Building Problems in Architectonic Heritage and Geotourism: Is there a Connection?

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Building Problems in Architectonic Heritage and Geotourism: Is there a Connection?

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Abstract. Architectonic heritage buildings attract millions of tourists for many reasons: their beauty, history, style, art, location, and so on. Presently, this list is being supplemented by the touristic exploration of the construction material, with particular emphasis on the natural stones. This material is the aim of urban geotourism because it can give precious information about its age, origin, paleo-environment, as well as its provenience, way of exploitation, transport, treatment and finally degradation by weathering, among others. Therefore, the study of the construction stones of heritage buildings constitutes a complement to the "classical" cultural items which are shown and presented during a visit. A particular segment in geotouristic activities may be the presentation of building problems to the visitors. There are many examples in this field, like moisture or cracks in the walls, unusual solutions in construction, disintegration of stones, and so on. These problems can have various causes: the capillary rise of groundwater in a wall, the lack of construction material, the heterogeneous composition of the substrate, the seismic activity, the weathering of material, to name but a few. For a visitor interested in science and technology, the knowledge of the problems, their origin and their solution (or, at least, the attempt of their solution) may be an unforgettable experience. The purpose of the work is to open a new point of view to architectonic heritage and its building problems, which can be used and explained in touristic activities. For this, mainly qualitative non-interventionist and participatory methodologies are applied. As a result, there will be the situation that the damage in one part leads to a profit in the other. This ambiguity may be resolved by considering that better knowledge about the state of the heritage building, which is made accessible to a larger public, will contribute to its preservation. So, the main conclusion is that geotourism applied to architectonic heritage and its problems is an important support to its maintenance because of the dissemination of the knowledge of what may happen with the construction material. Likewise, the knowledge acquired during a geotouristic visit may help to avoid similar problems in other buildings.

1. Introduction

The share of cultural tourism in world tourism is growing. The World Tourism Organization estimates that more than 39% of all touristic trips in 2017 had been realized to enjoy cultural heritage [1]. The aims of cultural tourism are changing: from visiting the tangible heritage, the trend goes towards participating and consuming cultural practices, which may include intangible heritage like traditions, gastronomy, etc., as well as "experiences" and "adventure trips" [2]. From a niche-market designated to clients with relatively high education levels and high income, cultural tourism converted into a market of mass tourism with a much wider range of people [2].

To satisfy the growing number of visitors who want to be entertained, new branches and products of cultural tourism have to be created. Geotouristic activities in the cities include the interpretation of the construction stone material and treatment methods, besides the “classical” historic and artistic features of architectonic heritage. Therefore, they are a link between cultural and natural tourism and may be a promising approach to attract and to diversify the touristic offer [3].

The main objective of this work is to show that the proper presentation and explanation of building problems in objects of architectonic heritage can open a new point of view for tourists concerned with historical, technical and scientific knowledge. To reach this aim, mainly qualitative non-interventionist and participatory methodologies are applied.

2. Geotourism in a City

Usually, geotourism in a city is understood as the presentation and interpretation of the construction and decorative stones of buildings, monuments, pavements, and so on. This includes the story of the origin of the rock material, its mineral and fossil content, its provenience, the treatment it was subjected to, the state of weathering by the influence of climatic players like rain, temperature, wind and others. The stones contribute to the esthetical aspect of a building by giving form and colour. So, the architectonic, artistic and historic dimension of a building is complemented by a natural one, connecting cultural and natural heritage [4].

The architectonic heritage of a city corresponds to an outdoor museum which shows the processes and events, catastrophic or not, which the object had to suffer. The building problems are exposed in an urban environment, they can be seen during the whole year, at nearly any weather. There is no need for pollutant cross-country vehicles or long and tiring walking-tours. Usually, the buildings are prepared to be visited by disabled persons and many seniors, so they can participate in practical geological activities. So, geotourism in a city is a contribution to inclusive tourism [5]. The inclusion of geotouristic themes into the cultural tourism program of a city will enrich its touristic offer and contribute to the growth of its economy.

