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Orginal Article

Analysis of the technical condition of the inner façades of the Donjon at the Kłodzko Fortress

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Abstract: The article presents an analysis of the technical condition of the interior façades of the Donjon in the Kłodzko Fortress. The aim of the study is to understand the processes leading to the deterioration of the architectural heritage. The Kłodzko Fortress, located in Lower Silesia, is one of the most important and largest fortifications in Poland, with a rich history dating back to the Middle Ages. Modern structures date mainly from the 17th and 18th centuries. The article focuses on the analysis of the technical condition of the internal façades of the donjon, which are exposed to various degradation factors such as weather conditions, human activity, and time. The studies were carried out in 2016 and 2023. They aimed to determine the current condition of the donjon's internal façades and the causes of the observed deterioration. The two surveys made it possible to assess differences in damage and the speed of degradation processes and their impact on the current state of the façades.

Keywords: heritage protection, fortification, deterioration, Donjon in the Kłodzko Fortress, technical condition of the façade, stone wall

1. Introduction

Addressing issues of heritage conservation and protection is an integral part of the care of historic buildings. Recently, much attention has been paid to the study of the processes leading to the deterioration of the architectural heritage and, in particular, the materials used in its construction [1]. The analysis of the technical condition is necessary to preserve the value of historic buildings and plays a key role in the process of historic building conservation.

Located in the town of Kłodzko in Lower Silesia, the Kłodzko Fortress is an excellent example of cultural heritage that is worth protecting. It is one of the most important and largest fortification sites in Poland. This unique research facility is an important part of the architectural heritage of the region, which is part of the fortifications of the Sudeten Fortress Belt [2]. The fortress has a rich history dating back to the Middle Ages, but most of the current structures date from a later period, mainly from the 17th and 18th centuries. For centuries, the fortress played a key role in the protection of the region and was the site of many conflicts and battles. Due to its strategic location in the Sudeten region, the fortress was extended and rebuilt several times in the following centuries. Over a period of many years, a number of prominent Austrian, Dutch, Prussian, and Italian fortress engineers of the 17th and 18th centuries designed and built the fortress. Thanks to this work, it was transformed into a powerful fortress. Although it lost its strategic importance in the 19th century, its history is full of fascinating transformations, from an important defensive point of the region to a prison [3]. It has also been used as a warehouse, an AEG weapons factory [4], and a wine processing plant [5]. In 1960, the Kłodzko Fortress was listed in the register of monuments [6] and later opened as a tourist and cultural site.

Historic buildings such as the Kłodzko Fortress need to be properly protected from external factors. The façade of the building, which is the main barrier against environmental degradation [7], is exposed to various forms of damage [8]. Effective protection of fortress objects is based on the elimination of factors that accelerate their degradation, such as vegetation covering defensive elements, direct contact with water, and constant humidity [9]. Therefore, a thorough analysis of the technical condition of the object, including the façade, is crucial. In 2016, as part of a student internship, the first complete assessment of the technical condition of the interior walls of the Donjon at the Kłodzko Fortress was carried out. Due to the passage of time, it was decided to repeat it in 2023. This will make it possible to compare changes and assess the speed of deterioration processes and their impact on the current condition of the façades.

2. Purpose of the study and research methodology

The purpose of this article is to present the results of a detailed analysis of the interior elevations of the Donjon of the Kłodzko Fortress, considering technical, historical, and conservation aspects. It is particularly important to address the technical condition of the interior façades, as they are an important structural element of the building and are simultaneously exposed to several degrading factors. The effects of time, atmospheric conditions, and human activity have contributed to a variety of problems, such as scratches and cracks, loss of masonry material and pointing, the development of biological corrosion, moisture, salt, and frost corrosion.

Based on the research carried out, the article aims to investigate the current state of the internal façades of the donjon and to identify possible causes of the observed deterioration. As a result, it will be possible not only to secure and preserve this unique element of the fortress for future generations but also to increase knowledge of the construction techniques and materials used in the past.

