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Regeneration of Panel Housing Estates from the Perspective of Thermal Technology, Sustainability and Environmental Context (Case Study of the City of Ostrava, Czech Republic)

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Abstract: The future of panel housing estates is influenced by a number of factors. Although panel housing estates have seen their share of commentary and analysis from both supporters and detractors, there has been no comprehensive effort to explore the field of panel housing estates in terms of building thermal regeneration measures. This article focuses on the links between thermo-technical regeneration measures in panel housing estates, and the application of External Thermal Insulation Composite Systems (ETICS) and their impact on the urban environment of panel housing estates. The paper contains three main sections in which we (1) synthesize the literature, sources, building physics context, and assumptions for the occurrence of biodeterization in the facades of prefab residential housing located in housing estates; (2) compare the case studies and their results from the 2010–2021 field reconnaissance, in situ diagnostics, and laboratory analyses; and (3) identify/illustrate common features, the extent to which the quality of prefab residential housing located in housing estates with ETICS exterior surfaces is influenced by the environmental context, whereby we understand the whole process of the environmental assessment framework as an interrelated complexity of the interacting links between the environment, urban planning, architecture and construction sectors, supporting a holistic approach to the issue at hand. The results show that regeneration work, on the one hand, improves the urbanized environment and the energy potential of a housing estate; on the other hand, we encounter new manifestations of defects and disorders in the form of biodegradation of facades that we did not expect.

Keywords: panel housing estate; prefab residential housing; energy; environment; composite; biodegradation

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1. Introduction

The issues of historical development, architecture, prefab structures, urbanism, and sociological aspects of housing estate development have received increased attention in recent years. The panel housing estates built in Europe after World War II are an integral part of today's urban landscape. In these countries there has been development of residential housing, built mainly with prefabricated panel technology. The development of panel housing estates in a number of countries is linked to the urban development of settlements and, after 2010, to the current new structural and architectural trends resulting mainly from energy legislation. These trends include the overall resilience of housing estates, the regeneration of prefab residential housing and their ability to adapt to climate change, thermal engineering measures for prefab residential housing to reduce energy consumption, creating healthy housing, a healthy indoor microclimate, and a healthy surrounding macroclimate. All of this becomes part of sustainable development, which the architecture and construction sectors are part of. From this perspective, construction and architecture can be seen as mitigation tools.

In particular, thermal-technical and energy efficient measures, in the form of the application of an External Thermal Insulation Composite System (ETICS) [1], on the facades of prefab residential housing located in housing estates contribute not only to the improvement of the environment and the aesthetics of buildings, but also to a better and more economical use of energy. The European Union (EU) understands ETICS as a composite material and technology that is environmentally friendly, part of the circular economy, and, last but not least, as a structural and architectural measure that leads to the aesthetic improvement of panel housing estates, as well as to the improvement of the quality of prefab residential housing. ETICS with an external render is currently the most widely used structural engineering solution for reducing the energy demands of buildings in the EU. More than 50 years of the application of ETICS have shown that it is a good solution in different climatic conditions and the factors that can affect the deterioration of the functional thermal insulation properties are relatively well mapped and described from both a theoretical and a practical point of view. However, there are failures in ETICS that we have not encountered before, such as the issue of deterioration of facades with ETICS by biotic agents [2,3]. Increasingly stringent legislative energy measures defined by the EU and the required fulfilment of thermal and energy criteria [4–9] leads to an increasing thickness of thermal insulation over time. The ETICS composite, in accordance with current legislation, reaches a thickness of 180 mm to 200 mm after 2020 with a panel perimeter wall thickness of 270 mm to 300 mm [10,11].

The experience of the last two to three decades shows that, when applying ETICS, it is necessary to pay increased attention to aspects that adversely affect the quality of ETICS, which often cause negative effects in the form of surface biodeterioration of the external surfaces of ETICS. Biodeterioration of the external surfaces of ETICS composites in prefab residential housing is, thus, becoming a modern defect that significantly degrades the aesthetic perception of prefab residential housing located in housing estates. Although the application of ETICS has been widespread in EU countries for more than half a century, no coherent European standard has been developed to date that could become the basis for assessing and verifying the stability of ETICS properties, in accordance with the AVCP (Assessment and Verification of Constancy of Performance), i.e., definitions, requirements, quality control and verification of stability of properties [12].

If we want to fulfil the quality pledges of the building ecosystem in the conditions of the 21st century and regenerate prefab residential housing in accordance with the principles of sustainable construction, it is necessary to ensure and assess the complexity of the interactive connections of the ecosystem of prefab residential housing as a whole with the external environment. The need to take into account the construction environment can be found in the arguments of many authors [13–16], stressing the need to revise the approach to the design, implementation, and operation of buildings, not only residential buildings but all buildings that are part of the civic amenities of the city and in the field of civil engineering in general.

The World Health Organization (WHO) states that the quality as well as the environmental context of housing can contribute to environmental inequalities [17]. Inadequate or poor housing conditions are one of the mechanisms through which environmental inequalities translate into health inequalities, which further affect the quality of life and accommodation standards in housing estates. Therefore, it is necessary that the structural–architectural design in the regeneration of panel housing estates focus not only on the prefab residential housing as a whole, but also on the links to the surrounding environment, on the macroclimate in the urban whole of the housing estate. The facades of prefab residential housing are among the most important structural and architectural elements in the initial visual impression associated with the evaluation of the residential environment, showing not only the culture of the immediate environment but the culture of society as a whole.

The aim of this paper is to show, using a comparison of results from field surveys and follow-up research activities carried out in prefab residential housing developments between 2010 and 2021, how necessary the interaction between construction, architecture, and the environment is, and to identify common features that lead to biodeterioration of ETICS in prefab residential housing located in housing estates, and that threaten the quality of the space of the housing estate itself. The field survey and monitoring of prefab residential housing was based on the assumption that the quality of the external surface of ETICS should be understood and assessed as a mutual interaction of all physical, natural, technical, and economic aspects. This means that it is the complexity of the interaction between construction and the environment with regard to the creation of quality and aesthetic improvement of the housing estate development.

2. Materials and Methods

The research flow strategy is divided into three basic phases in order to meet the objective of this article(Figure 1), with the initial research evidence based on case studies CS1–CS5 [18–22].

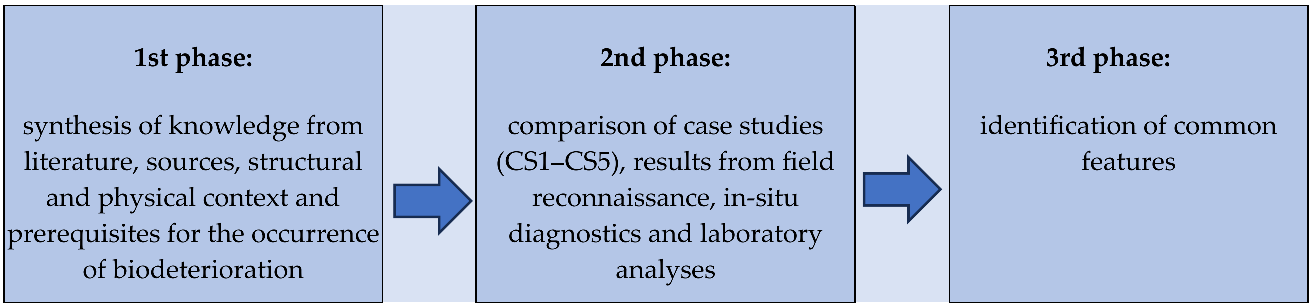


Figure 1. Research flow.

Research flow phase:

1. The first phase of the research was focused on the study of professional articles registered in the databases Scopus, Wos (Literature review), related to the topics of housing estates, heritage protection of housing estates, panel housing, regeneration of prefab residential housing construction, environment of construction, and biodegradation of ETICS. The websites of national and international organisations, such as the World Health Organization (WHO), Renovate Europe (RE), European Middle Class Mass Housing (MCMH-EU), Social Housing, Edibon-Europe (EE), etc., were also studied [23–29]. At the same time, the findings, background, and assumptions for the creation of biodeterioration of facades of prefab residential housing located in housing estates according to the building physics context and assumptions in addition to practical experience were described.
2. The second phase focused on comparing the results from case studies (CS1–CS5), which were carried out over a long-term period between 2010 and 2021 at selected sites (A1–A5). The case studies were focused on the locations of panel housing estates (A1–A4) and prefab residential housing (CS1 to CS4), where regeneration works on prefab residential housing stock were gradually carried out in order to improve their thermal engineering and energy efficiency properties through the application of ETICS; the material also included a case study (CS5), which focused on the location of a housing estate in the urban conservation area regime (A5) and the residential housing here was built using brick block technology. A summary is given in Table 1.
3. The third phase identifies/illustrates the common features of the issue of biodeterioration of prefab residential housing located in housing estates, according to phases 1–2.

Table 1. Overview of case studies.