Architectonic heritage objects which exhibit evidence of building problems can be seen as on-site urban geological laboratories, where it is possible to watch, for instance, phenomena of weathering of the rock material. The causes, processes, mechanisms, and forms of stone decay are due to interactions of the material with the environment, and are increased by wrong preservation treatment and air pollution [6]. Therefore, the interpretation and knowledge of such occurrences may help to attract attention to environmental problems.

In this article main emphasis is not given to the rock material itself, but to some kinds of building problems in architectonic heritage objects which occur by geological events or processes. These problems may consist of heterogeneous soil subsidence, cracks or moisture in the walls, earthquake damages, lack of adequate building material, capillary rise of groundwater, weathering phenomena in the stones, and others. When occurring in buildings in a typical way, the visible results of the depicted problems can be added to the field of geotourism because of their geological origin, and shown and explained as touristic attractions. This kind of tourism cannot be compared with tourism to actual disaster areas, as the presented phenomena had their origin many years or centuries before, and many of them developed in a slow way.

For instance, in the centre of the small historic town of Staufen, located at the eastern flank of the Upper Rhine Graben in southern Germany, the drilling of some boreholes to explore geothermal energy by the city hall in 2007 triggered a very complicated situation [7]. It is thought that the wells passed through layers with anhydritic lenses from upper Triassic "Gipskeuper" with a thickness of about 100 m, and that they opened the way for groundwater to get in contact with the anhydrite ($CaSO_4$). By the interaction of water and anhydrite, the mineral recrystallizes giving origin to gypsum ($CaSO_4 \cdot 2\ H_2O$). This process provokes a swelling of 61% of the volume of the mineral. Consequently, the ground in some places in the centre of Staufen suffered an uplift, sometimes of almost 50 cm. In some places, the calculated uplift rate was approximately 12 mm per month. The buildings in the centre of the town were severely damaged, sometimes they show open cracks with apertures of more than 10 cm [7]. A lot of houses got inhabitable. In 2010 the uplift still persisted, and in the last years, it slowed down [8]. The marks of this disaster, in which people lost their houses or parts of them, should not be shown as a merely touristic activity, because geotourism should not make a profit with the disgrace of today's people.

Especially in highly frequented places, a building problem and its reason may be interesting for the visitor, as their knowledge can satisfy his curiosity. One of the most famous places with a well-known building problem is the leaning tower of Pisa, which was founded on weak, highly compressible soils with high subsidence rates, and started leaning since its construction [9]. In this case, the tower's inclination, so to say the building problem, is the main touristic attraction, which is more valorised than the tower itself.

3. Examples

There are a lot of buildings in the whole world which show marks of problems originated by geological reasons and others which demonstrate how to neutralize them. These buildings may be famous or not, they may belong to the UNESCO World Heritage or not, they may be found in an urban or in a rural environment. What they all should have in common is to show the referred features in a clear, explainable and accessible way, to satisfy the visitors' expectations in a geotouristic route.

3.1. The Colosseum in Rome (Italy) – Earthquake Damages

One of the most famous buildings worldwide, the Colosseum in Rome, was inaugurated in 80 AD as Amphitheatrum Flavium. Today, the building shows a higher degree of collapse in the southern than in the northern side. It was damaged by earthquakes, in 443 AD, in 484 or 508 AD, 847 AD, 1349 AD, and 1703 AD [10]. During the Middle Ages until the Baroque era, the monument was used as a quarry to supply building stones for many palaces and churches of Rome.

The different states of collapse are believed to be due to a heterogeneous substrate (figure 1) [11]. The whole building rests on a layer of anthropogenic debris with thickness up to 15 m, as it is found everywhere in Rome. Below this layer, a Pleistocene rock composed by alluvial sedimentary and volcano sequences with good bearing capacities is found under the northern side of the Colosseum. The subsoil of the southern side is built up by Holocene not consolidated alluvial deposits of the former Labicanus stream [10], which was flowing from the east and turned to the south under the monument.

This heterogeneity may have been the reason for the different states of collapse of the Colosseum. Usually, the damages provoked by earthquakes in a building are more severe on a soft ground, consisting of poorly or not consolidated rocks, than on a stronger ground. As the subsoil under the southern side of the monument is made of alluvial material with weak bearing capacities, the consequence of an earthquake was more severe in this side than in the other. The fact that the risk of destruction in buildings set up in alluvial areas is greater [12], was observed in the earthquake that stroke Lisbon in 1755, when the lower part of the city, near the Tagus River, built on unstable alluvial deposits of a stream, was destroyed almost completely by the direct impact of the seismic waves, while other parts of Lisbon, planted on stronger rocks of the higher parts of the terrain, did not suffer the same cataclysm.

