biological colonization. Figure 5.18 is taken on the roof of Lot No. 67 and also here differential stains are present. In comparison with the previous figure, the stain looks different. It no longer contains lichen, the possible options according to Table 3.1 are either algae, or fungi. As mentioned in 5.2.2.1, the type of biological colonization, the difference in colour or the amount of the stains can be different due to the finishing coating or even the underlying layer. Because the façade of area 3 does not have any similarities with the characteristics of lichen, it is possible that the coating (acrylic) is not an ideal substrate for this type.

Figure 5.17: Biological colonization on the front of Lot No. 11

Figure 5.18: Biological colonization on the side of Lot No. 67

5.3.1 Magnifying glass

The first diagnosis method is the test with the magnifying glass, this glass has a magnification of 3.5x. As mentioned on Figure 4.1, is it possible to do the test in-situ or in the lab. Figure 5.19 and 5.20 are results of sample 2 and 6 carried out in the lab. Due to the poor quality of the pictures, not all results will be shown and discussed. These kind of method is limited because of the fixed magnification, but an attempt could be made to distinguish the shape and colour of the particles. In sample 2, yellow, grey and black colours can be observed and are larger in shape. Sample 6 contains black, white and green colours, but the particles are very small. With this test different types of biological colonization can be distinguished based on the shape and colour, but certainly not all particles in the samples. The different types can be due to the material of the finishing coating and possibly the underlying layer or the orientation, as discussed in 5.2.2.1 and 5.2.2.2

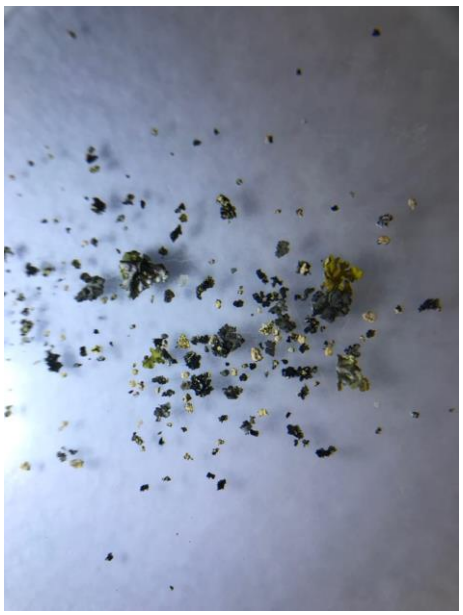


Figure 5.19: Result magnifying glass sample 2

Figure 5.20: Result magnifying glass sample 6

5.3.2 Dino-Lite Digital microscope and Bleach test

The second and third method are the test with the digital microscope and the bleach test. The identification of the types of stains continues in this section, in which the results of the digital microscope are explained. By means of a rotary knob (red frame on Figure 5.21) on the microscope, the magnification can be adjusted, with the rotary knob on the holder (blue frame) the scaling can be adjusted. Other materials used in this test are tweezers, alcohol and petri dishes. The tweezers must always be made sterile with pure alcohol beforehand so that no parts of the samples come into contact with them. Three collected samples were examined using the digital microscope: sample 2 (northeast, area 1 Lot No. 11), sample 3 (northwest, area 1 Lot No. 11) and sample 6 (northeast, Area 3 Lot No. 3). After the three samples were examined using the digital microscope, the bleach test was carried out at the same time. With the bleach test the dirt can be easily distinguished from the microbiological growth, according to ASTM. Only a part of the sample is used, because it can no longer be useful for further investigation. After the application of a drop of bleach, the sample will discolour after 60s or not (ASTM(b), 2017). If it discolours, it is microbiological growth. The results of both tests will be compared to see the difference in colour.

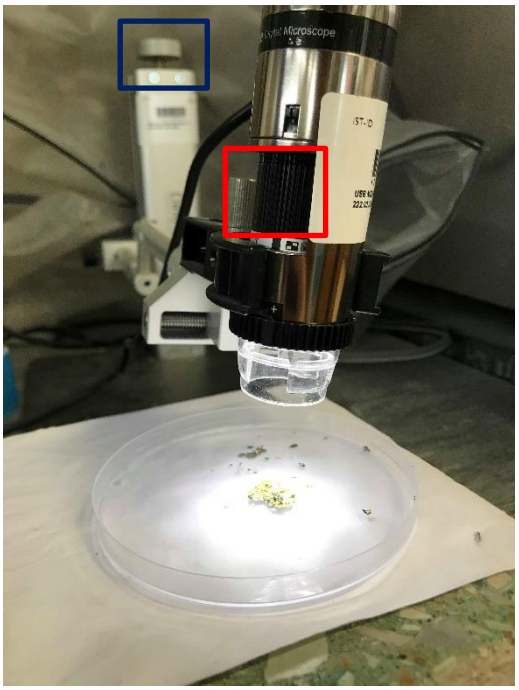


Figure 5.21: Digital microscope

5.3.2.1 Results of Sample 2 (area 1)

Figure 5.22 shows the result of the digital microscope (magnification 13x) and Figure 5.22 is the result after adding a drop of bleach (magnification 13x). The only type of biological colonization recognized during the visual assessment was lichen because of its yellow colour and shape. The extra magnification due the digital microscope allows colours and the shape of the particles to be better distinguished. At first sight there are four different types present. The number 1 indicates lichen, the numbers 2 to 5 can be algae, fungi or dirt. Of the types 1, 3, 4 and 5 can already be said with certainty that it is not dirt but microbiological growth. Type 2 has a light brown colour and dirt particles range from light brown to black. The results of the bleach test will further show if this determination is correct. Compared to the particles in Figure 5.23, all the types including type 2 have changed colour. A short overview of the colour changes is given below:

Type 1 (Lichen): Yellow → red/green
Type 2: Light brown → green
Type 3: Black/yellow → green at the edges
Type 4: Brown/grey → brown/green
Type 5: Yellow → green/red at the edges

