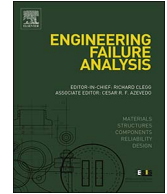




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Failure analysis of historical buildings due to climate change

Marius Mosoarca*, Alexandra Iasmina Keller, Cristian Petrus, Andrei Racolta

Politehnica University of Timisoara, Faculty of Architecture and Urban Planning, Traian Lalescu str, nr. 2/A, 300223 Timisoara, Romania

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ABSTRACT

Historic buildings have a high resilience in time due to the fact that they were designed by taking into consideration the environment and all the local conditions. However, nowadays not only their environment is changing fast. According to a current climatic change analysis, the climate all over the world has already suffered a severe change and, unfortunately, future scenarios indicate an even worse situation. The main effects of the climate change are as follows: high and long lasting temperatures during summer, precipitation pattern change, intensification of the local winds. To which we can add more intense or even frequent extreme events, such as: drought, abundant precipitation, snowfalls and hailstorms. All these changes have a heavily impact not only on the historic buildings, but also on the economy and society. The main purpose of this study to analyse the climatic change on different types of historic buildings, the way in which natural factors increase the degradation and the failure of the building structures/historic architectural details and how it can affect the aesthetics of the historic urban centres. The subject of the research was a small town in Romania, Oravita, which was chosen due to its diversity of its historical heritage and its special climatic condition. The study focused on simple buildings as well as on archaeological sites, railroads, bridges and dams.

1. Introduction

Generally, buildings are usually built taking into consideration the past and the current climatic conditions [1], which can have important implications on the historic cities and the built heritage. The main factors that can cause extensive damage to the historic built environment are: temperature growth, precipitation, wind and natural hazards. However, climate change cannot be simply reduced to these factors [2] and it is not enough just to be aware of them. Since climate change will amplify the existing risks, like flooding and landslides, it is important to determine the impact of these threats to the cultural heritage, to develop suitable conservation strategies [3,4] and create projections for the future.

In the recent years, many studies have been made to properly determine the impact of the climate threats upon the heritage buildings [5–8]. More than this, national and international projects on the prediction and the description of the effects of natural hazards and climate changes have been developed to work out complex strategies to adapt the built environment for future climatic conditions. We mention just some of them: The Climate for Culture - 2009/2014 [9], ESPON Territorial Observation no. 7 – 2013 [10], NOAH'S Ark - 2001/2007 [11], EU – DESURBS “Designing Safer Urban Spaces - FP7 Research Programme [12].

The studies made worldwide indicate that the natural threats have important implications both upon the structural integrity and the aesthetics of the surfaces of the heritage [13]. They also indicate that heritage buildings are, extremely vulnerable regarding future climate change, mainly due to their high value. Therefore, it is required to find protection solutions and strategies as soon as possible and to further develop the existing international and EU standards and polices related to the climate change impacts and

* Corresponding author.

E-mail address: marius.mosoarca@upt.ro (M. Mosoarca).

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Fig. 1. Effects of extreme events on the built heritage – Severe flooding in York (2015), according to [20]; Abergeldie Castle (2016) - river bank burst, according to [22]; Tornado near Venice (2014), according to [24].

adaptation (see EU Strategy on Adaptation to Climate Change - 2013 [14], ISO 31000 [15], Policy document on the impacts of climate change on World Heritage properties - 2008 [16]). Obviously, this cannot be done unless we have in-depth understanding of the current and future climate threats and its impact.

2. Recent extreme events

Specialists consider that the numerous extreme events recorded in Europe in recent years are effects of the climate change. We are going to give a few examples which illustrate the severe damage caused by flooding, tornados and heavy rain as well as their impact on the heritage buildings:

- (i) **Flooding.** Recent extreme flooding in Europe and all over the world has raised the awareness of the authorities upon the hydrological extreme events. However, it is estimated that the future flood risk will be even higher as the climate change will increase the frequency and severity of flood events [17–19].
 - One of the most tragic examples of flooding is the event of December 2015 when in the locality York (Fig. 1.), United Kingdom, 500 properties and many historical buildings were affected by the water of two main rivers from the city, Foss and Ouse [20].
 - The historic Abergeldie Castle is another case of built heritage threatened by flood (Fig. 1.). At the beginning of 2016, the river bank of the river Dee burst during severe flooding and brought the water near the castle [21]. Extensive works had to be done after the flood to put the castle back to safety and prevent complete failure of the structure [22].
- (ii) **Tornados.** Recent studies indicate that tornados are more frequent in Europe in recent years than ever before. Thus, these extreme events happened around 242 times in a year between 2000 and 2014 compared to 8 between 1800 and 1850 [23]. Only in last 5 years > 151 tornados, causing severe damage to heritage building, were recorded in Europe in Greece, Germany, Netherlands, Italy, Hungary, Sweden, United Kingdom, France, Poland, Spain, Portugal, Belgium, Ireland and Russia. One of the worst is the tornado in the Veneto region from July 2015 [24] (Fig. 1.).
- (iii) **Heavy rain.** This is another consequence of the climate change. The effects of heavy rain and high moisture loads were observed recently even in our country, Romania. Fig. 2 presents the severe structural damage caused by heavy rain at a 200 year old historic building, located in Arad, Romania. The heavy rain affected the interior basement surfaces and the general state of the building as well as, causing local settlement. Thus, during the visual inspection of the building, there were identified advanced signs of surface decay due to water infiltration in the basement and fissures on the walls and floors in the corner of the building due to terrain settlement.



Fig. 2. Severe damages by heavy rain and terrain settlement at a heritage building in Arad, Romania.

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