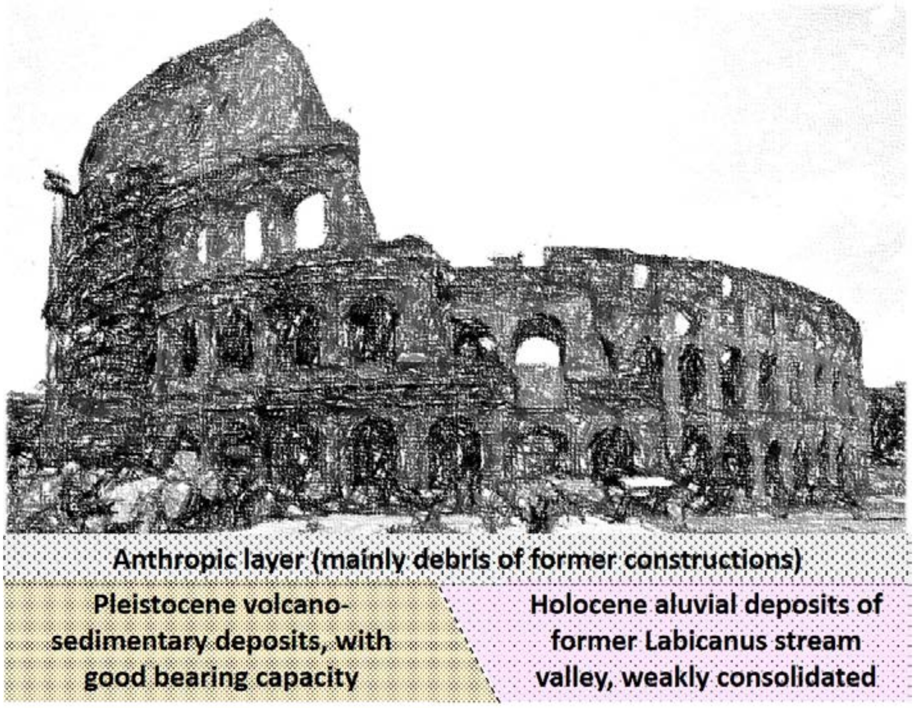

Figure 1. The Colosseum of Rome and the geological formations in the subsoil. Source: Authors, based on Google Earth Street View

The existence of earthquake damage in heritage buildings shows that a city is located in a seismic zone. The proportions of the damage help to define the intensity of a historic earthquake and to remember that probably such a catastrophic event may be repeated. The city of Rome, for instance, was stroke several times in history by strong seismic activities, which left their marks on a lot of antique and younger buildings [13]. The knowledge of these seismic events may help to settle proper rules for construction in the affected area.

3.2. St. George Church and Church Tower “Daniel”, Nördlingen (Bavaria, Germany)

The medieval town of Nördlingen is located in a very particular area. The almost round 26 km-diameter basin of the Ries between the hills of the Swabian and Franconian Alb in Southern Germany had a catastrophic origin about 15 million years ago, when a meteorite with a diameter of 1,1 to 1,5 km hit the place at a speed of 15-18 km/s, having released an energy of 10^{20} to 10^{21} J [14]. Due to the violence of the impact, a crater with a depth of approximately 950 m was created and large rock masses were ejected. Some of them are found today up to a distance of 450 km as “moldavite tektites” in the Czech Republic, in North Austria and in East Germany [14]. It is estimated that within a radius of about 1000 km nearly all life was extinguished.

In the crater, at the moment of the impact, the temperature rose up to 20.000 to 35.000 K during shock compression, and a large part of the struck rocks, as well as the meteorite itself, vaporized, melted or were fragmented. During the cooling of the molten mass and the re-deposition of ejected material, new rocks arose. One of them is the suevite, which consists of an impact breccia, whose particulate matrix contains rock and mineral fragments in all stages of shock metamorphism, including glassy or crystalline particles, sometimes in a pancake-like shape [14].