Case Study and Location	Reconnaissance over a Period of Years	Project a Period of Years Processing Project	Construction of Apartment Buildings over the Years	Characteristics of the Territory and Characteristics of the Perimeter Shell
CS1/A1	2010–2021	1965–1970	1970–1980	Housing estate development/SC *
CS 2/A2	2010–2021	1961–1965	1965–1980	Housing estate development/SC *
CS 3/A3	2010–2021	1965–1970	1970–1985	Housing estate development/SC *
CS 4/A4	2010–2021	1968–1970	1970–1975	Development of apartment blocks/GS **
CS 5/A5	2010–2021	1951–1953	1952–1961	Housing estate/urban heritage zone/brick blocks

Note: * SC–slag concrete; ** GS–gas silicate.

2.1. Literature Review and State of Art

The aim of the literature search is to provide an up-to-date view on the issue of urbanized areas with housing estates, and on the building material issues of ETICS composites with biodegradation effects in prefab residential housing that are part of housing estates.

After the end of World War II, the housing estate and the form of prefab residential housing, especially in the countries of Eastern Europe between 1955 and 1989, fulfilled the essence of the idea of "socialist welfare" [30]; this form of construction fulfilled the basic priority of the human need for housing. Given the current demographic, climatic, and overall global changes, the view of housing is changing and the quality of housing is becoming more important and acquiring different qualitative values. Housing quality in accordance with the environmental context of housing is a priority for society that leads to sustainability.

In some European countries, housing estates are characterised as an important part of the European building cultural heritage and the restoration of these large-scale sites is not only an architectural and structural engineering challenge, but above all a challenge for the EU [31].

Definitions of housing estates from the perspective of architecture and urbanism represent a diverse segment of views on this form of mass housing [32]. Most often the peculiarity with regard to urbanism or the method of construction, especially prefabricated panel technology, is emphasized. In the 1960s, the term "housing estate" itself was not commonly found in explanatory dictionaries. For example, in the Czechoslovak Republic (now Czech Republic since 1993), the term "housing estate" first appears in the discipline specific explanatory dictionary Architecture [33]; the term is characterized there as " … settlement near a crowded large city for housing people employed in that city … ". Subsequently, the term "housing estate" is defined " … as a residential unit, specifically located within settlements, that is, towns and villages, with a technological context of construction in the context of industrialized construction … " [34]. In 1989, the term "housing estate" was defined as " … a new form of mass housing … " [35]. The definition of a "housing estate" that best fits the current discourse is " … a functionally and territorially independent group of residential units built at the same time, usually on an open area on the outskirts of the city; … by its separation from the historical structure of the city, the housing estate is a characteristic product of the application of the principles declared in the Athens Charter … " [36]. This corresponds to the document "Manifesto of the Athens Charter", which was adopted at the "First International Congress of Architects and Technicians of Historic Monuments" in Athens in 1932; the Manifesto's intention was to promote the preservation of cultural heritage, to establish general principles on which it is legitimate to act in the field of restoration and to attempt a common synthesis of different doctrines. These principles were based on the need to protect the artistic and archaeological heritage of humanity as a value of common interest that is greater than the private interest. The Manifesto has become a basic document for building and conservation authorities, it also acts, among other things, as a basic document for the evaluation and classification of housing estates in terms of their possible heritage protection in the Czech Republic [37,38].

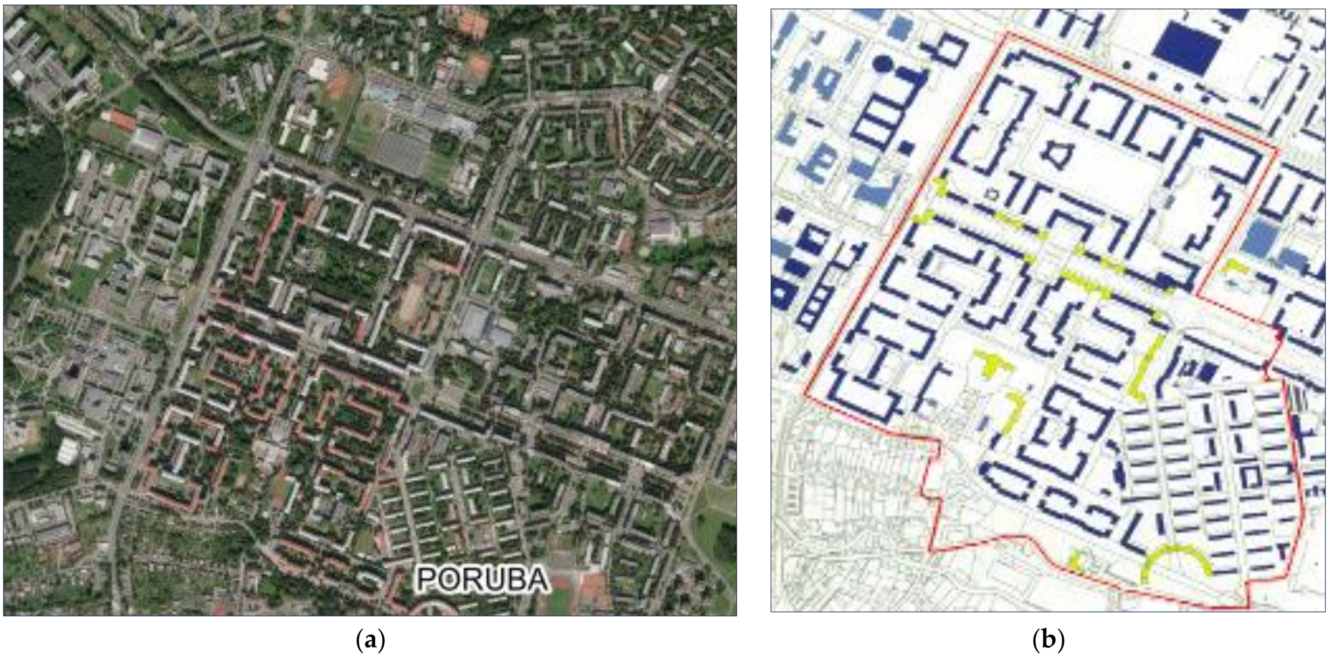
The countries of Eastern Europe, such as the Czech Republic, Poland, Slovakia, and the former East Germany, were among the most affected by the construction of housing estates in the second half of the last century. While the construction of prefab residential housing was abandoned in Western Europe as early as the 1970s (e.g., West Germany, France), this type of construction persisted in Eastern European countries until the late 1990s. The large-scale construction of prefab residential housing composed into panel housing estates thus represents a specific phenomenon in the countries of Eastern Europe, which was based on the political situation in Central Europe in the second half of the last century.

Opinions on the remediation and reconstruction of prefab residential housing, regeneration of housing estates, and forms of possible conservation protection vary between the political representation, society, and the professional community. The current views of architects are also divided. Some architects are critics, and, on the contrary, some see in the housing development the ideas of Le Corbusier's model [39].

There was a positive tone from an interview with William D. Eberle, during his visit to the Czech Republic, which states: " … it seems to me that you are severely underestimating the quality of your own housing estate structure, … Socialist housing estates are not a bad model at all … " [40,41]. Some positivity can be seen in a number of other views on 'panel housing estates'; for example [42] suggestions that these units should be referred to as " … large residential complexes … " or others [43], which refers to them as " … solitary cities … ". The Scandinavian countries take a positive approach to the issue of prefab residential housing and housing estates. They consider this form of mass housing to be a very good example of "the physical manifestation of the Scandinavian concept of the welfare state" [44]. The architecture of the Danish and Swedish housing estates in the 1950s was based on the qualities of vernacular humanist modernism; their architecture of construction was successful and based on social, cultural, and societal needs, coming from a different way of thinking than that of the socialist countries of Eastern Europe. Similarly to Sweden, the UK approaches the issue of panel housing estates by linking the post-war development of mass housing on estates with the building of the welfare state.

In terms of the possible conservation of housing estates or only selected prefab residential housing (solitary), the system of evaluation varies across Europe. The Nordic countries of Denmark and Norway have no settlements listed as state-protected monuments. Sweden and Finland, on the other hand, focus on selected housing estates. In Denmark, for example, the Bellahøj housing estate in Copenhagen is characterised by a residential complex of buildings built in both brick and panel technology. The same applies in the UK to London's Alexandra Road Estate in Camden with its concrete terrace houses [45–49].

In the Czech Republic, a part of the housing estate of the residential complex of the administrative district of Poruba in the city of Ostrava is protected, which is a residential housing development of apartment buildings built in brick block technology and the entire residential complex is characterized by the Sorela architectural style; an example is, among others, the very successful and internationally recognized urban concept of Poruba designed by the architect Meduna, V. in the 1950s (see Figure 2a,b) [50,51].



(**a**) (**b**)

Figure 2. Urban planning: (**a**) Concept of the Poruba housing estate [52]; (**b**) Marking of the territory of the urban conservation zone (red line) [32].