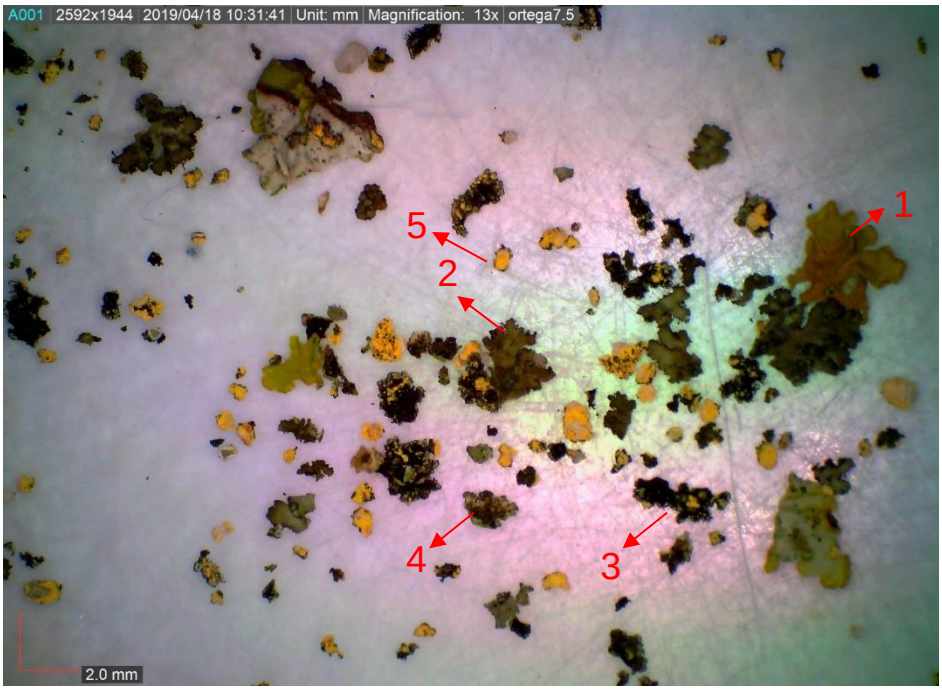


Figure 5.22a: Result of sample 2 without bleach, magnification 13x

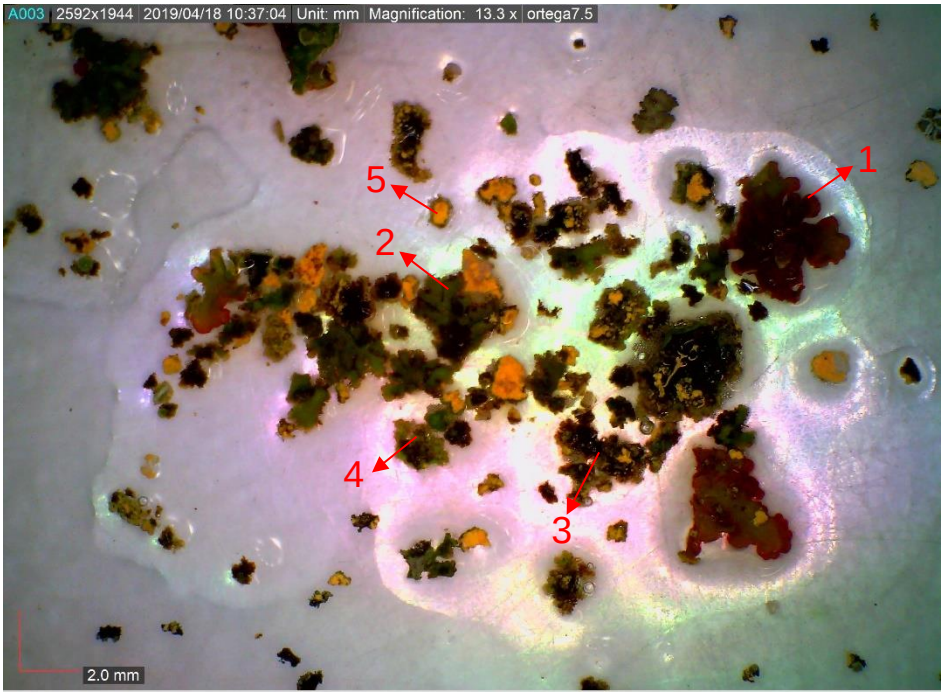


Figure 5.23b: Result of sample 2 with bleach, magnification 13x

5.3.2.2 Results of sample 3 (area 1)

Figure 5.24 shows the result of the digital microscope (magnification 13x) and Figure 5.25 is the result after adding a drop of bleach (magnification 13x). Again, a type of biological colonization, lichen (number 1), was detected during the observation. It is noticeable that the particles of sample 3 are very similar to

those of sample 2. The samples come from the same building with the same materials used for the ETICS. The shape and colours of the particles are very similar to those of Figure 5.22. The uncertainty about the numbers 2 to 5 also applies here, these can be algae, fungi or dirt. Due to the result of sample 2, dirt can probably be excluded. Because of the similarities with sample 2, these particles should also discolour after the bleach test. This result is confirmed on Figure 5.25, where everything has changed colour, only with type 5 the colour difference is difficult to detect. If a very close look is taken, a red colour can be seen at the edges. For sample 3 we also made a short overview with the colour changes:

Type 1 (Lichen): Yellow → red/green
Type 2: Brown/green → green and yellow/red at the edges
Type 3: Black/yellow → black/red/green
Type 4: Yellow → green/red at the edges
Type 5: Black/green-yellow –> Red at the edges

Figure 5.24a: Results of sample 3 without bleach, magnification 13x

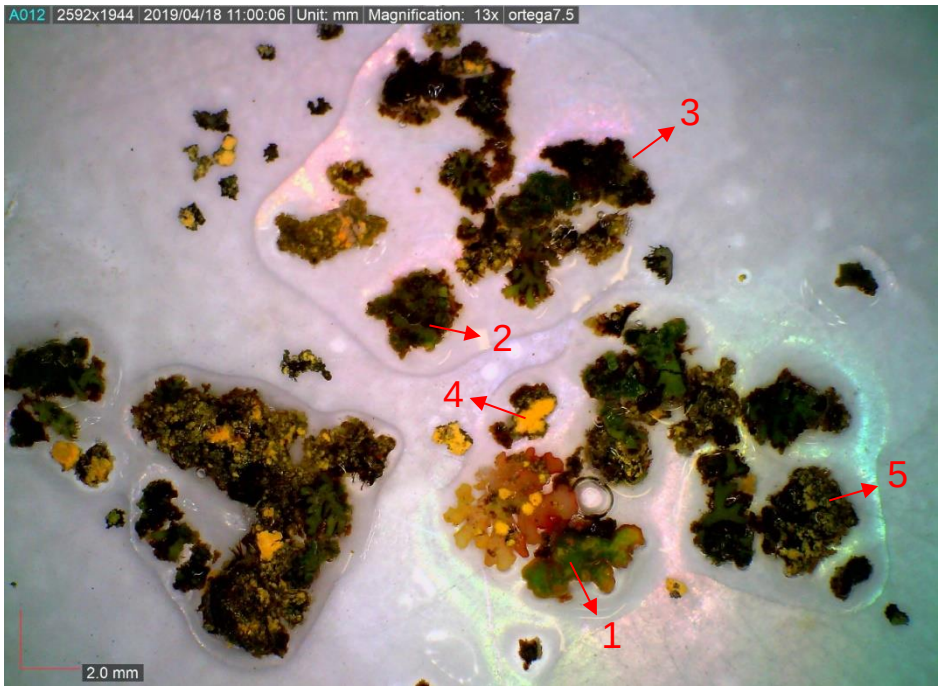


Figure 5.25b: Result of sample 3 with bleach, magnification 13x

5.3.2.3 Results of sample 6 (area 3)

Figure 5.26 is the result with a magnification of 26.5x and Figure 5.27 is the result after adding a drop of bleach (magnification 34x). Because of the small size of the particles a large magnification was chosen. Due to the lack of a picture with the same magnification, an indication was made on Figure 5.26, on which the bleach test will be performed. In comparison with the previous 2 samples the particles are different, this may indicate new types of biological colonization. Lichen can already be excluded because there are no similarities in the structure and colours. At first sight, four different types were identified with the microscope. Type 1 has both large and small particles and a red/black colour (other colours are difficult to perceive). Type 2 has a crystalline structure and white (sometimes in combination with a green/brown). Together with type 2, type 3 is common, they are green particles in the form of very small leaves. Type 4 has an orange/reddish colour and appears only once in the sample. After the bleach test all types got a different colour, but with type 2 there is sometimes confusion. Some particles seem to keep the white colour, but others have a brown/yellow shine. The white particles can be paint, by scrapping on the façades. The colour changes are summarized in the overview below:

Type 1: Red/black → green at the edges
Type 2: White/green-brown → yellow-brown
Type 3: Green → bright green/yellow-brown at the edges
Type 4: Orange/red → light orange-brown