The suevite is the main construction material of the St. George church and the church tower named “Daniel” in Nördlingen. The church and the tower were completed at the turn from the 15th to the 16th century in late gothic style. The suevite rock is a relatively smooth material, so it is easy to carve it. On the other hand, it is prone to weathering, so a number of original building stones had to be replaced by replicas made of synthetic suevite or sandstone (Figure 2) [15]. The synthetic suevite is composed of suevite, limestone, basalt, sand and Portland cement in various mixing proportions [16]. Both synthetic suevite and sandstone are visually distinct from the original suevite, so it is proposed to use natural suevite stones to replace the weathered ones [15].

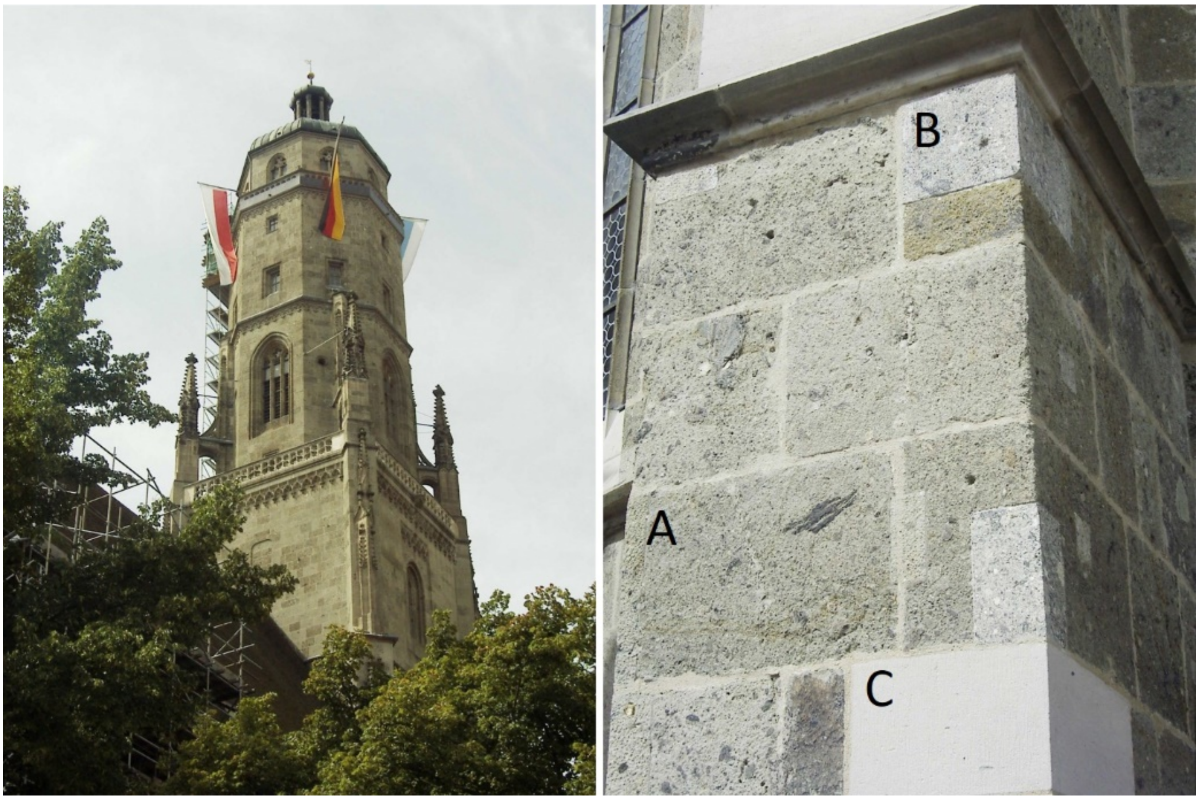

Figure 2. St. George's church at Nördlingen (Germany). Left: Church tower "Daniel". Right: Part of a buttress with building stones made of natural suevite (A), synthetic suevite (B) and sandstone (C). Source: Authors.