The gradual regeneration of panel housing estates in the long term leads to an improvement in the currents of opinion on panel housing estates; regenerated housing estates no longer create a problematic legacy of post-war architectural modernism in the wider context. The polarity of opinion is no longer so radical; the principle of the fundamental rejection of panel housing estates is overlooked and we can currently identify positive and viable ideas that support the renewal of housing estates as a form of post-war modernity [53–56]. Millions of people in Europe live in panel housing estates. The aforementioned renewal and regeneration of housing estates has acquired a clear concept of renewal, which includes structural technical, urban planning, architectural, aesthetic, and, in many cases, social aspects. Regenerated housing estates, regenerated prefab residential housing together with regenerated areas, eliminate the monotony of prefab residential housing, are a good prerequisite for ensuring positive housing values, create a good standard of housing, and contribute to the improvement of landscaping in spatial planning. Very good examples of regeneration of housing estates in the context of Central Europe are well known, e.g., Grossfeldsiedlung in Vienna (Austria), Petržalka housing estate in Bratislava (Slovakia), housing estate Black Bridge in Prague (Czechia), etc. [57–59].

The energy legislation and new strategies have brought a relatively fundamental change in the view of housing estates [60–64]. In the 1950s, the lifespan of prefab residential housing was estimated at around 50 years [65,66]. The launch of various subsidy support programmes by the EU has led to the regeneration of housing estates and to the massive application of composite systems on the façade of prefab residential housing, known as ETICS. The ETICS composites were applied in the required thicknesses to the original panel facade of the apartment buildings in accordance with the applicable thermal engineering and energy legislation. This not only achieved better thermal engineering parameters and energy savings, but also prolonged the lifetime of this prefabricated housing stock by at least another 25 to 30 years and significantly improved the aesthetics of the urban environment. The energy renovation of housing estates, in actual fact a gradual renovation of energy use, and thus achieving energy savings for heating and hot water, has become an essential and fundamental aspect of sustainable development of housing estates. Sources indicate that, for example, the application of 160 mm ETICS to the facade of prefab residential housing, together with the replacement of windows with insulating glazing, results in a reduction in energy demand reduction of approximately 85% and in CO_2 emissions of 84% per year [67]. The set measures in the form of ETICS application lead to the principles of clean technology, energy efficiency, emission reduction, responsible community energy policies, environmentalism and sustainability, and the circular economy.

The prefab residential housing of the housing estates built in the second half of the last century, are characterized by specific defects and failures that gradually began to manifest themselves. This was due both to the lack of experience with the behaviour of prefabricated buildings in the long term and to the rapid development of thermal engineering requirements. The problem of defects and failures of prefab residential housing constructions from the second half of the last century has been addressed by a number of authors whose works have been published since the 1960s–1970s [68–70]. These works mainly focused on defects and failures in the field of mechanical resistance and stability of prefab residential housing, using simulation techniques and probabilistic evaluation of prefabricated structures using finite element methods [71–73].

Gradually, with the development of thermal engineering and energy requirements, much attention was focused on defects and failures in this area around the 1980s. The aforementioned advent of strong energy legislative measures by the EU after 2000, focused on energy savings, sustainability in the construction sector, and led to research on facades of prefab residential housing with ETICS composites. Here, we can also find a number of professional studies [74–78] which, among other things, draw attention to defects in prefab residential housing in terms of thermal engineering and ETICS quality. Among the modern failures of prefab residential housing that have occurred, the degradation of the exterior plaster surface of ETICS can be included, which is the biodeterioration of the ETICS panel I. Professional studies on this topic can be found mainly by authors from Central Europe [79–81].

The issue of biodegradation raises the discussion of how faI the increasing thickness of the ETICS thermal insulator affects the conditions for colonisation of the outer surface of the ETICS by biodegrading agents, such as algae, fungi, lichens, and mosses. The study shows that, on the one hand, ETICS contributes to the improvement of thermal engineering and energy measures in prefab residential housing and, at the same time, to a better view of panel housing estates; on the other hand, the perimeter panel wall with ETICS creates suitable conditions for the settlement of microorganisms, which subsequently leads to the surface colonization of the façade and its subsequent biodeterioration. Ultimately, a facade that is degraded by biodeterioration negatively affects the overall aesthetic perception of a prefab residential housing in the overall context of the housing estate. This inevitably leads to a conflict with the regeneration strategy concept that regenerated housing estate developments contribute to the improvement of the urban environment, the external condition of prefab residential housing, and aesthetics.

There are also papers available by authors who address the issue of harmful microorganisms as potential allergens that contribute to respiratory disease. However, current scientific evidence does not suggest that biotic infestation on ETICS composites is the primary factor leading to respiratory disease [82,83].

Expert sources also cite some positive benefits of microorganisms for the construction sector. Microorganisms can have a direct or indirect positive effect on building materials. Materials research, for example, is concerned with technologies for the biological protection of cement-based materials to seal microcracks in structures, where the aim is to improve the durability of these materials. Similarly, technologies are being developed to reduce the recontamination of the surface of reinforced concrete structures and to improve the corrosion resistance of their metal reinforcements [84,85]. These positive material technologies cannot be fundamentally associated with the biodeterioration of the façades of prefab residential housing because the essence of positivity and negativity in microorganisms in relation to building structures is based on a different theoretical basis.

2.2. Prerequisites for the Development of Biodeterioration of ETICS Composites

The prerequisites for the development of biodeterioration of ETICS composites are mainly based on the principles of building physics and the requirements for the life of microorganisms [86,87].

2.2.1. Prerequisites for the Development of Biodeterioration of ETICS Composites

The constructional and physical context of ETICS is that the top layer of ETICS is not heated in the winter months due to the thickness of the insulation, so there are no conditions for the removal of condensed moisture from the top layer. Moisture contributes to the reduction in the thermal properties of ETICS composite systems and increases thermal conductivity (construction physical phenomena are further discussed in the Appendix A).

This applies particularly to north-facing façades. The phenomenon that occurs is that the lower the heat transfer coefficient U [W/(m^2.K)], the greater the risk of biodeterioration of the prefab residential housing facade because microorganisms have created suitable living conditions [88,89].

As an integral part of building physics, thermal engineering requirements are continuously becoming more stringent in terms of the required standard criteria. For Czechoslovakia (now Czech Republic) in 1962, the required value of the heat transfer coefficient was $U_{N,20}$ = 1.10 [W/(m^2.K)], currently the required value is $U_{N,20}$ = 0.30 [W/(m^2.K)] for heated residential buildings and the recommended value for passive buildings is $U_{Pas,20}$ = 0.18–0.12 [W/(m^2.K)]. Values refer to the climate zone of Central Europe [90]. In order to meet the required values prescribed by the standard requirements, the original facades of prefab residential buildings implemented as reinforced concrete prefabricated panels with a thickness of 270 mm to 300 mm are provided with additional ETICS contact insulation, which, according to the currently valid thermal engineering and energy efficiency requirements, reaches a thickness of 180 to 200 mm. In the long term, it appears that although prefab residential housing in Eastern European countries started to be insulated as early as the 1970s–1980s, the issue of biodeterioration of facades has started to emerge more significantly in the last 15–20 years [91,92], i.e., when the thickness of ETICS insulation increased to more than 100 mm. From the point of view of thermal engineering, when applying ETICS to panel cladding, the thermal resistance R [(m^2.K)W] of the vertical perimeter wall must increase from the interior to the exterior and the diffusion resistance or equivalent diffusion thickness [m] must decrease from the interior to the exterior.

In the Czech Republic, for example, around 200,000 prefab residential housing constructions with 1.2 million flats have been built using panel technology. For the Czech Republic, this means that the number of such flats is approximately 55% of all flats in apartment buildings and approximately 30% of flats in prefab residential housing that are part of housing estates [93,94]. These buildings have been or will be gradually remediated with ETICS. It is therefore clear that the issue of biodegradation needs to be addressed so that the remediation works of the housing stock are of high quality, effective, contribute to the positive view of the housing estates, and do not lead to increased demands for further repairs.

2.2.2. The Building, Construction Materials and Conditions for Microorganism

Microorganisms are an integral part of life on earth. Microorganisms need a suitable substrate, nutrients, sufficient moisture, and a suitable environment to grow. The basic sources of nutrition for algae include carbon from airborne carbon dioxide, salt, trace elements, and for fungi, organically fixed carbon and nitrogen sources. Other sources of nutrition are provided by rainwater, dust particles, high humidity, and condensation. Oxygen and pH of the substrate are also important factors [95–97] (Table 2).

Table 2. Conditions for the life of microorganism.

