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Publishable summary

The Narrative of the “Identification of cultural buildings as real and virtual demonstration in UNESCO sites” is the deliverable linked to WP5, Task **5.1 – Review and identification of the buildings located in World Heritage Sites** in the geographic area of mandate of the UNESCO Regional Bureau for Science and Culture in Europe in Venice, Italy. These sites perform as virtual and real demonstrators of the “Most Efficient, Easy and Low Cost Geothermal Systems for Retrofitting Civil and Historic Buildings” (“GEO4CIVHIC”) project.

This document provides the EU Commission with a detailed narrative of the efforts put in place by UNESCO and its partners on the assessments, consultations and field visits with stakeholders and further analysis undertaken to identify suitable and exemplary destinations to the innovative solutions proposed by the GEO4CIVHIC project. The driving purpose of our work was to find the most suitable hydrogeological and structural features within a friendly institutional environment to host GEO4CIVHIC solutions. UNESCO’s primary scope is to preserve the architectural integrity of the selected buildings, maximising the potential benefits in both CO2 emission reduction and avoidance of invasive traditional heating/cooling systems.

The selected sites are: **Angel’s Gate, located in the town of Ferrara in Italy, performing as a real demo case and the Museum of Croatian Archaeological Monuments in the town of Split in Croatia, as a virtual demo.**

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Abbreviations

DoW	description of work
GEO4CIVHIC	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
GSHP	ground source heat pump
LEED	Leadership in Energy and Environmental Design
MoU	Memoranda of Understanding
MHAS	Museum of Croatian Archaeological Monuments
UC	User Committee

Introduction

The work undertaken by UNESCO and the WT 5.1 partners sought to lay a suitable testing ground for GEO4CIVHIC shallow geothermal solutions, which required the identification of both virtual and real testing cases on which to work. The selection of the cases was essential to provide an exemplary assessment to which the geothermal energy system brought forward by GEO4CIVHIC is able to meet multiple and demanding targets.

The process of consultation involving a set of fundamental end-users for each site, starting with the management authorities, inclusive of upper level ministries and local technical experts, has brought us to identify the most interesting and suitable areas to physically host GEO4CIVHIC solutions producing a conducive environment for the following WP/WT.

A special note of mention is for the real case study related to the municipality of Ferrara, which enthusiastically welcomes GEO4CIVHIC implementation. This is worthy of mention since technical aspects have to be always put hand in glove with other dimensions such as human and institutional ones, which require the use of soft skills falling within the role played by UNESCO in the project. Moreover, the identification of suitable demo sites is instrumental to the achievement of two major milestones: (i) a well conducted in field demo capable to unfold a meaningful and tangible narrative of the project scope and goals and (ii) mainstreaming such innovative tools and methodologies for geothermal power solutions for the sustainable management of built heritage. This is the reason why, through our institutional work, the Green Building Council of Italy, is now part of the User Committee (UC) for the demo site in Ferrara and possibly playing a positive role also in mainstreaming such innovative solutions elsewhere in Europe and beyond in cooperation with UNESCO.

Our general purpose is to secure the coexistence between heritage-significance conservation in interior/exterior features of built heritage and sustainability, including the use of green and affordable energy solutions such those well devised by GEO4CIVHIC. By pursuing this, we are aware that other relevant achievements are viable: curbing CO₂ emissions, mitigating climate change and saving costs for operating heating and cooling of indoor spaces. These are highly appreciated outcomes to managers of monumental buildings, especially in countries where energy related infrastructures along with their maintenance, are of major impact on budgets.

However, WTT.1 was not meant to provide evidence of the overall impact of a GEO4CIVHIC solution, and the methodology used for the conduction of the preliminary assessment suggests a most likely successful achievement. For instance, the sharing of hydrogeological information and the empirically based evidence provided have clearly highlighted that the geological characteristics of the underground and local thermal conductivity in the soil have a potential to exploit.

As far as UNESCO is concerned, an additional asset of the undertaken activities is inherent to their relevance with regard to museums, with special reference to the Recommendation¹

¹ UNESCO Recommendations are non-binding instruments in which the General Conference of UNESCO formulates principles and norms for the international regulation of any particular question and invites Member States to take whatever legislative or other steps may be required in conformity with the constitutional practice of each State and the nature of the question under consideration to apply the principles and norms aforesaid within

concerning the Protection and Promotion of Museums and Collections, their Diversity and their Role in Society, approved by the UNESCO General Conference on 17 November 2015.