3.3. The Fishermen's quarter in Ulm (Baden-Württemberg, Germany)

The city of Ulm is a touristic magnet mainly because of the muenster's church tower, which is still the highest of the World with 161,5 m (when concluded in 2026, the Jesus Christ Tower of the Sagrada Familia Basilica in Barcelona will reach a height of 172,5 m). Another touristic highlight of Ulm is the Fishermen's Quarter, which is the most important ensemble of the old town. Half-timbered houses at the waterfront of the Blau stream channels, near their mouth to the Danube River, invite for a relaxing walk through "Swabian Venice".

In this neighbourhood, you find the Hotel Schiefes Haus ("Crooked House"), which has been awarded by the Guinness Book of Records in 1997 as the "Most Crooked Hotel of the World" (Figure 3). The half-timbered house was completed during the 15th century in the late gothic style. The northern part was built on Pleistocene glacial gravel deposits, relatively stable, which can reach a thickness of up to 11 m near the confluence of the Blau stream and the Danube River [17]. However, the southern part of the building was founded on Holocene alluvial deposits (gravel, sand, silt and clay), which are less firm than the gravel deposits [18].

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Figure 3. Left: Building of the hotel “The Crooked House” at Ulm (Germany). Right: Table with the Guinness Records Award “Most Crooked Hotel of the World”. Source: Authors.

Consequently, the weak substrate of the southern side, as well as the high groundwater level (two sides of the house are located directly at the waterfront of the Blau stream channels), allowed a heterogeneous settlement of the ground and the house was put in a crooked position. Moreover, the overhang of the southern wall over the channel worked as a lever which pressed this side of the building deeper into the ground (Figure 3). There were taken measures to stabilize the structure, like installing pillars, replacing wooden walls by stone walls, reinforcing the fundaments with concrete, moving weight from the southern to the north side, but the house remained in its crooked condition [18].

3.4. Church of Our Lady of the Virtues of Conil de la Frontera (Prov. Cádiz, Andalusia, Spain)
This church belonged to the Convent of Our Lady of the Virtues which was built in the 16th century for the order of Minims of St. Paula. The portal tower shows the Renaissance style of the epoch (Figure 4). In 1810 the friars were expelled and the building of the ex-convent was used for diverse functions. Today it hosts services of the city hall, while the church belongs to the parish of Santa Catalina of Conil de la Frontera [19].

One of the great problems in natural stone masonry is the capillary rise of water from the soil. Water is the main enemy of masonry buildings. The moisture increases the salt content inside the building stone, so the material will suffer from the expansion of crystallizing salt when drying, the cohesion between the stone’s components will be weakened and the resistance to weathering will be diminished. In many cases, major damages in masonry caused by weathering are observed near the ground, up to the maximum height of capillary rise of humidity.

At the church of Our Lady of the Virtues, a layer of blocks made of coarse limestone with large open pores is visible near the ground (Figure 4). In the authors’ opinion, this layer was installed as a horizontal barrier against the capillary rise of water, because this process only works in material with small pores whose diameters are less than 0,5 mm [20]. Other methods to prevent capillary moisture rise are the installation of a drainage system; the use of a horizontal barrier made of impermeable material, as it was done in Venice during the Middle Age, where a layer of blocks made of very poorly permeable Istrian Limestone was collocated between the wooden pillars and the brick walls of the buildings; or to rise the floor as it was done in some medieval churches [20].

Figure 4. Church of Our Lady of the Virtues of Conil de la Frontera (Spain). Left: Façade with Renaissance portal. Right: Basic layer made of limestone blocks with large pores as a probable barrier against capillary moisture rise. Source: Authors.

3.5. Farm Houses in the Causses Region (Southern France)

Building problems with touristic potential as they were related in the previous examples do not only occur in cities with architectonic heritage, but also in rural areas with vernacular heritage. This example shows that building problems do not only manifest themselves by damages or measures to avoid damages, but also by lack of construction material.

The Causses plateaus of Southern France are wide karstic plains built up by thick limestone deposits of Jurassic age, which overlie the southern margin of the Central Massif. The karstified rocks are criss-crossed by a dense net of caverns and open cracks, which absorb the rainwater almost immediately. Therefore, there is little water at the surface, and consequently, only poor vegetation with few trees is growing. The population density is low, being the farm houses often grouped to small agglomerations or standing alone [21].

