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Impact of the surface roughness of stones used in historical buildings on biodeterioration

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HIGHLIGHTS

- We found that surface roughness of the stone had a great impact on the growth of plant.
- The plants cover the stone surfaces and induce the visual pollution.
- The highest surface roughness values belong to the travertines with high porosity.
- The plants growing were mostly observed at horizontal or slightly sloped parts of the buildings.

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ABSTRACT

Rock surfaces are modified in natural outcrops depending on the interaction between the atmosphere and the rock. Biological factors are natural conditions that have persistent adverse effects on historical buildings. Because the effects of these factors are continuous and slow, the measures taken are mostly neglected. Primary biological effects come from plants that grow on buildings, which can cause them harm. In the field of study, there are significant historical buildings located in central Anatolia (Niğde region) that have hosted many civilizations over time. In this study, 6 historical buildings constructed with different stones were chosen to determine which plants grow on these historical buildings and whether they cause harm to these buildings. First, the mineralogical and engineering properties of the stones used in these buildings were determined; then, the studies regarding surface roughness were conducted. It was determined that the types of stones, their locations on the building and the surface roughness of the stone had a great impact on plant growth. It was observed that although the deserted churches were constructed using high strength stones, the herbaceous and woody plants growing in the gaps between the stones located on horizontal or slightly sloped parts of the building with a high level of surface roughness cause substantial harm to the roof coating.

1. Introduction

One of the most significant factors that determine society's place in civilization are the historical buildings that have endured over time and by their architectural properties. Historical buildings, however, are subjected to negative natural and anthropogenic factors.

Weathering processes lead to changes in rock surfaces from the moment they are exposed to open air, whether they are natural outcrops or buildings. In nature, changes in the rock composition is the result of different chemical, physical and biological factors, which lead to the production of (bio)-minerals (deposition) and/or to erosion processes that are either constructive or destructive phenomena, respectively [1].

The strategic significance of the city has attracted many civilizations to build cultural assets in and around Niğde. These cultural assets indicate a wide range of buildings such as castles, mosques, churches, mausoleums, masjids, bathhouses, madrasah, covered bazaars, water fountains, caravanserais, aqueducts and pools. In addition to being grand and important, these buildings are also found to be appealing for their artistic, cultural and aesthetic properties.

Some of these buildings have deteriorated and are still deteriorating for such reasons as earthquake, war, fire, negligence, intention, non-maintenance, climatic factors, and anthropogenic and biological impacts. Various acids formed by chemical reactions around plant roots lead to the deterioration of stones used for

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the construction of buildings, either directly or through an interaction with other compounds [2–11]. As a result of the aforementioned factors, cracks and fractures appear, and pores and cavities increase over time [12]. Even plants that are able to persevere under insufficient conditions need rather developed roots to survive. Thus, plant roots flourish in terms of both their surface and length. The roots of plants that flourish penetrate deep into the gaps between or the fractures on the stones used in the construction of historical buildings and induce chemical and physical weathering [13]. Furthermore, by mechanically pushing the stones, the roots cause an extension of fractures and the deep penetration of water; furthermore, the fractures extend as the water penetrates and freezes during the winter [13,14]. As the resistance of the building to external factors decreases, the deterioration of historical buildings becomes inevitable as a result of the combination of all biological, chemical, physical and climatological impacts [15].

Biological colonization is affected by substrate characteristics both physically (roughness and porosity) and chemically (mineral composition and surface pH) [16–18]. Some researchers think that of all of the properties, roughness is the one that has the most substantial impact [19,20]. Actually, because of the substrate's roughness, microorganisms and organic materials that are transported to the building by blowing wind and running water become adhered to the substrate. Moreover, a building surface that is not free of roughness has an impact on running water. Comparing rough and smooth building surfaces, the former is less resistant to biofouling [18,19,21,22]. Another factor affected by roughness is the absorption of the sun's radiation. For a specified color, the surface roughness is directly proportional to the absorption of solar radiation and, thus, to the surface temperature. This phenomenon is observed more intensely when the substrate color is lighter [23]. Biological colonization is largely affected by roughness. Algal cells easily adhere to rougher surfaces, and yet algae have the ability to extend on such surfaces [24].

The definition of biodeterioration includes the changes in a material's properties experienced by living organisms as a result of their activities for survival in a way that is not quite preferred. These undesired changes are the results of chemical, mechanical and physical impacts [1,4,25–27].

Microorganisms flourishing on the surface lead to microbiological deterioration and chemical deterioration [28–30]. According to the first impacts of inorganic agents that cause deterioration, the biodeterioration process, generally regarded as a degradation process, occurs. As the structure changes and the substrates that consist of organic and inorganic nutrients increase, the agents make the stone surfaces susceptible to microbial contamination. Microorganisms, observed on the facades of buildings, consist of bacteria (including actinomycetes), algae (including cyanobacteria), lichens and protozoa [15,18,29].