We do believe that innovative sustainable energy technologies are especially relevant with regard to the *functions of museums and the growing role of technologies in everyday life. These have a great potential for promoting museums through the world and performing as ambassadors of sustainability for educational and scientific purposes alike.* With this spirit, UNESCO, along with the national authorities of Croatia, identified one museum among the virtual recipients of our demos. Despite the real case will engage us the most, we will secure any resource and energy needed to follow up adequately such a first phase presented in this report with inspiration and strategic vision for the future activities.

their respective territories. These are therefore norms which are not subject to ratification but which Member States are invited to apply.

1 Ferrara, Italy to host GEO4CIVHIC solution in its real demo

Ferrara, City of the Renaissance, and its Po Delta is a UNESCO World Heritage Site since 1995². It is located in the Emilia Romagna region in northwest Italy. The site is comprised of the city centre of Ferrara, as well as the adjoining cultural lands within the Po River Delta. The city is famous for its achieved urban planning, as it was the first Renaissance city to be developed this way. It was created with a network of streets and walls (including the encircling city walls) that were linked directly with the palaces, churches, and gardens to give the city an overall harmonious and aesthetic value as opposed to individual buildings. Additionally, this method focussed on balancing the architecture with open spaces, the needs of the city and local traditions. The history of Ferrara also directly is connected to the Este family with their ruling during the Renaissance and bringing the city to an importance of the arts, economics and politics that rivalled Venice, Florence and other cities of prominence throughout Europe at the time.

Today, Ferrara has a strong legacy with European projects on sustainable energy and, in particular with geothermal power, the administration has used it to strengthen its city policies for climate change adaption and mitigation. Additionally, it has set a Memorandum of Understanding (MoU) with the World Green Building Council and works closely with the Green Building Council of Italy for sustainable historical heritage. It has therefore become a pilot promoter for the implementation of its territory of “Leadership in Energy and Environmental Design” (LEED) certificate, adapted to the historical buildings, which is the most widely used green building rating system in the world. The innovative shallow geothermal application introduced by GEO4CIVHIC has been welcomed warmly by the city administration since in full compliance with the aim of preservation of the architectural integrity and authenticity of the hosting building, which falls within the borders of the core area of the UNESCO property.

UNESCO undertook the selection process and data retrieval for the Ferrara site over the series of four visits. The first, held on 3 May 2018, introduced the GEO4CIVHIC project to the management authorities of Ferrara. During this time, the User Committee (UC) was formed. The UC for GEO4CIVHIC, set in place jointly by UNESCO and the municipality of Ferrara, is composed of members from the Municipality of Ferrara (Department of Urbanism and Urban Regeneration), Green Building Council- Italy, CNR-ISAC, RED and the University of Padua (engineering and geological studies departments). The UC looked to determine a site with the following characteristics: (i) foreseen refitting works, (ii) provided with heating terminals or fan coils to perform cooling/heating functions, (iii) a suitable exterior space for drilling, and (iv) an interior space for the installation of a control room. Initially, the following buildings were shortlisted: the house of Ludovico Ariosto, Ariosto’s cell, Angel’s Gate, House of the Motherland, Tasso’s Cell in the public auditorium, and the Este Palace.

During the next visit, 28-29 June 2018, the list of site options then was narrowed to Tasso’s Cell and the Angel’s Gate, both of which are within the borders of the World Heritage property of the city of renaissance of Ferrara and its Po delta. After an assessment by the technical teams of both sites, the Angel’s Gate (*Porta degli Angeli*) was chosen for a GEO4CIVHIC solution. Angel’s Gate³

² <https://whc.unesco.org/en/list/733>

³ All historical information regarding Angel’s Gate is taken from: Comune di Ferrara (1996); Onofri, S. and Testoni, V (2011). Photos are from above 2 sources and J. Runte.

is equipped with an old and inadequate heating and without any active cooling system. It frequently hosts expositions and meetings organised by local institutions and additionally is visited by a large number of both tourists and residents alike. Angel’s Gate represents one of the iconic places for the natives and a masterful work of fortified architecture, which through GEO4CIVHIC will have the potentiality to become more accessible and comfortable for its visitors in all seasons by maintaining its features and characteristics.