Due to the lack of wood for geological reasons, the rural architecture is dominated by limestone. The carpenter work in traditional buildings is reduced to a minimum, floors made of wood in other regions are substituted by stony arches made by limestone blocks (Figure 5). This technique allows the floor to bear great loads, particularly as the houses’ coverage is made of limestone shingles, also using a minimum of wood [21]. Besides the few trees growing in the region, the disuse of wood has another reason: Due to the water shortage, there is hardly an alternative extinguishing agent to water in the case of a fire in the house. This is all the more true since many houses are single, with the next neighbour often living some kilometres away.

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Figure 5. Farm houses in the Causse region. Left: Abandoned farm house in Causse de Sauveterre, with arches made of limestone blocks and roof made of limestone shingles. Right: Agglomeration of houses in the Tarn River gorge. Source: Authors.

4. Results and Discussion

The touristic exploitation of building problems caused by geological phenomena may be profitable not only for the tour guide or his company, but the spreading of knowledge by tourism may have effects also on building security, especially by sensitizing the owner of a building, a construction company or the local administration. A lot of problems could have been avoided by studying and analysing the geological setting of a building place, as well as the building materials.

The knowledge of the occurrence of antique earthquakes, as was shown in the example of the Colosseum, has to be used for the elaboration of proper building instructions in the affected region, whose correct application has to be monitored. This is intended to prevent that the main number of victims and damages of an earthquake are provoked by construction errors or, worse, by the false or fraudulent economy of material in structural elements, as it happened in earthquakes which occurred in the last decades.

The same kind of consideration should be applied to the study of the substrate conditions in a building place, to avoid the origin of cracks in the walls or an inhomogeneous settlement of the ground. There are a lot of buildings built on a problematic ground, with unsuitable foundations, which show the signs of movements by uneven settlement.

Some rocks suffer weathering in a harder way than others, as was shown in the example of the church of Nördlingen. Therefore, natural stone used as construction material must be analysed with regard to the climate and the way of application to guarantee security and save later upcoming costs for repair works. Even a global player like Standard Oil Company made this experience when its administration building in Chicago was covered with 44.000 panels made of one of the most prestigious rocks in the world, the Carrara marble. Each panel was on average 1,25 m high and 1,05 m wide, with a thickness of about 30 mm, and weighed between 125 and 160 kg. Only one year after the inauguration of the building in 1972, some panels began to fall. In 1979, in a detailed inspection, it was found out that over two thousand panels had cracks and had bowed convexly about 12,5 mm. Some years later, from 1988 to 1992, the company, now Amoco, decided to remove the marble panels and to reconstruct the cover of the whole building with 50 mm thick granite slabs, for safety reasons [22].

5. Conclusions

The information given by geologically determined building problems like damages or deformations is capable to be a precious complement to the cultural heritage and its history. The view and the explanation of such a feature in a heritage building increase the visitor's emotions, especially when he has former knowledge about it. A geological feature in a building is a natural heritage which is linked to the cultural heritage.

A lot of urban heritage buildings (and others) are made of natural stones and have an easy access. So, they can be visited during the whole year and persons with special needs are able to visit the places [5]. Often, it is easy to recognize building problems without the use of instruments. The spreading of knowledge can be promoted by folders, guided tours, digital online information, and other media. The language should be in a style easy to understand, without many technical or geological terms, to be understood by non-specialists. The target group consists mainly of culturally, scientifically and technically interested people who are willing to pay for guidance and instruction, so this kind of touristic activity may be a complementary branch of the existing offer in a city.

Showing the building problems in a geotouristic ambience arouses curiosity in the people. It is an effective way to disseminate the reasons for the problems and to attract new followers [23]. At this point it should be noted that urban geotourism has to differentiate itself from “disaster tourism”, as areas where severe problems or disasters recently occurred which affect the population should not be visited for touristic reasons.

However, in touristic visits to elements of architectonic heritage, there will be the situation that the damage in one part leads to a profit in the other. This ambiguity may be resolved by considering that better knowledge about the state of architectonic heritage buildings, which is made accessible to a larger public, will contribute to its conservation and preservation, as well as it may help to prevent future damages in new buildings.

And, last but not least: Don't forget that you cannot use the geologist's hammer in an urban geologic tour, for understandable reasons!

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