The research methodology adopted in the article, which relates to the assessment of the technical condition of the façade of a historic building, includes several steps and techniques aimed at assessing and analysing the current state of conservation of the structure. It also refers to the identification of any areas that may require maintenance, restoration, or repair. This type of survey is essential to protect and preserve the historical and architectural value of a building while ensuring its safety and structural stability.

The methods used by the authors to assess the technical condition of the interior elevations of the Donjon at Kłodzko Fortress are presented below:

- A visual assessment was made of the condition of the materials, the presence of damage, the preservation of architectural details, etc.
- Photographic documentation was made, which served as a visual database for analysis.
- Laboratory tests for moisture and salinity were carried out.
- Drawings and plans were prepared: the use of 3D laser scanning made it possible to produce accurate drawings and plans, taking into account all structural details and areas of damage and deterioration.

The above steps were carried out twice, the first study in 2016 and the next in 2023, and a comparative analysis was carried out, resulting in this article.

3. Degradation processes of stone walls

Stone is more durable than many building materials, such as brick or wood, but it is also more susceptible to deterioration [10]. Stone deteriorates because the conditions in which it is used are different from those in which it was formed. Minerals become unstable and change into more stable forms in the new environment [11]. The process of masonry deterioration is complex and dynamic, influenced by a variety of different factors. These factors come from both internal and external sources. They include, but are not limited to, the physical and chemical properties of the materials from which the masonry is constructed, the standard of its construction, the corrosiveness of the environment in which it is located, and the age of the structure. This is a complicated set of interactions that requires in-depth analysis to understand the full course and mechanisms leading to masonry deterioration. Here are the main phenomena affecting the deterioration of masonry structures [12]:

- Chemical – caused by the action of chemical compounds present in the masonry or from the environment, such as aggressive liquids or salt crystallisation processes.
- Biotic – caused by microorganisms such as fungi, moulds, or lichens, as well as annual and perennial plants [13, 14].
- Climatic – caused by climatic conditions such as humidity, temperature fluctuations, UV radiation, wind action, or tectonic processes.
- Mechanical – resulting from external forces such as stress or impact, abrasion, or frost damage.

The quality of the materials used in the construction of masonry is the main determinant of its susceptibility to deterioration. It is the physical, chemical, and mechanical properties of the components, such as stone, brick, and mortar, that affect the resistance of historic masonry and any subsequent repairs or additions. The main factors leading to masonry deterioration are environmental factors related to climatic conditions, such as moisture, temperature changes, UV radiation, or wind. There are also chemical influences, such as chemical compounds in the masonry or from the external environment, and biological factors, such as microorganisms or vegetation.

Water in masonry structures plays a key role in deterioration processes. From an engineering perspective, water is a key element in reducing the durability of structures [15], [16]. Its presence increases the effects of corrosion, such as salt or frost damage, and also affects the growth of biological organisms. Water, especially that from precipitation, which accumulates on the external surfaces of masonry, penetrates its structure, and accelerates the deterioration of stone, brick, and mortar. It is therefore water that has a decisive influence on the progressive deterioration of masonry structures.

Water in masonry first causes the bonding agents in the mortar to dissolve. This eventually leads to the weakening and destruction of the joints [17]. Groundwater that rises causes similar damage to rainwater. Damp walls are more susceptible to damage from cyclical freezing and thawing of water in their structure. Freezing water increases in volume, damaging the material, and the effects of frost are more pronounced on south-facing façades.

Another factor resulting from dampness is the corrosive processes associated with salt [18, 19]. Salt can crystallise on the surface of the masonry, causing stains, patches, and other aesthetically unpleasing formations. In warmer conditions, salt crystallisation can occur deeper in the masonry.

Excessively wet masonry is more susceptible to biological corrosion [20]. This includes destruction by organisms such as fungi, insects, and plants [21]. Even a small amount of humus in the masonry can lead to the growth of vegetation, which over time can cause damage and delamination of the masonry, especially by plant roots [22].