Over 30-31 October 2018, the third visit, the Councillor for Urbanism and Urban Regeneration of Ferrara committed to delivering a set of data that would be needed to do the first energy assessment of Angel’s Gate’s indoor spaces. It also was during this time that a resolution was submitted to the city council in order to provide internal binding provisions for the implementation of the project and ensure institutional sustainability along its entire lifespan regardless possible political and administrative swings due to elections foreseen in Spring 2019.

The most recent visit to Ferrara, 10-13 December 2018, was in conjunction for a national based workshop on sustainability in built heritage co-organised by UNESCO, the municipality of Ferrara the Green Building Council and CNR ISAC This visit also included an additional field visit to Angel’s Gate by UNESCO representatives and to obtain more data from by the “Servizio Beni Monumentali” office of Ferrara.

1.1 Description of Angel’s Gate

The ancient turreted gate and access-way was planned at the end of the 15th century in the plan of “Erculea Addition” (*Erculea Addizione*) at the end of the *Via degli Angeli*, today called *Corso Ercole I d’Este*, in honor of the duke who, together with architect Biagio Rossetti, conceived the famous urban expansion to the north of the Estense castle.



Figure 1 - Angel’s Gate and map of Ferrara showing city walls and location of Angel’s Gate

However, Angels Gate was not built in its final structure until around 1525 when a series of works were made to transform the existing construction and the adjacent walls, built between the late 15th and early 16th centuries.



Figure 2 - City walls of Ferrara

According to tradition, the Gate's entrances/exits were closed and walled up when Cesare d'Este, who was forced to move away from the city following the devolution of Ferrara to the Papal State, had last come through it in 1598. In reality, archaeological excavations carried out and the archive documentation suggest that Angel's Gate remained open, albeit alternately, at least until the end of the 17th century.

In the 16th century, it was considered one of the most prestigious entrances of the entire city walls because, in addition to the ambassadors and important personalities, the dukes of Este came in and out from it when they went hunting in the "*Barco*" in front of it (now *Parco Bassani*).

Located on the tree-lined embankments of the northern walls, the Gate is the only fortified access from the Este period still largely intact. It originally only consisted of the lookout tower, to which later was added the lower building, formerly used as a military building or base. As a whole, it preserves typical elements of extreme interest for historical and tourist aspects, even if over time it was subjected to a series of interventions, which adapted the interiors to the very different uses. During the 19th century alone, the building first was used as a slaughterhouse, then a powder magazine, and from 1894 to 1984 as a residential building. However, the charm of the 14th and 16th century architecture remains largely unchanged, both outside and inside.

The Civic Museum of Ancient Art, in connection with the Friet-Mura-Parco project, conducted archaeological investigations in 1986. During this time, the main door was recovered, re-opened, and restored. It was constructed to connect with a metallic bridge to the arrow rampart (*rivellino*) inside the building that was rebuilt with respect to the original dimensions. The excavations also discovered the ancient treading floor (later restored) and original threshold of the south gate, which was integrated with modern bricks as part of a restoration.