Conditions for the Life of Microorganisms	Characteristics
pH of building structures	For the growth of microorganisms, a slightly acidic to neutral pH is optimal. In general, buildings have a relatively high pH. For example, exterior mineral plasters (renders) have a pH value of up to 14 due to the calcium binders; the risk of microorganisms is, therefore, lower. However, with a relative humidity $\geq$ 75% and a pH value $\leq$ 10, buildings can become an ideal environment for the establishment and subsequent growth of microorganisms, at outdoor temperatures of approximately +5.0 °C to +10.0 °C [98].
Diffusion resistance factor for building materials	If the building material has an extremely high diffusion resistance factor μ [-], and the effective removal of condensed water vapour is not possible. It is necessary for ETICS to have a positive overall water vapour balance at the end of the period, i.e., more water vapour evaporated in the summer months than condensed in the winter months. At the same time, the amount of condensed water vapour must be less than 0.10 kg (m^2.a). Therefore, for the climate zone of Central Europe, the thermal resistances R [(m^2.K)/W] of the individual ETICS layers should be ranked from the lowest to the highest values from the interior to the exterior. Otherwise, positive condensation of water vapour cannot be ensured. The transport of water vapour can be further influenced by a suitable choice of material, especially of the render layer, where we monitor the diffusion resistance factor μ [-], which should be as low as possible [99,100].
Ambient pH	The pH value of the surrounding external environment has a great influence on the activity of microorganisms because it is an important factor in the uptake of nutrients by the microbial cell. High pH stops the growth of microorganisms. Microorganisms are able to significantly change the pH of the building substrate. Changes in the pH of the environment are determined by the number of acids and bases secreted by the macrobiotic agents and by the dissociation constants of the individual compounds. This mechanism by which microbes adjust the pH of the surrounding environment is of great non-corrosive importance. Most of the freshly laid thin-film renders with polymer binder used for ETICS have a pH value in the range of approximately 6–7. This means that these renders are not naturally protected against algae and micro-organisms compared to other types of mineral-based renders, which have a pH level of 10.50 to 11.60. On the contrary, they have a pH suitable for the occurrence of micro-organisms [101].
Water	The growth and expansion of microorganisms is promoted by the presence of water. The layers of ETICS renders, which are most often acrylic, silicate, or silicone, are more stressed by moisture compared to renders of a single-layer construction. Water moves from the surface of the render, which does not have a layer of polystyrene underneath, by capillary conduction towards the drier material and, thus, the appearance of a water film is significantly shorter compared to insulated façades. Because EPS insulation is not water soluble and has a closed microscopic structure, the closed pores in its structure absorb almost no water. Water cannot penetrate the ETICS thermal insulation, or the thin plaster layer including the reinforcing screed and accumulates on the surface [102].

2.2.3. Regional Conditions, Environment

Areas where atmospheric precipitation or fog is more likely to occur are areas with a high probability of facade biodeterioration on prefab residential housing. Other negative phenomena in the region are smog and dust. Rainwater, especially in areas of residential development that are regionally close to or directly part of an industrialised landscape with air pollution, contains large amounts of dissolved nutrients. Rainwater is then a source of nutrients for microorganisms. The same is true for airborne transmission of spores by dust particles. All this is a good prerequisite for starting the biodeterioration process. Spores transmit algae and fungi. In the process of biodeterioration of the façade with ETICS, the proximity of green areas and bodies of water whether natural or artificial, must also be taken into account as they are a source of spores. Another source of spores in housing estates is most often the growth of trees and shrubs, on whose bark green coatings commonly form [103,104]. In general, a greater concentration of dust particles will degrade the surfaces of cladding with ETICS with higher thermal resistance. Thus, where the outer surface temperature is lower. Paradoxically, in terms of the building's physical context, the perimeter wall with ETICS with better thermal technical parameters will be more degraded. The areas from which more heat escape will be less degraded.

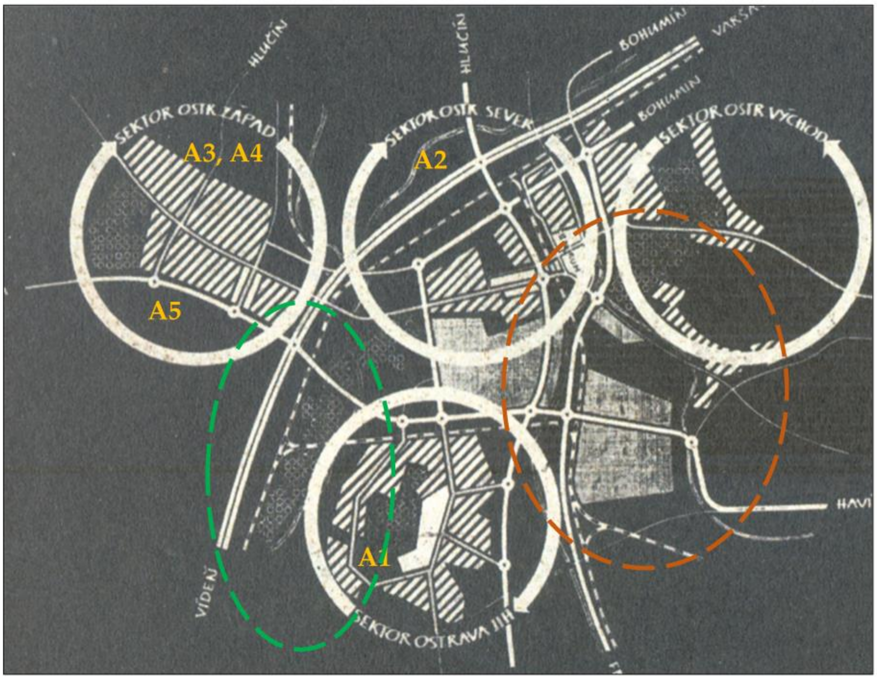
This phenomenon again promotes a greater risk of biodegrading. Locations where the concentration of work particles is longer-term will have a greater risk of infestation by biodegradation agents than the locations where the concentration of dust particles is more favourable.

2.3. Field Reconnaissance, In Situ Monitoring and Diagnostics, Case Studies

The field reconnaissance of settlement sites focused on the territory of the city of Ostrava in the Czech Republic (Case studies CS1 to CS5, geographical coordinates (49°50′8″ N, 18°17′33″ E), monitored sites marked A1 to A5, Figure 3a). The urban concept with the main locations of the housing estates, implemented between 1955 and 1985, is documented in Figure 3b; large scale prefab residential housing developments are located in these housing estates. The concept includes an urban sector of heavy industry and also a recreational area in the valley of the Oder river. The city of Ostrava, historically an industrial location with heavy industry is characterised by the fact that heavy industry was centralised in the middle of Ostrava, with new housing developments after 1955 concentrated to the west, east, and south. Gradually, satellite settlements were created, but they have a very well-built transport infrastructure and are, thus, well connected to the city centre. Within the case studies CS1–CS4, selected prefab residential housing in the form of block or point buildings, with a height level of 4–12, upper floor, where the ETICS composite with thermal insulation layer of EPS was applied, were monitored. From 50 mm to 120 mm on the original slag–concrete (SC) panel cladding or gas–silicate (GS) cladding. The monitoring followed the manifestations of biodegradation of the cladding of prefab residential housing, always with an area greater than 0.50 m^2.

(**a**)

Figure 3. *Cont.*



(**b**)

Figure 3. Locations: (**a**) Locations A1–A5 for case studies CS1–CS5 [52]; (**b**) Urban composition of the city of Ostrava (CZ) with four residential sectors, an industrial (orange colour) and a recreational zone in the Oder river valley (green colour), [32].

The case study CS5 focused on housing estates in brick and block technology, built between 1955 and 1962. For case study CS5, biodegradation manifestations were visually observed similarly, with an area greater than 0.50 m^2 (Table 3). At the same time, the environment was visually monitored for CS1–CS5 (Table 3).

Table 3. Overview of case studies and monitored parameters—construction area.

Case Study	Designation Locations	Monitoring Objects with ETICS (Number) and the Number of Samples Taken	Visually Visible Biodegradation of the Façade According to the Orientation of the Facade	Laboratory Results and Determination of the Genus of Microorganisms (According to Diagnostics In Situ)	Species External Plasters ETICS	Thickness Perimeter Walls (mm) and ETICS Thickness mm	Thermal Transmittance Original and with ETICS	Diffusion Resistance Factor EPS and External Plaster μ [-] ***	Coefficient of Thermal Conductivity **** λ [W/(m.K)]
CS1	A1	2	North Northeast > 0.50 m^2	Green terrestrial algae *Chlorophycae* and *microorganism Rotifera (Rotifera)*	Silicone	270–300 (SC)	1.769–1.651	20–40	0.029–0.041
		4				50–100	0.274		
CS2	A2	99	North Northeast > 0.50 m^2	Green terrestrial algae *Chlorophycae* and fungi *Dothideomycetes*	Silicone	300 (SC)	1.651	20–40	0.029–0.041
		4				50–120	0.274		
CS3	A3	71	North Northeast > 0.50 m^2	Green terrestrial algae *Chlorophycae*	Silicone	270–300 (SC)	1.769–1.651	20–40	0.029–0.041
		6				50–120	0.274		
CS4	A4	3	North Northeast > 0.50 m^2	Green terrestrial algae *Chlorophycae*	Silicone	270 (GS)	0.645	20–40	0.029–0.041
		2				80–100	0–216		
CS5 *	A5	20	No.	No *****	LCP **	450 (BBT)	0.427	No *****	0.80–0.88
		0				0	0.427		

Note: * Residential buildings of brick and block technology; urban conservation area; ** lime-cement plaster; *** the values of the materials used by the manufacturer; **** the values of the materials used by the manufacturer; ***** diagnostics were not performed and EPS was not applied.