The destructive factors described above, and the degradation processes they cause practically never occur in isolation. In practice, masonry is often exposed to many of these factors simultaneously, resulting in cumulative degradation effects [23].

4. Characteristics of the Donjon at the Kłodzko Fortress

Fig. 1. Aerial photo of the Donjon at the Kłodzko Fortress, 2022. *Source:* Michał Wac

The Fortress, located on a rocky hill (369 metres above sea level) dominating the town, known as the Castle or Fortress Hill, is one of Kłodzko's greatest tourist attractions [24]. It was designed to take maximum advantage of the natural terrain for defence. The fortress features a variety of architectural styles, as it has been continually expanded and modernised at various stages of its history to meet modern military standards. The massive walls, numerous bastions, caponiers, and mine channels make the fortress a fascinating place to explore and a testament to the evolution of defence techniques.

In the Middle Ages, the term "donjon" referred to the defensive residence of a feudal lord, with characteristics of a residential tower and a castle. In the terminology of modern fortification, it was used as a name for a retrenchment [25]. It served as a command centre and was the key (last) defensive point. It was usually solidly built with thick walls to withstand a siege. Inside were living quarters, storage, and defensive positions.

In the Kłodzko Fortress, the Donjon (Fig. 1) was built between 1770 and 1774, when the High Castle was replaced by a specialised facility [26]. This change transformed the main fortress into a coherent defensive complex. The number of storeys of the donjon varies according to the direction of the world. There are three floors on the eastern side, two on the northern side, and one on the southern and western sides. The casemates housed rooms adapted for mixed functions, both defensive and non-defensive. Access to the casemates was through an irregularly shaped courtyard.

The walls of the building are mostly made of stone - sandstone. The masonry is made up of elements of similar dimensions, precisely worked with chisels and arranged in a defined pattern, sometimes supplemented by smaller elements. The lintels are made of stones arranged in an arch. All the elements were made in a similar style to give the whole work a uniform appearance. The thickest blocks of stone are placed at the base of the façade, along the plinth, which is also made of carefully carved stones of similar size.

From the top, the building is covered by a grassy earth mound, piled on top of the cradle brick vaults. The upper parts of the façade show characteristic stone swales, part of the Donjon's drainage system, into which water from the insulating layers located on the vaults is drained. Although many of them are authentic, not all of them have been preserved. Some of the drainage elements have been re-bricked. The site has window and door woodwork- most of which is secondary, although some of the historic woodwork has also been preserved. Some of the openings have also been bricked up. At the entrances to the halls, masonry work is noticeable; based on archival documents, it was determined that the woodwork in these places dates from a later time.

A clear negative effect on the condition of the masonry is the use of cement pointing. Originally, the masonry in the Donjon was joined with lime joints, which are less strong. The use of strong joints is detrimental to the stones, as the joints should be the first to react to loads. As a result, while the joints remain intact, some of the stone blocks show signs of damage.

Other types of stone and brick were also added to the masonry. In some places, window and door openings have been altered over the years, changing their form and function. Brick was also used in the construction of the steel halls added to the donjon in the 1950s [27]. These elements can still be seen today in the structure of the donjon. See Fig. 1.

As a result of adapting the site to new modern functions, two halls were built in the eastern and western parts of the Donjon. To create them, it was necessary to demolish the historic casemate vaults and replace them with steel structures on trusses. As a result of this work, the halls were given modern shapes, and their roofs were covered with black bitumen felt. Inside, on the façades of the Donjon, parts of the walls were removed to create modern entrance gates to the halls. The stonework was also supplemented with other types of stone and brick. In some places, window and door openings have been altered over the years, changing their form and function. Most of the additions date from the period when the Donjon was used as a winery, between 1960 and 1998 [27].

5. Façade damage analysis

Due to the slight differences between the damage in 2016 and 2023, it was decided to present the current technical condition of the façade. Owing to the comprehensiveness of the study, only sections of solid walls were shown in the drawings. The selection of the sections of the façade was mainly guided by the representativeness of the damage present on the face of the wall. Most of the damage is described in Table 1, in the form of a comparison of the state in 2016 and 2023.