Because of their photosynthetic features, algae and cyanobacteria are generally characterized as the first microorganisms to conquer historical monuments. These microorganisms may cause chemical or mechanical deterioration of the stones, and the traces of patina or crusts on the surface indicate the existence of these microorganisms. Because of the high level of resistance to desiccation and extreme temperatures, lichens, as well as mosses and vascular plants, are generally thought to play a role in the biodeterioration of stone. The stone decays physically and chemically by being exposed to autotrophic and heterotrophic bacteria found in the biofilms. Finally, fungi that settle on the substratum also play a role in the chemical or mechanical deterioration of stone [31].

Although plants have been known to flourish on historical buildings, leading to the deterioration of a building's structure, the amount of research conducted in this field is limited. Early studies primarily categorized wall flora [20,32–35]. Recently, the number of studies conducted concerning lichens has increased, and these studies have specifically addressed these plants as being bioindicators or environmental pollution sensors [9,15,29]. Because the damage caused by lichens on buildings is less and slower than those by herbaceous plants, it is essential to consider these damages as being predictors. Despite various studies in the literature regarding the deterioration of stone buildings caused by biological effects [3,5,6,8,9,11,16–18,22,24,25,34,36,37], the studies that discuss the effects of location, surface roughness and the porosity of the building's stone on biological weathering are not sufficient [19,20,24].

The biota on buildings' stones represents a complex ecosystem that develops in various ways, depending on the environmental conditions and the physicochemical properties of the material in question. At this point the field needs to move beyond basic characterization to develop a better understanding of material behavior [38] and the maintenance necessary to sustain long-term performance [39]. It is important to determine petrological descriptions, surface roughness, porosity, capillarity, mechanical strength and the velocity of sound by investigating with a scanning electron microscope and XRD analyses to understand the relationships between biodeterioration and rock performance.

Based on such aspects, this study significantly contributes to the literature. The subject of this study is the deterioration of historical buildings by plants according to the type and location of the stone (in the foundation, wall, roof and exposure), stone surface roughness and climatic agents.

2. Materials and methods

2.1. Site description

Niğde is a province in the southern part of Central Anatolia, Turkey. The province is surrounded on three sides by the Taurus Mountains, including Mount Hasan and the Melendiz Mountains. To the west is the Emen plain, which opens into the wide plain of Konya. Niğde is located between 37 degrees 25 min south (S) and 38 degrees 58 min north (N) latitude, and 33 degrees 10 min west (W) and 35 degrees 25 min east (E) longitude. The study area has an average elevation of 1229 m above sea level. A typical continental climate is dominant in central Anatolia. Summers are hot and dry, whereas winters are cold with moderate snowfall and spring is rainy. The annual average rainfall is 330.7 mm. Therefore, the hillsides are more or less bare of vegetation, with some forest at the higher altitudes. The meteorological records of the Niğde station for the period 1954 and 2013 are provided in Table 1. The use of meteorological records for the Niğde region on the temperature-precipitation graph recommended by Fookes et al. [40] reveals that very slight weathering (both physical and chemical) is expected in the study area (Fig. 1). This is in good agreement with the field observations. No air pollution problem exists around the monument because it is in a rural area.

The Niğde meteorological records of the Niğde station for the annual dominant wind direction are 23.3% NE, 16.3% SW and 14.4% WSW. The statistics are based on observations taken between 01/2013 and 08/2014, daily from 7 am to 7 pm local time. The annual average wind speed is 6 km/h.

Climate is the act of all atmospheric events such as rainfall, temperature, wind, air pressure, humidity, etc. In recent years, the altered natural environment and climate observed in Turkey has negatively affected monumental buildings. The country's cultural treasures have been degraded by various natural effects for a long time. However, because monumental buildings are of great importance for their identity of transferring old era information to future generations, special precautions should be taken against the deterioration of monumental buildings [41]. The climate-related deterioration of monumental buildings is a result of temperature differences between summer and winter and day and night, the water movement within a building caused by capillarity, the abrasive effects of rain water, salt and other chemicals, the particles carried by wind and air pollution [42]. No marked corrosive effect of wind and precipitation of the studied historical buildings were observed. However, because of the higher humidity of the northern aspects, decomposition reactions took place faster than other aspects. The decomposition of rocks used in the northern aspects was relatively greater than for other aspects. It was thought that because seeds and spores carried by the wind adhere to the surface of the buildings' stones located at these aspects, the chance of germination increases. Indeed, more flowering and non-flowering plants growing on the north-face of certain buildings than on the other aspects supports this view.

2.2. Sampling sites

The stone monuments constructed between the 2nd and 19th centuries in the Niğde region are well-known examples of various civilizations [43–46]. The 6 main historical stone monuments identified within the Niğde region (Fig. 2) were chosen