The organization of the in situ observation and diagnosis in CS1–CS5 was focused on:

- In situ diagnostics with render sampling from the facade with ETICS (at the 1st floor level, approximately at a height of 1.00 mm to 1.80 mm above the prepared terrain), with an area of >0.50 m^2;

- Laboratory analysis, the aim of the laboratory analysis was to determine the genus of microorganisms present in the samples. In one case, samples were taken from the adjacent green area (CS1/A1), where extensive surface loading of vegetation was visually evident [105];
- Orientation of the prefab residential housing to the cardinal directions;
- Possible sources of spores from surrounding greenery and bodies of water;
- Type and parameters of external plaster (render);
- Thermographic measurement of biodegraded spots in the façade of a prefabricated apartment building;
- PM10 concentration and other air pollutants (for sites A1–A5 were assessed using data from [106]);
- Obvious defects on the facade with ETICS due to technological indiscipline.

2.4. Comparison of Results from Case Studies

The comparison of the results achieved in case studies CS1–CS5 focused on the construction and environmental domains (Tables 3–5).

Table 4. The period of construction of housing estates and the period of project preparation.

Case Study	Locality	Project (Flight Period)	Construction (Period of Years)	Area for Monitoring (ha)	Monument Protection
CS1	A1 (c)	1965–1970	1968–1985	2	No.
CS2	A2 (b)	1964–1975	1967–1985	90	No.
CS3	A3 (a)	1963–1966	1966–1974	50	No.
CS4	A4 (a)	1968–1970	1970–1972	2	No.
CS5	A5 (a)	1951–1953	1952–1961	5	Yes (since 2003)

Note: (a) The total area of the western part of the site is 635 ha. (b) The total area of the northern part of the site is 178 ha. (c) The total area of the southern part of the site is 597 ha.

Table 5. Overview of case studies—environmental area.

Case Study	Designation Locations	Concentration PM10 (Annual Average of 2016 and 2020) and PM2.5	Other Components (Annual Average)	Natural Water Resources	Artificial Water Bodies	Proximity to Greenery	Proximity to an Industrial Site
CS1	A1	29.60–21.90 16.40–23.70	NO_2, BZN, BaP, As, PB, Ni, Cd	Oder river	No.	Poodří protected landscape area, park improvements	No.
CS2	A2	30.20–22.50 17.30–26.10	NO_2, BZN, BaP, As, PB, Ni, Cd	-	No.	Park improvements	Chemical industry
CS3	A3	27.30–20.50 15.90–22.20	NO_2, BZN, BaP, As, PB, Ni, Cd	-	No.	Park improvements	No
CS4	A4	27.30–20.50 15.90–22.20	NO_2, BZN, BaP, As, PB, Ni, Cd	-	No.	Forest park	No.
CS5	A5	27.30–20.50 15.90–22.20	NO_2, BZN, BaP, As, PB, Ni, Cd	-	No.	Park improvements	No.

2.5. Interpretation of Results of Case Studies CS1–CS5

In all monitored prefab residential housing, additional contact insulation with ETICS composite and EPS thermal insulation was implemented, with the thickness of EPS insulation ranging from 50 mm to 120 mm, with a perimeter panel wall thickness of 270–300 mm (SC) and with a perimeter panel wall thickness of 270 mm (GC), always with external silicone render. Table 6 show the differences in thermal transmittance when applying ETICS with EPS with a thickness of 100 mm compared to the original panel wall without thermal insulator. This corresponds to partial water vapour pressures at a typical location of the structure under steady design conditions. Figures shows the condensation zone of a panel wall construction without thermal insulator (Appendix A, Figure A1a), and panel wall construction with EPS thermal insulator with a thickness of 100 mm (Appendix A, Figure A1b) and shows a perimeter wall made of brick blocks (Appendix A, Figure A1c) [107]. The graphs show the significant influence of the additional insulation layer on the surface temperature and the temperature inside the structure. Determination of temperature inside the material layers of structures at steady temperature leads to the definition of the partial pressures of water vapour in the structure and then the determination of the condensed water vapour. When contact insulation is carried out with ETICS composite on a panel wall, initially single layered, we create a multi-layered construction where the occurrence of condensation is more dangerous, which can result in defects in materials and structures.

Table 6. The characteristics of perimeter casings.

Peripheral Wall Material and Peripheral Wall Thickness	Thermal Transmittance Original U [W/(m^2.K)]	Thermal Transmittance Inc. EPS Thermal Insulation th. 100 mm U [W/(m^2.K)]	Thermal Resistance of the Original Design R [(m^2.K)/W]	Thermal Resistance of the Structure Inc. EPS th. 100 mm R [(m^2.K)/W]
SC 300 *	1.651	0.274	0.436	3.483
SC 270 *	1.769	0.274	0.395	3.830
GS 270 **	0.645	0.216	1.380	4.468
BBT 450 ***	1.307	Without EPS	2.173	-

Note: * SC—slag concrete; ** GS—gas silicate; *** BBT—block brick technology, [108].

The outer surface is damp. It is clear from the differences that:

- Condensation zone moves towards the exterior according to physical principles;
- When the EP thermal insulation is placed on the outside of an ETICS panel wall, condensation does not usually occur inside the structure, but if condensation does occur, the condensation zone is then closer to the outer face;
- A larger area of biotic infestation of facades is supported by a panel wall with ETICS, compared to a brick wall without ETICS. For masonry without thermal insulation, the risk of night-time condensation lasts for two months during the calendar year. In the case of masonry with thermal insulation, the risk of condensation of water vapour on the facade surface is up to 6 months under the right conditions during winter;
- In the case of facade renders that have a diffusion resistance factor $\mu = 5$ [-] the moisture permeation through the final ETICS layer, i.e., through the external render, is extremely slow. This means that the moisture load on the ETICS facade surface is longer, thus providing better and longer lasting conditions for the life of microorganisms.
- For all prefab residential housing (CS1–CS4) in all locations (A1–A4), visual inspection revealed biodeterioration in the facade area (Figure 4). The most frequently affected areas were mainly the north, north-east, and north-west oriented gable walls; places where there was an increased incidence of condensation (e.g., building expansion joints, part of the facade outside the area of the internal heating system, places where there were obvious technological defects, e.g., poorly executed plumbing and thus leakage, etc.). A thermographic survey was carried out at selected sites of biodegradation, which confirmed thermal inhomogeneity in the facade area (Figure 5). The thermographic image showed the temperature map of the ETICS surface. Irregularities in the temperature field were found in the measured parts of the house. Inhomogeneity predicts degraded thermal insulation properties of external materials and technological discipline. The thermography can obtain a sufficient picture of damp places in ETICS, with the possibility of biodeterization. Thermography can be seen as a sufficient non-destructive method for the potential development of biodegradation.

(**a**) (**b**)

Figure 4. Biodegradation of facades of panel apartment buildings with ETICS (examples): (**a**) Facade in the shade; (**b**) Technological indiscipline.

Object Parameters	Value
Atmospheric Temperature	-4.0 °C
Relative Humidity	75.0 %
Sp1 Temperature	-4.0 °C
Sp2 Temperature	-3.4 °C
Sp3 Temperature	-2.9 °C
Sp4 Temperature	-3.5 °C
Sp5 Temperature	-2.9 °C
Sp6 Temperature	-2.8 °C
Sp7 Temperature	-2.4 °C
Sp8 Temperature	0.5 °C

Figure 5. Biodegradation of the facade at the point of expansion of a panel apartment building and thermographic determination of temperature inhomogeneity [107,109].

The diffusion resistance factor μ [-] for external silicone renders reached values of 20–40 [-] Ø 30 [-]; the diffusion resistance factor μ [-] for EPS reached values of 20–70 [-]; Ø 45 [-]; the thermal conductivity coefficient λ [W/(m.K)] for the external silicone render reached values from 0.029 to 0.042 [W/(m.K)]; Ø 0.035 [W/(m.K)]; and the thermal conductivity coefficient λ [W/(m.K)] for EPS reached values from 0.033 to 0.039 [W/(m.K)], Ø 0.360 [W/(m.K)]. The coefficient of thermal conductivity of ETICS will significantly affect humidity. If the humidity increases, the thermal conductivity will increase and its thermal insulation capabilities will decrease. The load on the facade with ETICS moisture will affect the declared values of the materials, although they can be considered correct from the point of view of the design.

For case study CS5 at Site A5, the biodegradation of the façade was not found to be a significant area of colonisation of the façade by microorganisms. 'Greenish' spots were found locally on details, such as the plumbing around skirting boards; however, this can be characterised as technological indiscipline resulting in the defective area being damp.

Considering the building from a physics context of water vapour diffusion and the rule that for the order of layers in a multilayer construction, the diffusion resistance of the layers decreases from the first inner layer to the last outer layer, it follows that the values μ 20–40 [-], Ø μ = 30 [-] for silicone external render and μ 20–70 [-], Ø μ = 45 [-] for EPS have a minimal difference. It will always depend on the specific type of external render, the grain size, and the bulk weight of the EPS. When designing the ETICS composition, a render with high diffusion resistance should not be used; the render should be designed as vapour permeable, with the lowest possible diffusion resistance factor. The lower the diffusion resistance factor number, the higher the amount of water vapour permeating the material, i.e., the insulator "breathes better". It is therefore desirable that the diffusion resistance factor of the insulation system layers towards the interior is as low as possible, so that water vapour can pass freely through the structure of the insulation system and subsequently evaporate through the render layer.