The technical condition of the masonry varies, changing in relation to its exposure to sunlight. In places where the sun shines much longer on the façade (Fig. 3 Section A), the technical condition can be described as good (Figs. 16-17, Figs. 20-21). Where there is less light, the technical condition of the masonry is usually sufficient. On the inner façades of the Donjon, there is localised washout of the joints and biological corrosion resulting from a poorly functioning rainwater drainage system. There is also damage to the crown cornice, through which water from the earthen embankment moves causing dampness to the interior of the masonry and façade surfaces (Fig. 3 Section D, Figs. 4-5). The gargoyles are damaged in several places, rendering them unfit for purpose (Fig. 3 Section B, Figs. 4-5, Figs. 10-11). There is also surface crystallisation of salt, causing localised efflorescence and staining.

Above the window and door openings are arched lintels made of stone. Their technical condition is mostly assessed as good (Figs. 20-21). No obvious cracks or cavities are visible. Only locally, powdering of the stone surface and losses in historic joints were found (Figs. 6-7). Near the stone bands of the door and window openings, damage to the face of the masonry is present: losses in the pointing, salt corrosion of the mortar, damage to the face of the stone blocks (Figs. 14-15).

Damage is particularly visible on architectural elements that protrude from the face of the wall, i.e., window and door bands, gargoyles, and cornices (Figs. 4-5, Figs. 12-14, Figs. 18-19).

The stone plinth is largely in a poor state of repair. Along almost the entire inner perimeter of the Donjon, there is a high level of dampness in the area of the plinth. This is caused by leaks in the band and the condition of the masonry, particularly in the lower part, and is detrimental to the growth of living organisms (Fig. 3 Section C, Figs. 18-19). In addition, the poorly profiled slope of the courtyard surface contributes to the elevated moisture levels in the lower parts of the Donjon façade (Figs. 22-23).

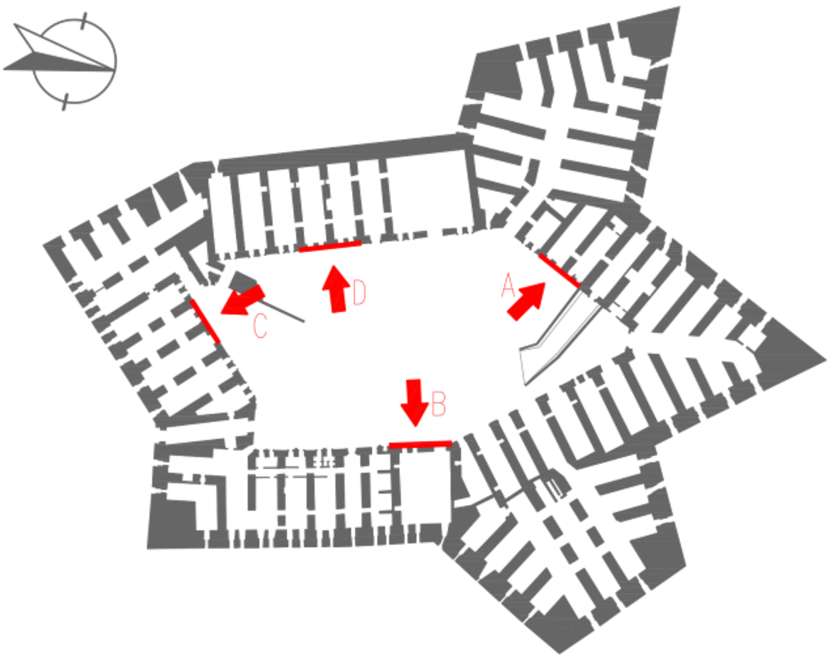

Fig. 2. Schematic drawing showing the sections of the Donjon façade selected for damage analysis. *Source:* own study