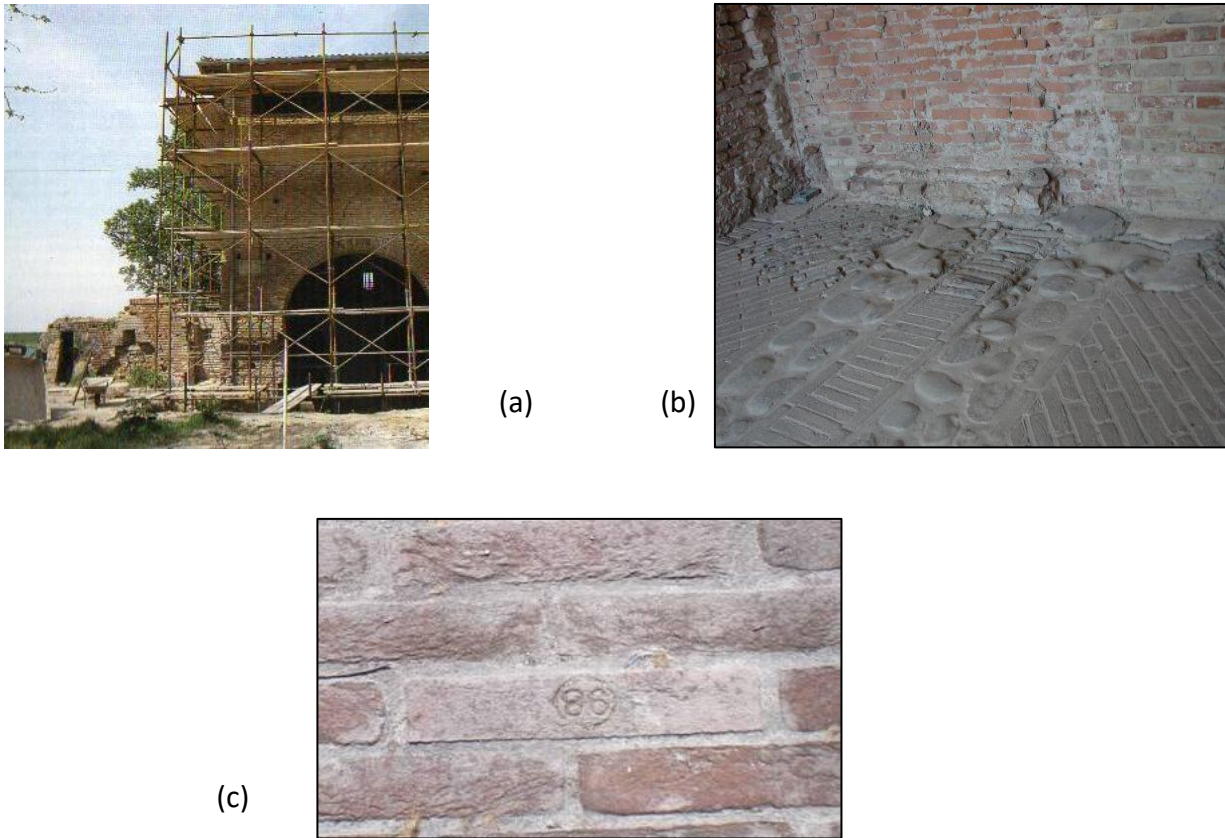


Figure 3 - (a) Restoration work on southern arch entrance, (b) treading on floor, and (c) modern brick stamped with "86" from work in 1986

The entire northern walls of the city and the Angel's Gate were restored by the Municipality of Ferrara and officially inaugurated in May 1999.