Important aspects of ETICS design include the correct choice of render and pH value (pH value has a considerable influence on the activity of microorganisms, as it is a key factor in the uptake of nutrients by microbial cells). A high pH stops the growth of the microorganism (historically, for example, the "bleaching" of walls with lime for hygienic and disinfection reasons is well known). A lime-cement plaster on brick block masonry with a thickness of 450 mm for CS5/A5 seems to be optimal (it contains lime), however, it is not used as an external render of the ETICS composite.

Samples collected for analysis and genus determination showed that green terrestrial algae *Chlorophycae* that formed colonies were present in all samples at CS1–CS4 sites A1–A4, and fungi of the genus *Dothideomycete* were also present at site A2. It can be summarized that the surfaces of the ETICS exterior render were colonized by autotrophic organisms that contributed to the biodeterioration of the ETICS exterior render; this concerns the category of algae and cyanobacteria (Figure 6).

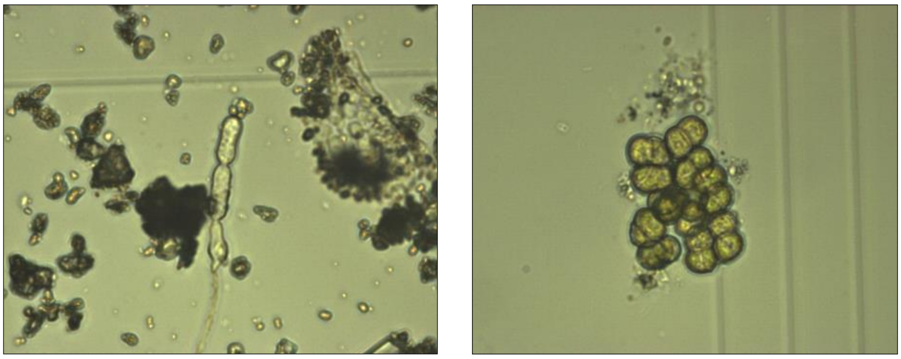


Figure 6. Magnified photomicrograph of sample leachate 400× (CS1–CS5); microorganisms of terrestrial algae Chlorophycae.

At Site A1, the green terrestrial algae *Chlorophycae* was detected in samples collected from trees adjacent to park landscaping. These are the same microorganisms that were detected on the facade of prefab residential housing (CS1).

In one case, the microorganism Rotifera was detected on prefab residential housing, where the Oder river and the Poodří protected landscape area are located nearby (detection at site A1). If we characterize the genus *Rotifera*, then it is a strain of invertebrates that lives in the wild, in open water in the plankton of lakes and ponds, in polluted waters, in moist soil, drying moss, among grains of sand and is also found in mine shafts; females and males live singly or form colonies. The highest species richness of Rotifera is in waters with low pH and its main food sources are algae, protozoa, and bacteria. Micro-organisms such as fungal spores and fungal typhi were detected in lower abundance in the samples collected. The occurrence of the microorganism Rotifera was sporadic; we decided to associate this sporadic occurrence with the character of site A1. It is most likely that it was a stray individual that was "accidentally" transported to the site by the migration of living hosts.

Out of the total area of 1.410 ha of housing development (for A1–A5), 10.60% of the housing development area was monitored and in all cases the same species of micro-organisms were identified for biodegradation infestations.

From the point of view of the timeline (2010–2021) of ETICS application on prefab residential housing, it can be observed that the biodegradation manifestations for facades with EPS that had a thickness of 100 mm or more started in a shorter period of time than façades where the EPS is not as thick. It is believed that the process of "settling" microorganisms on the ETICS surfaces eventually converges over time, and the biodegradation events occur simultaneously regardless of the thickness of the EPS insulator. This corresponds to the type of microorganisms that were detected on the surface of the façades of prefab residential housing and also to the relationship between the thickness of the ETICS thermal insulation and the temperature of the façade surface under standard conditions for the temperate climate zone of Central Europe.

In site CS5/A5, no samples were taken for the residential housing because there were no anomalies in the façade area that would indicate that the render was affected by surface biodegradation.

- Emissions at the monitored sites are based on the classification of the area, which can be characterised as an industrial area with chemical plants, heavy steelworks and, in the vicinity of the Czech Republic–Poland border underground coal mining. Statistical overview data according to [106] were used to document emissions. The data show that all sites fall within areas with higher concentrations of PM10 and PM2.5. However, the most burdened site is A2, which is located near an industrial area (chemical plants, steelworks). For the first quarter of 2019, the PM10 = 31.9 [μg.m^{-3}] and for site (A1, A3, A4) PM10 = 25.0 [μg.m^{-3}] (see Appendix B, Figure A2a,b). Although PM10 concentrations at sites A1, A3, and A4 were recorded at lower levels, the biotic infestation was comparable to site A2, which is close to industrial activity. This fact can be influenced by prevailing winds, and also by vegetation, because sites A1, and A4 are located near vegetation (natural forest park, park landscaping, and protected landscape area Poodří with natural flow of the river Oder).

2.6. Identification of Common Features for the Onset of Biodeterioration

The identification of common features for the initiation of biodeterioration was conducted on the basic of the criteria defined in Section 2 (and Appendix A, Figures A1 and A2). Character identification:

- Condensation zone moves towards the exterior;
- Regional conditions, industrial sites and elevated PM10 concentrations;
- The same type of microorganisms in the studied sites;
- North orientation of the facade;
- Type of external render ETICS (silicone);
- The material of the original cladding made of lightweight concrete (slag–concrete, gas–silicate);
- Diffusion resistance factor;
- Coefficient of thermal conductivity;
- Technological indiscipline.

An interval ranging <1–5> was introduced to assess common identifying features, with the interval (a) <1–3> characterised as a standard rating (favourable and less favourable), with no major intensity of negative impacts against panel housing estates and prefab residential housing; (b) <4–5> characterised as having a greater intensity of negative impacts against panel housing estates and prefab residential housing (less favourable to unsatisfactory).

The features identified according to Table 7 show that environmental aspects are an integral part of the building criteria. If the identified environmental features in a housing estate site exceed more than 50% (Table 7, Figure 7, not rated C5), it is advisable to design other external render materials for ETICS, with different structural and physical parameters, because the negative impact on the construction area will be approximately 60–80% (not rated C5). Therefore, environmental features can be described as primary features and construction features can be described as secondary features, which are caused by insufficient consideration of the environment and lead to the emergence of biodeterioration of the ETICS facade, at different time horizons in terms of the initiation of the biodeterioration process (usually within 5 years from the application of ETICS). The application of ETICS cannot be seen primarily as an individual construction activity, but as part of the macroclimate of the urban environment, which includes environmental aspects.

Table 7. Identified characters.

Part	Characteristic and Case Studies	CS1/A1	CS2/A2	CS3/A3	CS4/A4	CS5/A5
Environment part	Proximity to greenery	<4–5>	<1–3>	<1–3>	<4–5>	<1–3>
	Proximity to bodies of water	<4–5>	<1–3>	<1–3>	<1–3>	<1–3>
	Increased concentration PM10	<1–3>	<4–5>	<1–3>	<1–3>	<1–3>
	Proximity to an industrial site	<1–3>	<4–5>	<1–3>	<1–3>	<1–3>
	Predominant microorganisms in the surrounding environment	<4–5>	<4–5>	<4–5>	<4–5>	<1–3>
Building part	Wall thickness 270–300 (mm) and material (SC)	<1–3>	<1–3>	<1–3>	-	-
	Wall thickness 270 (mm) and material (PS)	-	-	-	<1–3>	-
	Wall thickness 450 (mm) and material (block brick technology)	-	-	-	-	<1–3>
	A type of exterior plaster	<4–5>	<4–5>	<4–5>	<4–5>	<1–3>
	Diffusion resistance factor EPS and exterior plaster	<4–5>	<4–5>	<4–5>	<4–5>	<1–3>
	Coefficient of thermal conductivity	<4–5>	<4–5>	<4–5>	<4–5>	<1–3>
	Technological indiscipline	<4–5>	<1–3>	<1–3>	<1–3>	<4–5>
	Facade orientation (north, northwest)	<4–5>	<4–5>	<4–5>	<4–5>	<1–3>

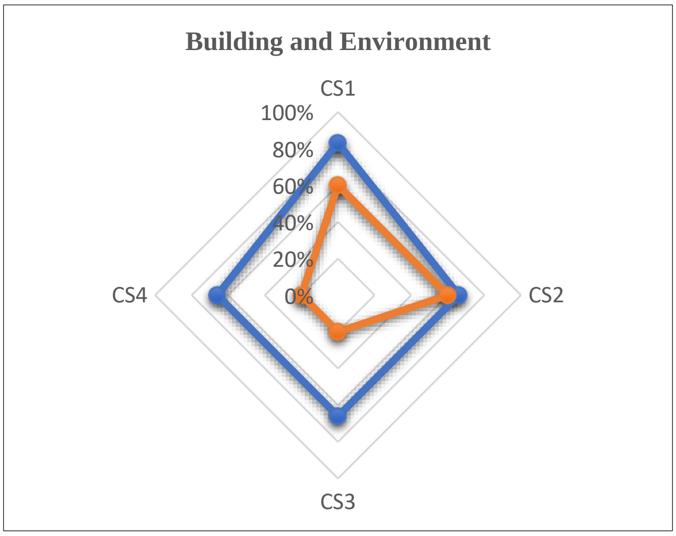


Figure 7. Percentage in relation to the prediction of biodegradation for environmental and building characters (for CS1–CS4), orange colour—environmental part and blue colour—building part.