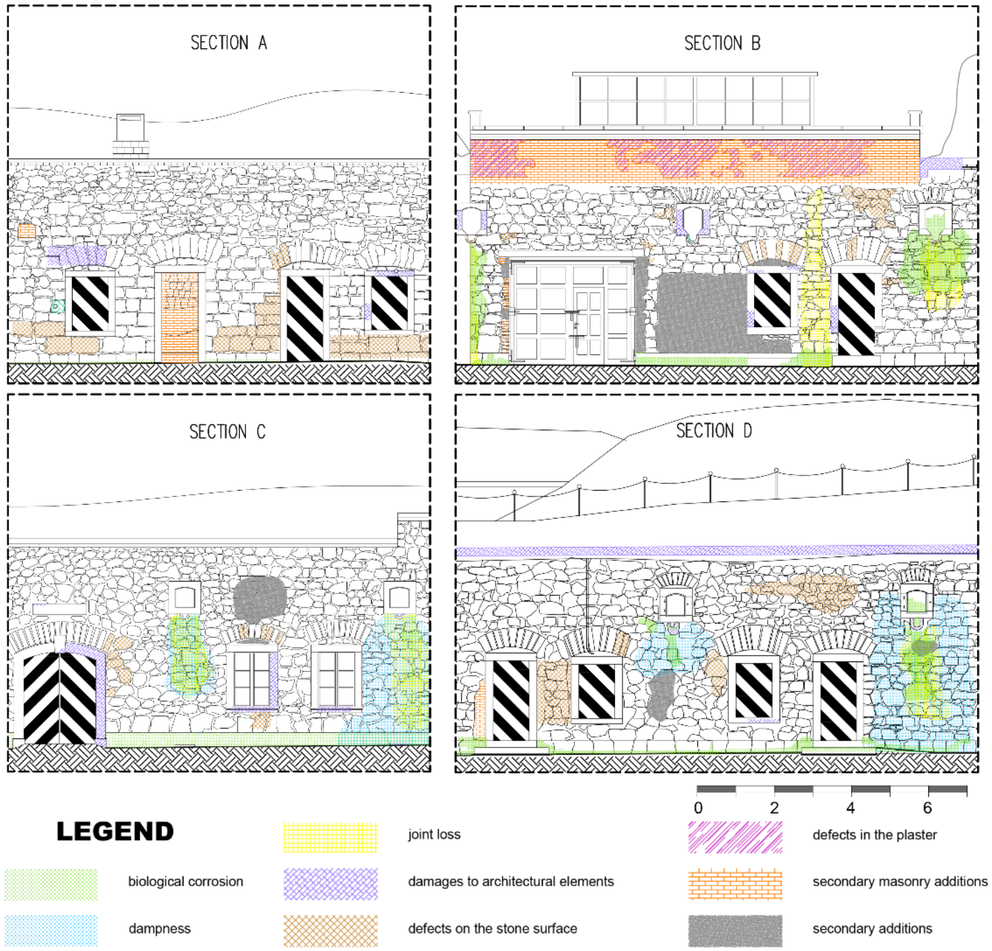

Fig. 3. Damage analysis of selected sections of the Donjon façade. *Source:* own study

Table 1. A compilation of the most characteristic damage to the Donjon façade at Kłodzko Fortress based on the 2016 and 2023 surveys, along with their description. *Source:* own study

2016	2023
	

Fig. 4., Fig. 5. Progressive deterioration of the plaster and masonry of the clay brick superstructure. Damage to the upper layers of the stone façade due to salt and frost damage in areas of increased moisture. Deterioration of historic limestone masonry joints

	

Fig. 6., Fig. 7. Surface damage to the stone blocks of the lintel of the casemate gate. Visible powdering of the stone surface, loss of historic joints

	

Fig. 8., Fig. 9. Proliferation of perennial rooted vegetation in the wall void below the damaged stone gargoyle. Deterioration of the joints around the gargoyle due to poor drainage of rainwater. Water runs directly down the face of the masonry