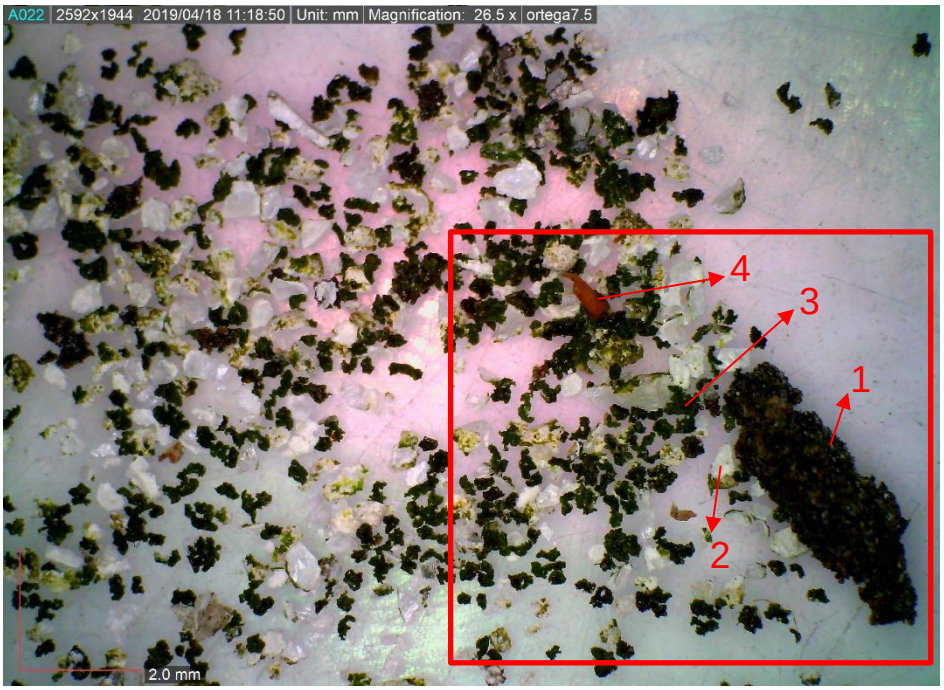


Figure 5.26a: Result of sample 6 without bleach, magnification 26,5x

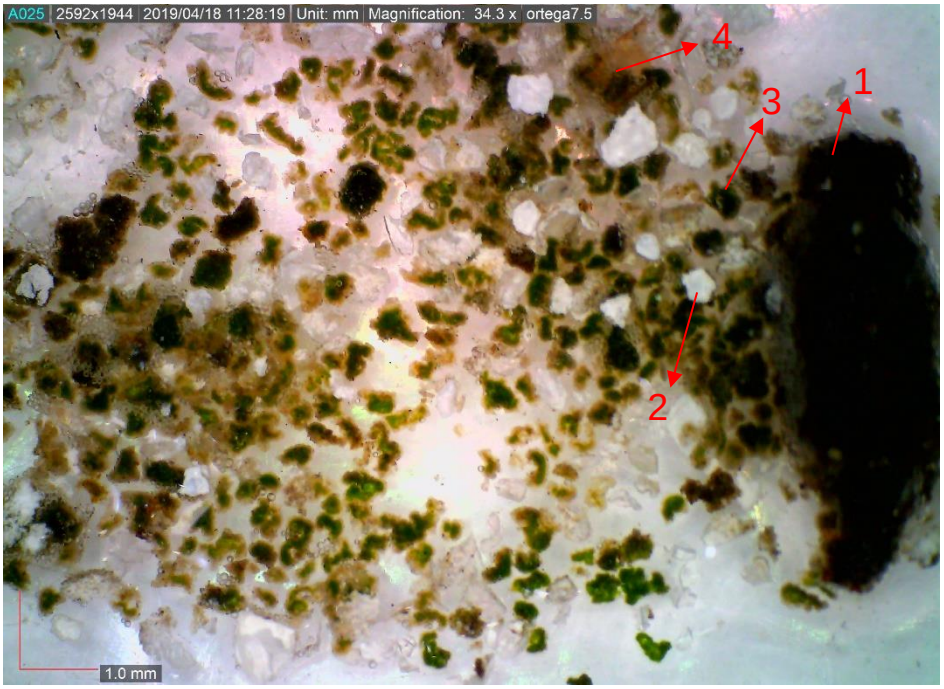


Figure 5.27b: Result of sample 6 with bleach, magnification 34x

5.3.3 Scanning Electron Microscope

A final step to identify biological colonisation is by use of the scanning electron microscope. With this device, high quality images with high magnification, sharpness and resolution can be created to study the particles (Piontek et al., 2016). The operation was as follows: the work was always done in three

steps, where first an image is made of an area with a magnification of 100x. The same area was then examined in more detail with a magnification of 500x and 1000x. More than one area was examined per sample because several types of biological colonization may be present. These are the same 3 samples that were used in the previous tests (sample 2, sample 3 and sample 6). The preparation of the biological samples went as follows: a carbon tape will be placed on both sides of the samples, after which it will be placed on an aluminium sample holder. This holder goes to the Sputter Coater (Q150T). The Q150T system is a versatile sputter coater for preparing specimens for examination by electron microscopy. The Sputter Coater will apply a thin conductive coating (3mm or 6mm carbon rods or cords) on the top of the samples, to make the samples conductive. In Figure 5.28 is the result of the preparation of the samples. The samples are placed on the aluminium holder and this is placed in the SEM [W7].

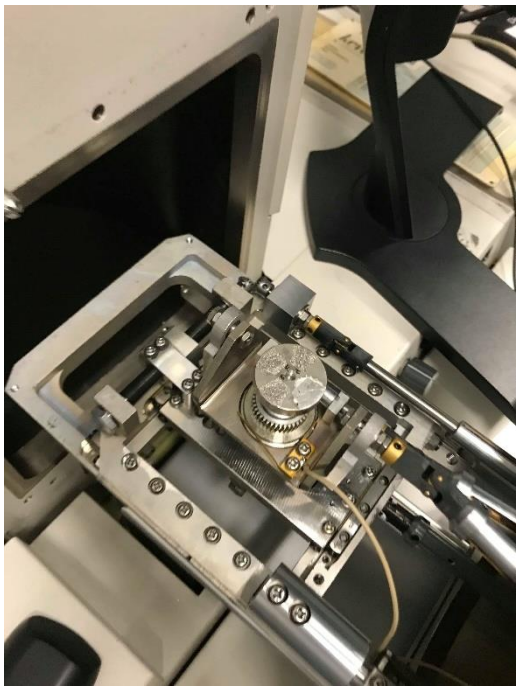


Figure 5.28: Result of the preparation of the samples for the SEM

5.3.3.1 Results of sample 2 (area 1)

The SEM test will be performed first on sample 2, Figure 5.29-5.31 are results from a first area. Figure 5.29 has a magnification of 100x, where first a larger image is used to search for biological colonization. Figure 5.30 shows the circled area with a magnification of 500x. Particles with different structures are identified, such as the wire structures, better known as filaments (red arrows). The filaments structure corresponds to fungi (Rosado et al., 2013). The structure on Figure 3.6 does shows some similarities. The biological colonization might indicate fungal hyphae (Rosado et al., 2013). There is also a spherical structure (red circles) identified but is more visible with a magnification of 1000x (Figure 5.31). This structure may be a different type of biological colonization, like another type of fungi, algae or bacteria, but with this data it is not possible to identify the type of biological colonization. There is further research necessary to identify this type.