A different situation occurs in the construction of apartment buildings using block brick technology, where the application of ETICS is not carried out and the houses have a traditional external lime-cement render. These buildings are more energy-intensive, but in terms of construction physics, they are less susceptible to facade biodeterioration.

3. Results

Panel housing estates and prefab residential housing are an integral part of society and housing in the 21st century. The identifying features show that the environment is an essential and necessary part of the architectural disciplines in the creation of a new or regenerated building work. If we consider the modern disorder in the form of biodeterioration of the facades of prefab residential housing located in housing estates, the elimination of biodeterioration of ETICS should be understood as an interaction of environmental, urban, structural–architectural and technological contexts, which, as a whole, create a holistic approach to the problem (Figure 8) and which we project into the investment process of construction with the use of ETICS. Panel housing estates and prefab residential housing are an integral part of society and housing in the 21st century. The identifying features show that the environment is essential and necessary. From the implemented case studies (CS1–CS5) in selected locations (A1–A5), it can be concluded that the main emphasis on the elimination occurrence of biodeterioration of the ETICS facade should be placed in the design phase of the regeneration of panel housing estates and in the design of ETICS composites, including the optimal choice of building materials. In terms of the construction investment process, this corresponds to the pre-investment phase and particularly to the investment phase. The investment phase includes Basic Design (BD) and Detail Design (DD) projects. In these design documents, the occurrence of biodeterioration can be adequately and maximally eliminated by taking into account the environmental criteria (Table 7), so that an informed decision can be made on the choice of appropriate insulation systems and their composition. The next stage, when the occurrence of biodeterioration can be eliminated, is to conduct a thorough and qualified structural and technical survey, including taking samples from the original facade for laboratory analysis, the aim of which is to decide whether or not the original panel façade is influenced by bio-agents. If the laboratory analysis confirms that the original panel facade is infested with microorganisms and the façade is not cleaned well before the application of ETICS, then the probability of biodeterioration of the ETICS facade is almost 100%. A separate phase is the technological phase, i.e., the actual implementation of ETICS. Here, it is necessary to consistently implement technological procedures and eliminate technological indiscipline to prevent possible leakage towards the ETICS, e.g., by leaks of plumbing installations, etc. These wet areas can create a very suitable environment for the establishment of microorganisms.

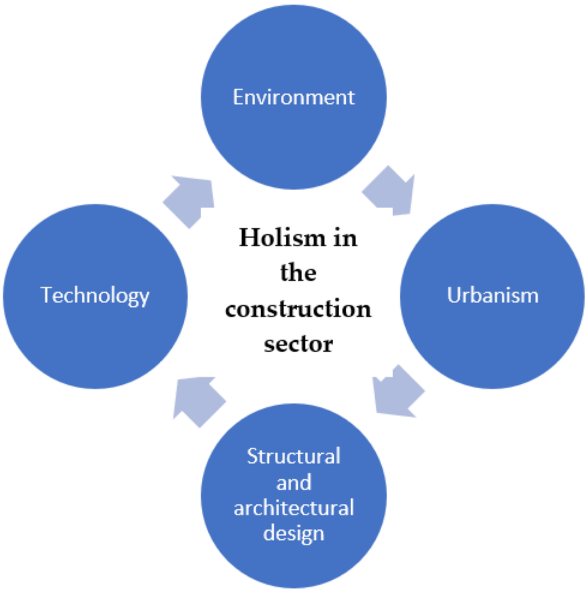


Figure 8. Biodegradation and holistic approach.

4. Discussion

The EU’s strategic goals for 2030 and 2050 show that energy efficiency, CO_2 reduction, climate neutrality, and the Green Deal, are strongly accentuated in the construction sector, and, in addition to new builds, also the reconstruction and regeneration of existing buildings, which includes the regeneration of prefab residential housing. The ETICS composite is a key material for this strategy in increasing energy savings, a material that fulfils the principle of the circular economy. If we compare external walls with and without ETICS, the positives clearly outweigh the negatives in terms of energy savings and thermal-technical properties.

There is no clear solution to prevent the occurrence of microorganisms on the facades of prefab residential housing equipped with ETICS. If we know that the facades of prefab residential housing located in housing estates, near areas of vegetation or natural bodies of water, are mostly shaded during the day, it is appropriate to choose other effective technologies to improve thermal engineering and energy efficiency measures.

The facade of prefab residential housing that is affected by biodeterioration often raises concerns among the general public that the facade degraded from biodeterioration is harmful to health, and that spores from microorganisms may migrate to the indoor environment and thus deteriorate the quality of the indoor microclimate. There are no citations on the harmfulness to human health of the mentioned microorganisms on the surface of ETICS. However, the available scientific sources indicate that fungi and moulds which develop on organic and building materials gradually form colonies; in the introduction we defined that microorganisms reproduce by means of spores that can then spread in the surrounding environment through the air or by animals. In this case, allergic problems may occur. For example, some species of the microorganism genus *Alternaria* are known as major plant pathogens, are common allergens, and can cause allergic symptoms in some individuals. Additionally, moulds, algae, fungi, and typhi can cause allergenic reactions in particularly sensitive or allergic people; more sensitive people may be more susceptible to infections [110]. The inhalation of allergens from the biodegraded surfaces on the ETICS surface when the individual is indoors, and thus triggering an allergic reaction, is very unlikely. An individual's indoor exposure to allergens is limited by the time of exposure and the concentration of potential allergens. In the case of prefab residential housing, we do not assume that the migration of allergens from the external environment from the ETICS surface towards the interior is large or otherwise systematic, and a higher concentration of the allergens in the closed environment is not assumed over a longer period of time. However, with a higher intensity of natural ventilation through the windows and the corresponding climatic conditions, including the prevailing wind direction towards the buildings, some microorganisms (e.g., microscopic filamentous fungi) that are present on the external render can be released into the air and, through natural air transport, enter the interior spaces. However, this area of research requires coordination of technical and medical as well as natural science disciplines, so that the hypothesis of transport of certain micro-organisms into the indoor environment and thus the direct negative impact of allergic manifestations on people can be evaluated in a relevant way [111,112]. The issue of micro-organisms, including biocorrosion of ETICS façades, leads to calls for building microbiology to be integrated to a greater extent into interdisciplinary research and standard legislation relating to the quality of both the internal and external environments of buildings.

The discussion on the possible heritage protection of panel housing estates shows that the approach of society to the problem of possible heritage protection of panel housing estates varies in European countries and results mainly from historical, social, and economic contexts. The views of conservationists in terms of heritage protection generally head towards two areas. The first part of the heritage protection can include modern urban concepts and the second part of the heritage protection can include prefab residential housing, mostly solitary buildings, where the modern post-war design of the construction, the technology used, or other distinctive structural architectural elements are in some way interesting. The protection of entire panel housing estates, including prefab residential housing, is not widespread in Europe and it is probably not the priority of societies to protect housing estates on a larger scale. As stated, for example, by the authors [113,114] " . . . the point is not to glorify prefabs ("panelák" (prefab) is a colloquial term for a prefabricated apartment building in the Czech Republic.), but it would be a mistake to try to erase them from architectural history and pretend that they can have no architectural qualities . . . " Additionally, if such a selected prefabricated solitary building is to be protected (listed), then it is imperative that it should be of high quality, not only in terms of structural and urban design but also in terms of aesthetic value. This means that in the case of ETICS application the modern disturbance in the form of biodeterioration of the panel façade is completely undesirable.

5. Conclusions

Quality of housing is an essential component and requirement in people's lives. In the 21st century, the approach to accessing housing quality assessment is becoming multidisciplinary. Healthy and quality housing, along with an aesthetically pleasing external environments, must respect not only the technical, architectural, and structural principles of design and construction, but also the social, cultural, societal, and environmental contexts. The aim of this work is to balance and optimize the above-mentioned contexts so that the regeneration of prefab residential housing with the application of ETICS, assuming systematic maintenance, will extend the quality life of these panel buildings by at least another 25 to 30 years.

Clearly, the energy aspect is central to today's society in a global sense. The innovation potential in the application of new environmentally friendly materials is fast moving in the construction industry; therefore, the application of ETICS has a great potential for further development. The ETICS composite must be seen as an efficient technology that is environmentally friendly, improves the energy performance of prefab residential housing in terms of energy efficiency, and works effectively in good time, i.e., without biodegradation surface defects.