Fig. 10., Fig. 11. Further growth of weeds and young shrubs after removal of mature shrubs. Root systems of perennial vegetation cause degradation deep within the wall

Fig. 12., Fig. 13. Biological corrosion of the limestone joints of the masonry face. The growth of moss and algae causes micro-damage to the mortar, creating a substrate on which annual and perennial vegetation can grow. This development intensifies the degradation processes

Fig. 14., Fig. 15. Changes in the condition of the masonry face due to salt and frost damage. Over a number of years, there has been increasing damage to the surface of the masonry and significant deterioration of the historic and secondary pointing of the masonry

Fig. 16., Fig. 17. Vegetation growth inside the gargoyle. Inadequate drainage of rainwater results in streaking on the face of the wall. Damage to the stone face and joints from moisture, salt and frost corrosion is an additional problem


Fig. 18., Fig. 19. Replacement of the completely damaged entrance door and the panel in the window opening with new ones. Changes that significantly improve the aesthetics of the Donjon's façade


Fig. 20., Fig. 21. Renovation of the gate leading to the casemate, repainted in the original style. Removal of the metal chain-link fence and its replacement with a low wooden fence

Fig. 22. Donjon's visual state for 2016. Source: authors

Fig. 23. Donjon's visual state for 2023. Source: authors

6. Conclusions

The analysis and assessment of the technical condition presented in this paper have enabled the identification of the causes of degradation phenomena. A detailed research methodology, involving a variety of stages and techniques, has not only accurately determined the current technical condition but also delineated areas in need of conservation or restoration. This type of approach is crucial for protecting the historical and architectural value of the building while ensuring its safety and structural stability for the future.

The analysis, based on data collected in 2016 and 2023, indicates that the technical condition of the donjon façade of the Kłodzko Fortress has shown limited changes in terms of damage. Although degradation factors have slightly increased over these seven years, the specific nature of the stone from which the building is constructed means that the evolution of this damage is slow. Importantly, the current changes do not significantly impact the overall assessment of the site's condition, and there is no urgent need for restoration work. The aesthetics of the site have improved over the past 7 years. The following works have been carried out over the years: renovation of the gates leading to the casemate, new paintings in a historical style, removal of metal posts with chains, and their replacement with a low wooden fence.

Despite the relatively stable condition of the façades, some changes have been observed depending on the exposure of the wall to the sun. The northern and eastern elevations, which receive more sunlight, are in a better state of repair. However, in the less sunny areas, washed-out joints and biological corrosion can be observed. The latter is the result of a dysfunctional rainwater drainage system, where damaged gargoyles no longer fulfil their function.

Phenomena such as surface salt crystallisation result in localised efflorescence and damp patches, but these do not threaten the structural integrity of the building. Furthermore, elements such as the arched lintels over the window and door openings are in good condition, with no obvious losses or cracks.

The condition of the stone base of the Donjon is of some concern. Its technical condition is inadequate, particularly in the plinth area. This is affected by leaks as well as the inappropriate slope of the courtyard surface, which contributes to increased moisture levels in the lower parts of the façade.

Although the level of damage has not deteriorated drastically in recent years, several areas require attention in future conservation work. Rainwater is a contributing factor to the poor condition. Repairs and waterproofing of the walls are recommended in the short term. Repairs are required for the masonry copings in the form of stone slab cornices. Filling cavities, correctly profiling slopes, and sealing slab joints will significantly reduce water ingress into the façade.

The next steps should include addressing all the stone gargoyles. Currently, most of the water flowing down the drainage channels penetrates the brickwork, causing considerable damage to the facing brickwork immediately below the buttresses. In most cases, the stone elements of the buttresses need to be replaced.

In areas where there has been significant damage to the facing layers, work will need to be carried out to fill joints, replace or repair stone blocks, and clean sections of the façade of dirt and organisms that cause biological corrosion.

At present, however, there is no urgent need for major repairs, which means that long-term restoration work can be planned with confidence.

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