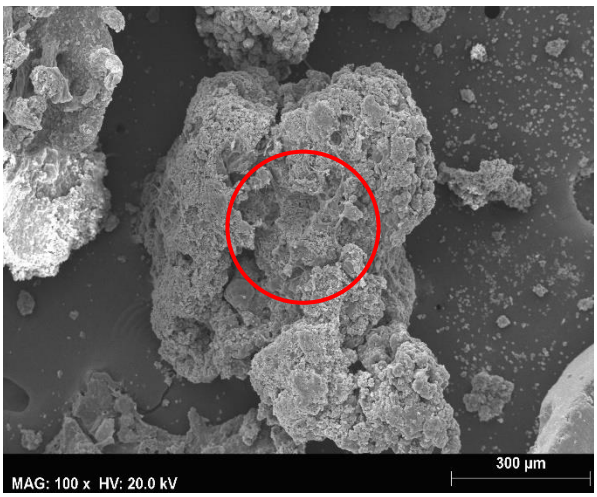


Figure 5.29: Sample 2, magnification 100x

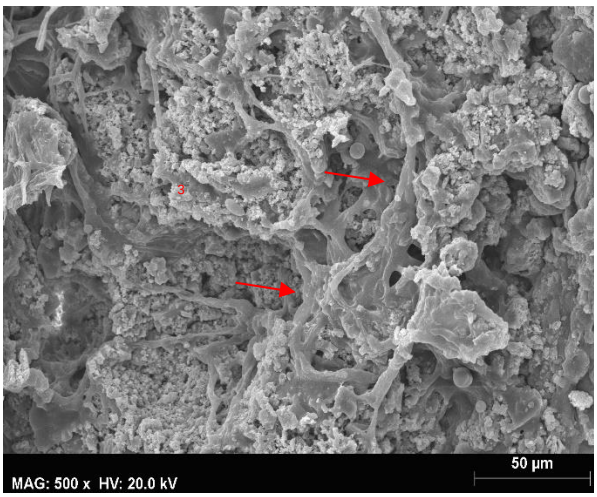


Figure 5.30: Sample 2, magnification 500x with the arrows indicating fungal hyphae

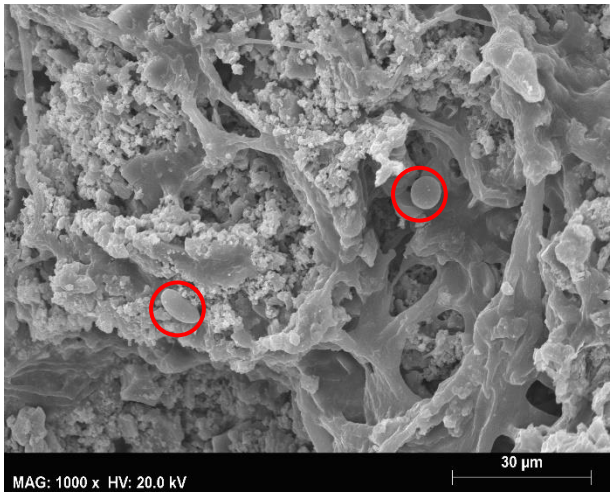


Figure 5.31: Sample 2, magnification 1000x with the circles indicating another type of biological colonization

To identify other types of biological colonization, proceed to another area (area 2) in the same sample. On Figure 5.32 the filaments are visible again, but the shape does not correspond to that of the previous area, this might be a different type of fungi. The arrow on Figure 5.33 noticed that the structure of the fungi is damaged or intact. The structure of the fungi was probably broken and damaged by scraping against the façade during the collection of the samples. If a larger magnification (1000x) is used on the part of the circle A, the spherical structure is visible again (Figure 5.34). it is now present in a much larger quantity, but it cannot be said with certainty whether it is of the same type (Figure 5.31). By scraping on the stains, it is possible that the structures are interrupted, as shown on Figure 5.35.

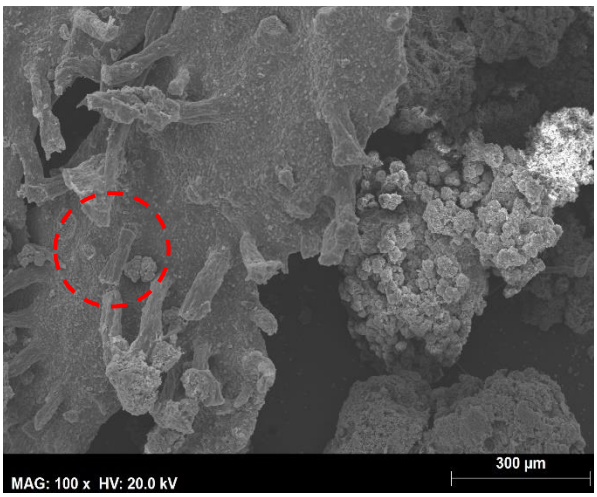


Figure 5.32: Sample 2 (area 2), magnification 100x

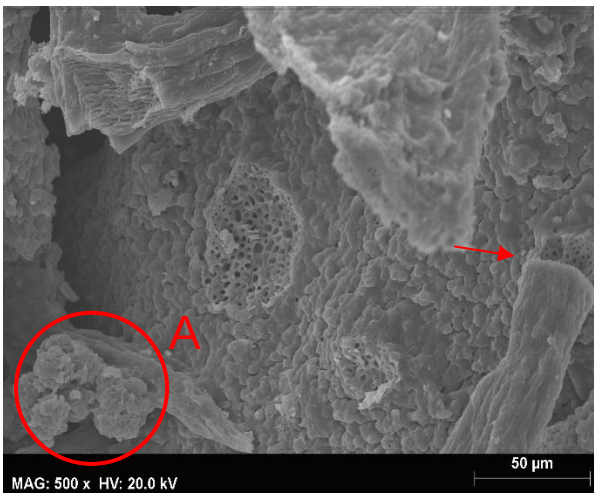


Figure 5.33: Sample 2 (area 2), magnification 500x with the arrow indicating fungi and circle A is another type of biological colonization

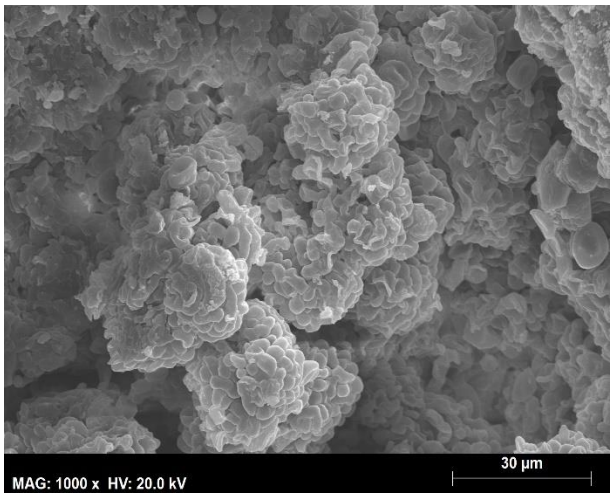


Figure 5.34: Sample 2 (area 2), magnification 1000x

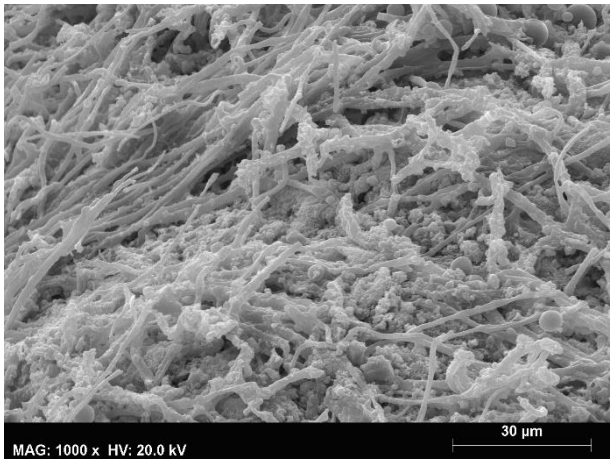


Figure 5.35: Interrupted filaments (magnification 1000x)

5.3.3.2 Results of sample 3 (area 1)

After the digital microscope it was concluded that sample 2 and 3 contain a lot of similarities. The samples have similar particles, in terms of shape and colours. After the SEM this could be confirmed again, like the structure of the filaments (fungi) and the spherical structures. The area in the circle on Figure 5.36 will be examined in more detail in the following figures. The structures on Figure 5.37 are very similar to those on Figure 5.30, the filaments are indicated by arrows and circle A shows again the spherical structure. The structures can be seen even more clearly at Figure 5.38.