The needs and demands of contemporary society are changing. Society is made up of different sociodemographic groups in the housing sector and panel housing estates are an integral part of people's lives. Therefore, improving the energy efficiency potential of panel housing estates using ETICS is also justified in the coming decades. Prefab residential housing and panel housing estates will be a form of housing, especially in Eastern European countries, for at least the next 50 years and probably longer. The quality of regenerated prefab residential housing, with the use of ETICS, can have a very positive and long-term impact on the stability of urban areas and settlements, as well as the way and intensity of using housing estates, especially by the middle class. All of this leads to the desired social and economic sustainability of the housing estate localities. It is therefore necessary that current structural and architectural design emphasises the connectivity of the external and internal environment and the associated biocorrosion factors of ETICS already in the pre-investment and investment phases, and the interaction between the building sector and the environment has become one of the main criteria that significantly influence the sustainability and future of prefab residential housing and the aesthetic quality of panel housing estates.

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Data Availability Statement: Data are stored with the author of the article.

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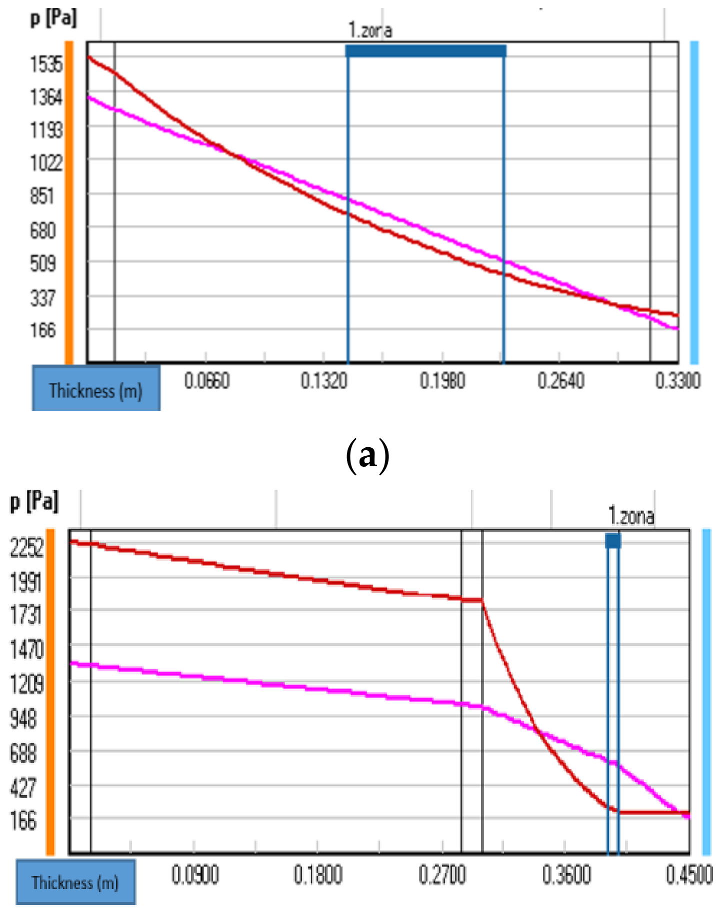
Conflicts of Interest: The author declares no conflict of interest.

Appendix A

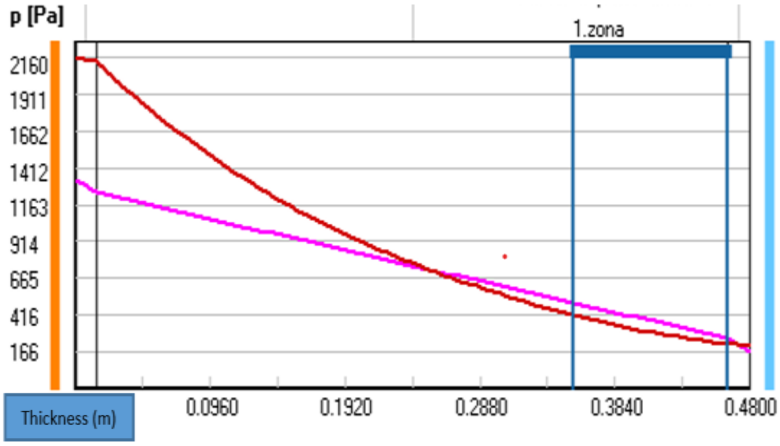
It follows from the generally known building-physical contexts that external plasters of ETICS, which are most often acrylic, silicate, and silicone, are subjected to more stress by moisture than plasters of single-layer finishes. Water from the surface of external plasters applied on a base that is not provided with ETICS migrates by capillary conductivity towards a dry surface, and thus the occurrence of water emulsion is significantly shorter compared to facades provided with ETICS. In contrast, the polystyrene used in ETICS is insoluble in water and has a closed microscopic structure, whereby closed pores in its structure absorb almost no water and water is concentrated on the surface [12,16,17]. The surface layer of buildings with ETICS stays cold, especially in the autumn and spring months, and it is not warmed by the heat that escapes from the interior of the buildings through the walls, as is the case with buildings without ETICS, the single plaster layer of which warms up. Conversely, the greater the thickness of the ETICS insulation, the greater the theoretical prediction of moisture on the outer surface and the impact of biodegradation on the facade.

ETICS external thermal insulation keeps the interior warm, whereas its external plaster cool down is intense, especially on clear nights, when the ETICS surface temperature drops faster than the ambient air temperature. If the temperature drops below the dew point, moisture condenses on the cold surface of the facade. Condensate and moisture form under cold conditions and stay on the surface of the facade, particularly on the northern side of the building or on sides that are more shaded. The conditions for the growth of microorganisms thus become favourable (published 2021, Kubečková, D., Vrbová, M., [18–21,94]).



(b)

Figure A1. *Cont.*

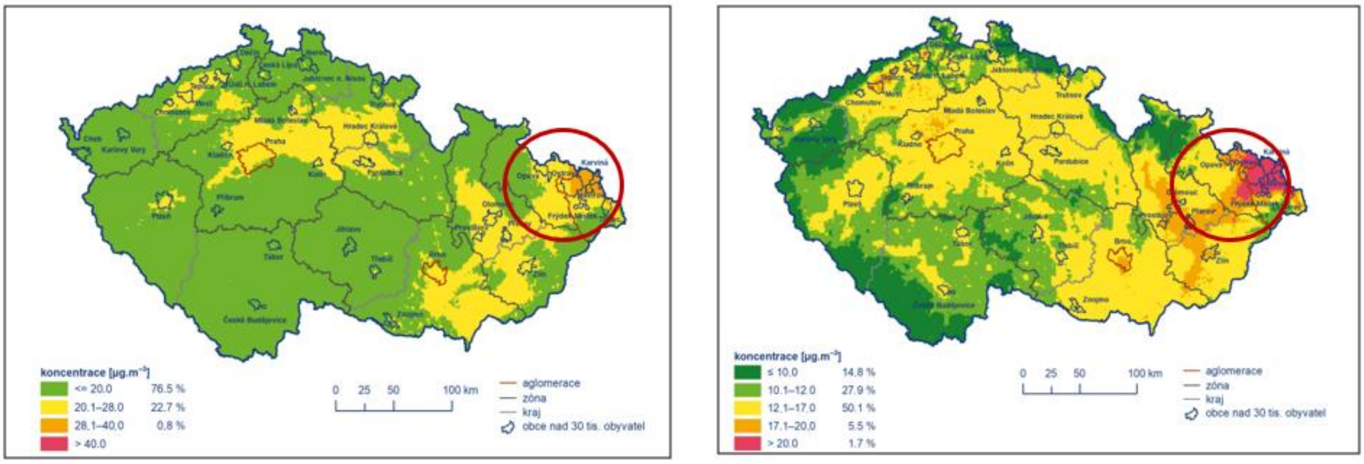


(**c**)

Figure A1. Partial pressures of water vapour at a typical location of the structure under steady design conditions [107]; (note: Figures show the course of water vapor pressures with the condensation area of the peripheral shell wall marked. The course of water vapor pressures was verified in accordance with the requirements of Czech Code 73 0540, Software Heat. The horizontal axis shows the equivalent diffusion thickness sd [m] and the vertical axis shows the distribution of water vapor pressures in the peripheral shell P [Pa]). (**a**) Condensation zone in panel wall construction without thermal insulation. The construction is simple. (**b**) Panel wall construction with EPS heat insulator in thickness 100 mm. Composite, multilayer (sandwich) construction. (**c**) Perimeter wall made of brick block blocks. The construction is simple.

Appendix B

The annual limit of PM10 is 40 μg.m^{-3}. The value of the air limit for an average 24 h PM10 concentration is 50 μg.m^{-3}. The legislation (for CZ) admits a maximum of 35 exceeding the value of the daily limit for a year; with a higher number, the limit is considered exceeded. In terms of human health, the more problematic are suspended particles of PM2.5 (annual limit of 25 μg.m^{-3}). The highest number of exceeded was recorded at the stations of the Ostrava City agglomeration, see Figure A2a,b; (source: http://portal.chmi.cz/files/portal/docs/uoco/web_generator/exceed/summary/limit2011_cz.html, accessed on 1 March 2021).



(**a**) (**b**)

Figure A2. Concentration of PM10 and PM2.5 [106]: (**a**) Five-year average of annual average concentrations PM10, 2016–2020; (**b**) Five-year average of annual average concentrations PM2.5; for period 2016–2020.

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