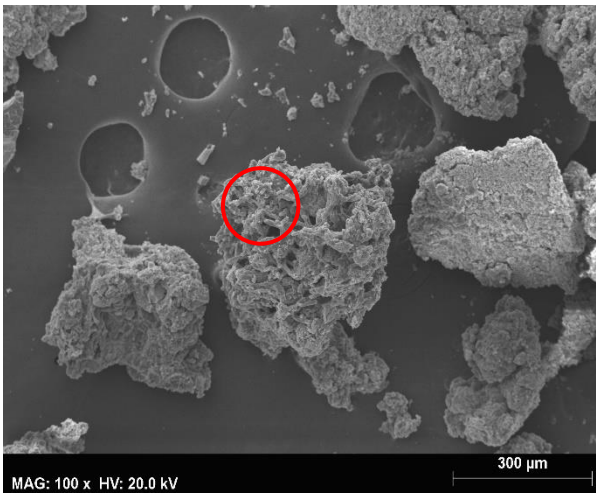


Figure 5.36: Sample 3, magnification 100x

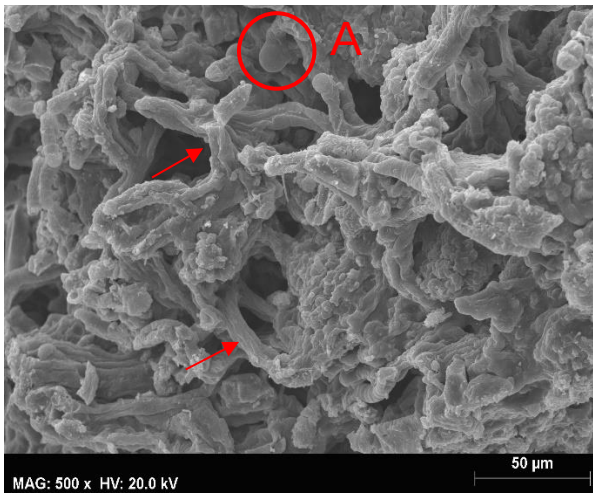


Figure 5.37: Sample 3; magnification 500x with the arrows indicating fungi and circle may indicate another type of biological colonization

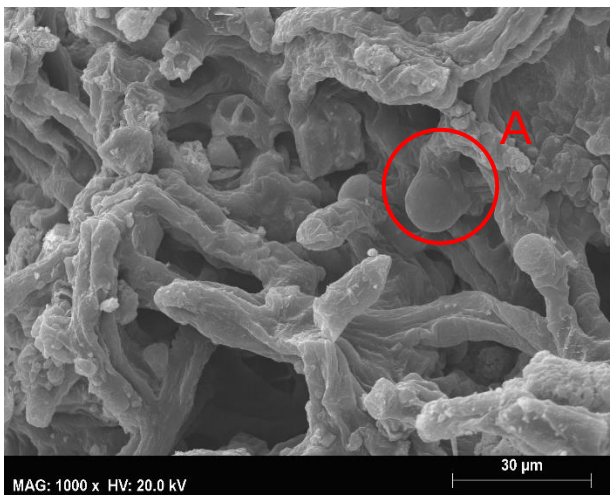


Figure 5.38: Sample 3, magnification 1000x

Figure 5.39-5.41 are in another area of sample 3. The area in the circle on Figure 5.39 is magnified to a magnification of 500x. The shape of the biological colonization on Figure 5.40 and 5.41 is similar to Figure 5.34. The circle is magnified each time to look in more detail. With this data it is not possible to

identify the type of biological colonization.

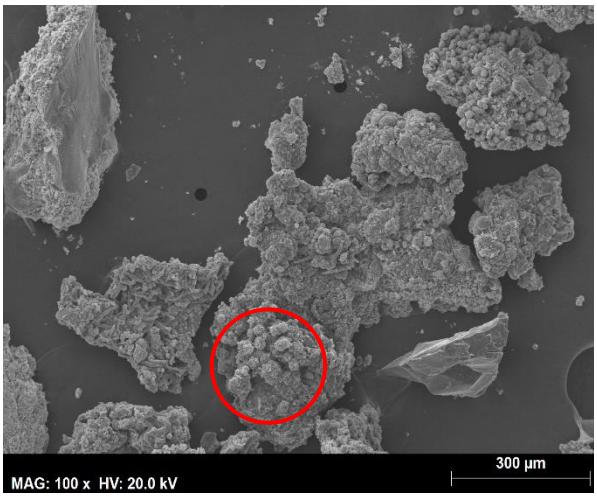


Figure 5.39: Sample 3 (area 2), magnification 100x

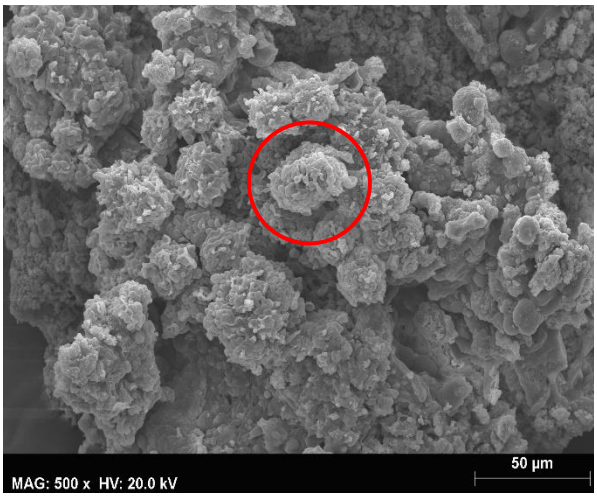


Figure 5.40: Sample 3 (area 2), magnification 500x

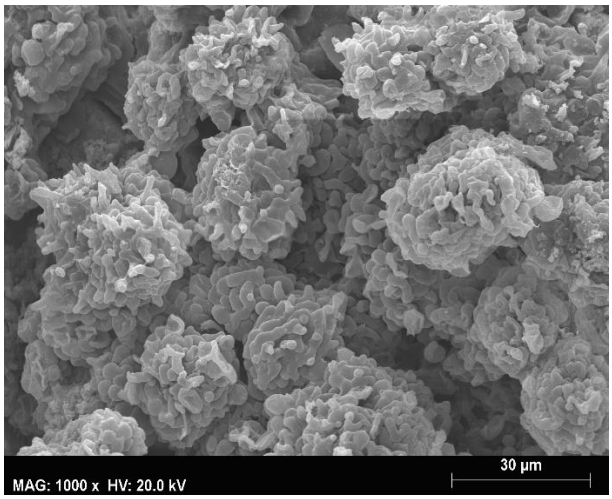


Figure 5.41: Sample 3, magnification 1000x

5.3.3.3 Results of sample 6 (area 3)

Sample 6 is different from sample 2 and 3 because of the different type of finishing coating, as shown by the visual assessment and the other diagnosis methods. On Figure 5.42 the biological colonization is only present in small quantities. The area in the red circle will be examined in more detail. Remarkable are some particles in the sample that do not match biological colonization. The area in the blue circle can be a particle of the paint. These particles were not observed in the results of the magnifying glass, the digital microscope and the bleach test. The area in the red circle is enlarged on Figure 5.43 and 5.44, it is difficult to determine which type it is. A comparison with the structures of sample 2 and 3, does not offer an immediate solution. in Figure 5.44 it may be difficult to see, but the particles contain very small dots, this may indicate another type of biological colonization.

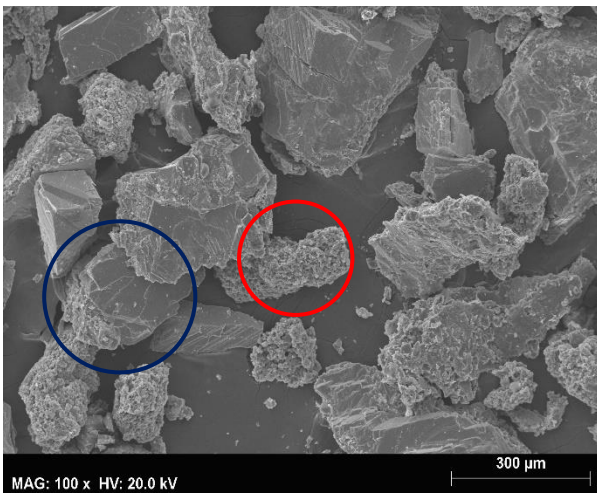


Figure 5.42: Sample 6, magnification 100x (Some particles can be paint, blue circle)

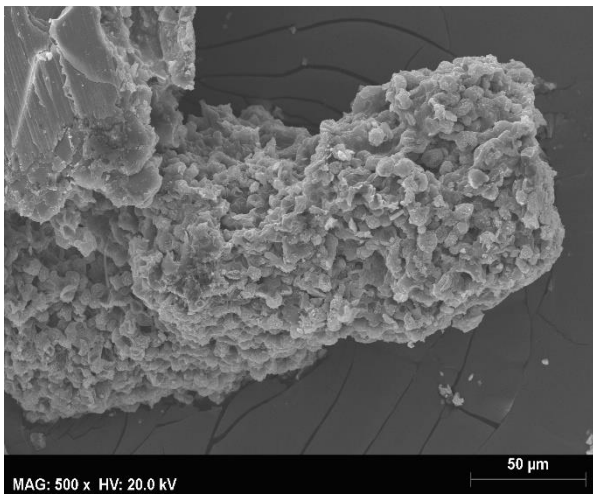


Figure 5.43: Sample 6, magnification 500x

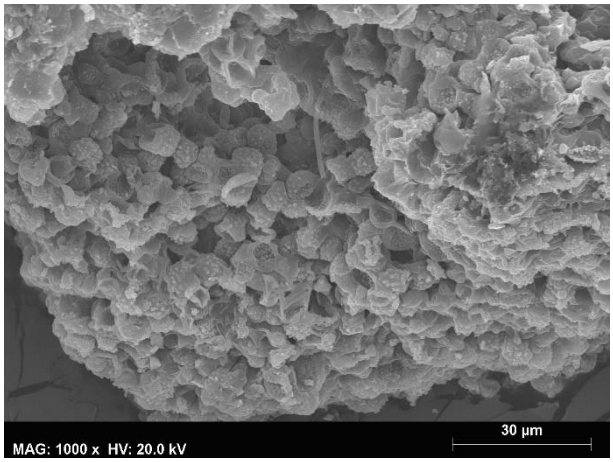


Figure 5.44: Sample 6, magnification 1000x with small dots on the particles

Figure 5.45 and 5.46 are the results of an investigation in another area of sample 6. Compared to the previous area, the particles do have a similar structure. If a very close look is taken at Figure 5.46 (enlargement area in circle), it seems to be the same type of structure as the previous one. The particles, which sometimes have a spherical structure, contain very small dots. These results are from a different area but show the same result. The number of different types of biological colonization may be more limited in this sample.

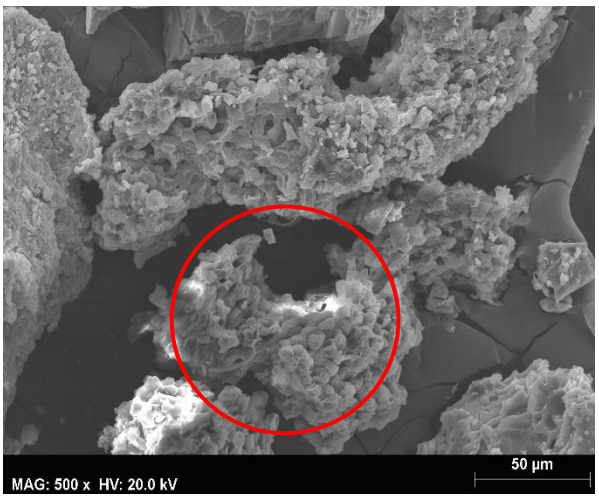


Figure 5.45: Sample 6 (area 2), magnification 500x

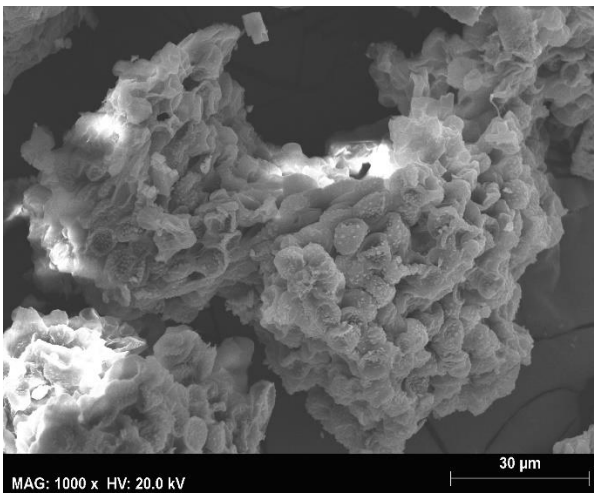


Figure 5.46: Sample 6 (area), magnification 1000x (small dots on the particles)

5.4 Conclusion of this chapter

The methodology of investigation was explained in chapter 4, the different steps were systematically mentioned on the basis of a flow chart. This chapter started with the results of the visual assessment, which mainly dealt with the deterioration of the façades, which were affected by anomalies. Microbiological growth was the most common anomaly, followed by peeling, efflorescence, cracks and oxidation stains. Of the 56 façades or 22,000 m² of ETICS that were inspected, 100% was affected with microbiological growth. It is therefore important to investigate ETICS, especially to find out what the causes are. The deterioration of façades can affect the performance of the system.

The visual assessment is limited because of the difficulty to recognise different types of biological colonization. During the visual assessment it soon became clear that identification of biological colonization was not an easy task. The observations were limited to distinguishing different types of stains and colours. Dirt may contain a dark colour, but stains from microbiological growth may also be dark. In the literature review, the differential and uniform stains were placed in the group of stains. In the beginning it was assumed that it was dirt, but because of the visual inspections, it was assumed that the stains are mainly biological colonization. These stains can be subdivided according to the causes, whereby the uniform ones are the result of the superficial condensation. This is because the low thermal mass of the outer coating combined with a high thermal resistance of the insulation layer leads to overcooling of the coating surface by exchanging long wave radiation from the air. At night, the temperature of the outer surface will drop until it reaches the dew point temperature of the outer air. From the dew point temperature, the water vapour in the air will be converted to water and this will settle on the surface, called superficial condensation (relative humidity 100%). It is not only the superficial

condensation that leads to stains. There also the thermophoresis, this is a force generated by the temperature gradient between hot air and a cold wall. The difference in temperature causes an attraction of particles present in the air, such as dirt or small spots of biological colonization. These particles affect and compromises the aesthetics of the façades. Dirt or biological colonization can be repelled if the surface is hotter than the outer air. The differential of the poor construction details or deficient materials.

The influence on the amount of stains was mainly due to the orientation and type of finishing coating. The results in area 2 and 3 were influenced by the orientation, the façades facing south were better than those facing north. The affected area on the façades to the south is largely between 5 to 25%, and to the north it is between 25 to 50%. These results correspond to the theory of the drying process, as mentioned in the literature review (chapter 3). The input of orientation in area 3 could not be explained because the results from the south and the north were the same.

It is difficult to define which type of finishing coating is better, in term of prevention of microbiological growth. The façades with silicate paint were much more severely affected than those with acrylic paint. There are several reasons why this could be the case. Silicate is more negatively affected if there is a lot of moisture or heavy rainfall. This causes water stains on the coating as a result of the water absorption capacity or the waterproofing. On the other hand, silicate has a high permeability, which leads to a better breathability of the surface and a drier surface. The quality of the paint can also be a possible cause or the combination of the lime-resin coating with the silicate paint can also have an influence. As mentioned earlier, the thermophoresis can also be a cause of staining. Silicate is more porous than acrylic, so it can hold more particles. Acrylic has a low water absorption, so there are almost no water stains on the façade (especially in areas where poor detailing is evidence), which can lead to microbiological growth. Both types of paints have advantages and disadvantages, more analyses must be carried out to understand the difference in properties and performance but is out of the scope of this thesis.

The collection of samples was mainly dependent on accessibility. It was difficult to collect samples of different façades because it was only possible on the roof and under the guidance of Eng. Luis Brás. The results of the SEM show that interrupted structures were observed in the results of sample 2. The broken structures were the result of scraping against the façade. In a next test it might be better to use a different technique, so that the structures remain intact.

The diagnosis methods made it possible to distinguish different types of biological colonization. The magnifying glass, which can be used both in-situ (but the façades were difficult to reach) and in the laboratory, was a first method in which a distinction was made by analysing the shape and colours of particles. The method is rather limited because of the fixed magnification, making the small particles less clearly visible. With the digital microscope, a distinction has been made between the shape and colours of particles. In sample 2 and 3, 5 different types of particles were identified and in sample 6, 4 types. The particles of sample 2 and 3 are similar because they come from the same building. Due to the various magnification, the microscope could be used to go into even more detail and thus also has its added value. All the particles discoloured after the bleach test were of microbiological growth and not

dirt. The use of bleach is therefore a simple test to make a distinction. The last step was the scanning electron microscope, with which images with a very high resolution and magnification could be obtained. The particles with a filament structure belong to the fungi and those with a spherical structure needs further research. It can be a different type of fungi, algae or other micro-organisms. Again, there are many similarities between the biological colonization types of sample 2 and 3. In sample 6, a type was not immediately identified, it resembles the spherical structure, but the particles also contain very small dots. The uncertainty that was present in the beginning will be reduced by the combination of the different diagnosis methods. The methods in different phases will lead to additional information because of the more detailed studies. Even though there is a certain knowledge, it is still difficult to distinguish different types of biological colonization. In the methodology of the thesis DNA was mentioned as the last step. This is an even more far-reaching study that can lead to the identification but is out of the scope of this thesis.

6 Conclusion and further developments

6.1 General conclusion

ETICS is one of the most widely used systems in Europe because of the many advantages it offers. But in addition to all the advantages, there are also major disadvantages. A first conclusion is that the systems are still very sensitive to anomalies. First of all, the choice of materials, like the particular details, reinforcements and compatibility between layers, etc. are palying an important role. Depending on the outdoor conditions, certain insulation materials and plasters, with better dehydration, may be more suitable than others. If the system is not installed in detail, such as the poor construction details or the use of deficient material, the problems can quickly accumulate. Faults in the construction can lead to water infiltration with major consequences for the aesthetic of the façades. Very careful installation and knowledge of the system is required.

In this thesis, a methodology was proposed in order to identify and characterize different types of anomalies, with particular attention to the microbiological growth. It includes three main steps: problem definition, visual assessment and the diagnosis methods. It is important that attention is paid to the performance of ETICS.

The different anomalies, the possible causes and the diagnosis methods were worked out in the literature review. This study contained 19 anomalies, organized in three groups according to appearance on visual inspection; material failure, stains and microbiological growth. Three tables were made to identify and clarify the anomalies. This could be helpful during the investigation.

The methodology proposed was divided into five steps. First there was the visual assessment in which anomalies, types of stains and colours were identified. The next 4 steps were part of the diagnosis methods, the order was as follows: magnifying glass, digital microscope, bleach test and the scanning electron microscope (SEM). The magnifying glass (in-situ or in the lab) tried to distinguish particles on the basis of the shape and colours. The digital microscope also tried to distinguish the particles but there was a higher magnification possible. The bleach test distinguished the dirt particles with the microbiological growth. Lastly, the SEM distinguished different types of biological colonization due to the structure of the particles. DNA analysis was also mentioned as an important step towards the identification of biological colonization, but this investigation did not fall within the scope of this thesis.

The results of the application of this methodology on a case study were analysed. There was an investigation on 56 façades or ± 22 000 m² of ETICS in the Boavista district (centre of Lisbon, Portugal). A first remarkable point was that the façades of the buildings were in poor condition. The most part was affected by biological colonization, with especially the presence of uniform and differential stains. These types are due to poor construction details, deficient materials and hygrothermal behaviour. The

differential stains occur at the site of windowsills and the roof coverings due to poor installation. The superficial condensation, in which the cladding surface becomes moist, will lead to the uniform stains, on the free cladding surface. The other identified anomalies were peeling, white stains, oxidation stains and cracks. Graffiti was also present in one of the façades but was considered art and not bombing.

The façades with orientation northwest and northeast are most sensitive to microbiological growth. In Portugal, the drying process will be faster in the south façade and slower in the north façade. The most dominant wind directions in Lisbon are north and northwest, followed by northeast. This has also an impact on the façades, as both wind and rain carry pollutions. The results do not indicate that the amount of condensation is the same for each façade. The figures and statistics confirm the theory of the influence of orientation. The façades oriented to the south have better results, less differential and uniform stains due to the drying process. The façades oriented to the north have more stains, because of the dominant wind directions and by the lesser exposure to solar radiation and this may can lead to more thermophoresis. According to the statistics in chapter 3, microbiological growth is the most common anomaly. This conclusion was also confirmed during the case study. Microbiological growth was 100% present, while the next anomaly was peeling (25%), followed by white stains (14,58%), oxidation stains (5,36%) and cracks (4,17%).

The façades with an acrylic paint were generally better. The acrylic paint (organic) scores better than the silicate paint (mineral), the amount of stains was remarkably less. No façade was affected by more than 5%, while in area 1 and 2, the majority was between 5 to 25% and 25 to 50%. Silicate absorbs more water but has better water vapour permeability. According to the results, the façades have to contend with too much moisture because there are so many stains present. The amount of pigment (colour) can also influence the quality of the coating. The properties of both paintings can be weighed against each other, but in this case study acrylic scores better. In order to give a clear explanation, more research is needed but this was not a part of the thesis.

Identifying different types of stains is in principle easy, it points out that there are several mechanisms that give rise to this. After the visual observations were only lichen was observed, it was found that it was difficult to recognize all types of biological colonization, but this was also the case during the diagnosis methods. In preparation, characteristics and growth conditions of types can be compared. Only with this general knowledge this was still a difficult task. With the magnifying glass a first step was taken to make a distinction between the particles, by comparing shape and colours. This test is limited due to the fixed magnification, which made small particles difficult to detect. A various magnification is possible with the digital microscope, for the 3 samples examined, 4 to 5 different types of particles were distinguished per sample. Because of the finishing coating and/or orientation, samples 2 and 3 contain different types of biological colonisation than sample 6, this was concluded based on the shape and the colours. The bleach test showed that all particles are microbiological growth and not dirt. This is an easy method to distinguish dirt.

After these tests it was still difficult to identify a type for the particles. A final step was the scanning electron microscope (SEM), this test makes it possible to distinguish biological colonization by its

structure. The filaments structure corresponds to fungi. This was the only type that could be identified with a particular certainty. A spherical structure was also observed, but the type of biological colonization is not known. Because of the high uncertainty after this test, it can be concluded that further research is necessary. A specific type of fungi or algae can be identified by a DNA test. Some particles of sample 6 do not indicate microbiological growth, but paint particles by scraping off the sample. This was difficult to detect after the bleach test because they are very small particles. The use of bleach is a simple test, but it can happen that it is not always clearly perceptible.

A general conclusion is that microbiological growth is a major problem and that much attention should be paid to it. It is necessary to identify biological colonization, but it is not as simple as expected. Types are different according to their structure, which requires thorough investigation to note the differences. The different diagnosis methods lead to results, but it is still difficult to distinguish different types of biological colonization. The combination of all the tests of the proposed methodology reduce the uncertainty of the diagnosis. It is also important to define the causes and try to eliminate them.

6.2 Further developments

The DNA test was not in the scope of the thesis, but it is an important step to identify types of biological colonization. This can lead to a type of fungi, algae, etc. There were a lot of properties of the finishing coatings that can have an influence on the creation and amount of stains. It can also not be said with certainty that it is only the finishing coating, the combination with the underlying layers such as the key coating, can also play a role. In order to demonstrate a clear difference in quality between materials, more research is required. Buildings that have been damaged can be cleaned in a very simple way with bleach. In this study, the façades were severely damaged. Intervention is strictly necessary, so bleach can certainly be a solution here. After the results of the SEM, some structures (especially the filaments structures of the fungi) were interrupted, this was probably the cause of scraping on the surface during the collection of the samples. New methods could be tested in the future so that this would not happen again. When preparing the sample for the SEM, the particles are placed between a carbon tape. Maybe there is a possibility to stick that tape directly on the façade.

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Appendix

A.1 The calculation results of the visual assessment

Table A.1-1 Identification of each anomaly in area 1 (red box of Figure 4.4)

Area 1			
Northwest (8 façades)			
Anomalies	% affected	Total in %	Total in No. Of façades
Peeling	<1%	12.5%	1
Microbiological growth	>50%	100.0%	8
Northeast (4 façades)			
Peeling	1 à 5%	25.0%	1
Efflorescence	<1%	25.0%	1
Microbiological growth	5 à 25%	100.0%	4
Southeast (8 façades)			
Peeling	1 à 5%	37.5%	3
efflorescence	1 à 5%	37.5%	3
Microbiological growth	5 à 25%	100.0%	8
Southwest (4 façades)			
Cracks (horizontal, diagonal, mapped)	1 à 5%	50.0%	2
Microbiological growth	5 à 25%	100.0%	4

Table A.1-2: Identification of each anomaly in area 2 (blue box of Figure 4.4)

Area 2			
Northwest (8 façades)			
Anomalies	% affected	Total in %	Total in No. Of façades
Peeling	<1%	25.0%	2
Microbiological growth	>50%	100.0%	8
Northeast (4 façades)			
Efflorescence	<1%	25.0%	1
Microbiological growth	>50%	100.0%	4
Southeast (8 façades)			
Peeling	<1%	25.0%	2
Efflorescence	<1%	25.0%	2
Microbiological growth	5 à 25%	100.0%	8
Southwest (4 façades)			
Microbiological growth	5 à 25%	100.0%	4

Table A.1-3: Identification of each anomaly in area 3 (yellow boxes of Figure 4.4)

Area 3			
Southwest (4 façades)			
Anomalies	% affected	Total in %	Total in No. Of façades
Oxidation stains	<1%	50.0%	2
Microbiological growth	1 à 5%	100.0%	4
Northeast (4 façades)			
Oxidation stains	<1%	25.0%	1
Peeling	<1%	50.0%	2
Microbiological growth	1 à 5%	100.0%	4

Table A.1-4: Results of microbiological growth area 1 and 2

Southeast (16 façades)		**Northwest (16 façades)**	
Lot No.	% affected	Lot No.	% affected
11	5 à 25%	11	5 à 25%
12	25 à 50%	12	25 à 50%
13	5 à 25%	13	25 à 50%
14	5 à 25%	14	25 à 50%
15	5 à 25%	15	25 à 50%
16	5 à 25%	16	25 à 50%
17	5 à 25%	17	5 à 25%
18	5 à 25%	18	5 à 25%
19	5 à 25%	19	5 à 25%
20	5 à 25%	20	5 à 25%
21	5 à 25%	21	>50%
22	5 à 25%	22	>50%
23	5 à 25%	23	>50%
24	>50%	24	25 à 50%
25	5 à 25%	25	>50%
26	5 à 25%	26	5 à 25%
Total in No. of façades		Total in No. of façades	
1 à 5%	0	1 à 5%	0
5 à 25%	14	5 à 25%	6
25 à 50%	1	25 à 50%	6
>50%	1	>50%	4
Total in %		Total in %	
1 à 5%	0.0%	1 à 5%	0,0%
5 à 25%	87.5%	5 à 25%	37.5%
25 à 50%	6.25%	25 à 50%	37.5%
>50%	6.25%	>50%	25.0%

Table A.1-4 Results of microbiological growth area 1 and 2 (continued)

Northeast (8 façades)		**Southwest (8 façades)**	
Lot No.	% affected	Lot No.	% affected
11	25 à 50%	11	5 à 25%
12	25 à 50%	16	5 à 25%
13	25 à 50%	17	5 à 25%
18	25 à 50%	18	25 à 50%
19	>50%	19	5 à 25%
21	5 à 25%	21	1 à 5%
22	5 à 25%	22	1 à 5%
26	5 à 25%	26	5 à 25%
Total in No. of façades		Total in No. of façades	
1 à 5%	0	1 à 5%	2
5 à 25%	3	5 à 25%	5
25 à 50%	4	25 à 50%	1
>50%	1	>50%	0
Total in %		Total in %	
1 à 5%	0.0%	1 à 5%	25.0%
5 à 25%	37.5%	5 à 25%	62.5%
25 à 50%	50.0%	25 à 50%	12.5%
>50%	12.5%	>50%	0.0%

Table A.1-5: Results of microbiological growth in area 3

Northeast (8 façades)		**Southwest (8 façades)**	
Total in No. of façades		Total in No. of façades	
<1%	2	<1%	2
1 à 5%	6	1 à 5%	6
5 à 25%	0	5 à 25%	0
25 à 50%	0	25 à 50%	0
>50%	0	>50%	0
Total in %		Total in %	
<1%	25.0%	<1%	25.0%
1 à 5%	75.0%	1 à 5%	75.0%
5 à 25%	0.0%	5 à 25%	0.0%
25 à 50%	0.0%	25 à 50%	0.0%
>50%	0.0%	>50%	0.0%