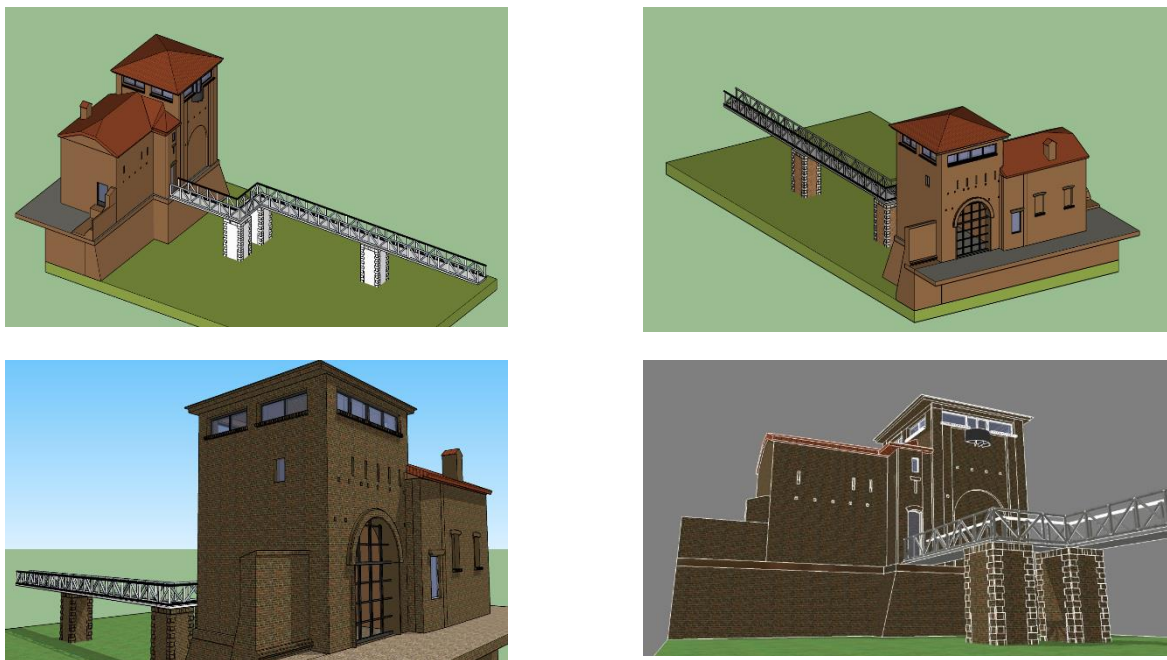


Figure 4 - 3D computer designs for planning of restoration work in 1999

During this time, the main archway on the north side, which originally connected the wooden bridge to the valley, was fully closed and buffered.



Figure 5 - Before and after restoration work on north archway and closing of it

The works allowed the discovery of the original foundations of the ramparts in front of the Gate and the ancient support pylons of the ancient bridge connecting the two buildings. These findings have allowed a rebuilding of the bulwark that was made in the 16th century to defend the Gate before it was demolished definitively in 1859. A raised passage today allows for access to the same rampart, thus opening a walkway between the Angel’s Gate and the underlying valley where a cycle path is located.

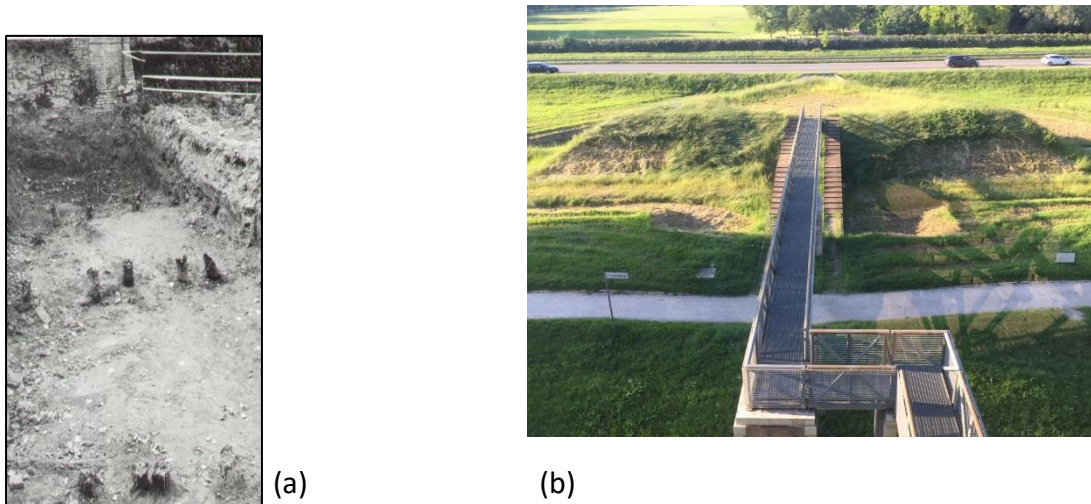


Figure 6 - (a) Discovery of original pylons for wooden bridge, (b) new bridge made during restoration connecting Angel’s Gate building with valley

Furthermore, the watch tower specifically was restored. A modern, spiral staircase was added to give more access and not take up extra space, attempting to maintain the integrity of the building. The access quota (m.0 00) was connected with the upper level (m.4.94) with a mixed vertical connection system of a ladder and spiral and straight staircase. The window openings

were covered with shatterproof glass giving extra protection to the room, where one can have a 360-degree view of the area surrounding the tower.



Figure 7 - Restoration of watchtower with shatterproof glass, addition of spiral staircase

The open space surrounding Angel’s Gate, probably originally used for military exercises, also was paved and benches and grass added.



Figure 8 - Renovation of exterior space with pavement, grass, and benches

One chamber on the wall hosts an obsolete heating system out of service, which will be removed to give space for cabling and connection during the implementation of the geothermal power system.

1.2 Hydrogeological setting

The historical, urban and architectural evolution of the city of Ferrara, located in the eastern sector of the Po Valley, always has been characterised by the presence of both superficial water (fluvial dynamics of the Po River) and underground resources (Figure 9a).

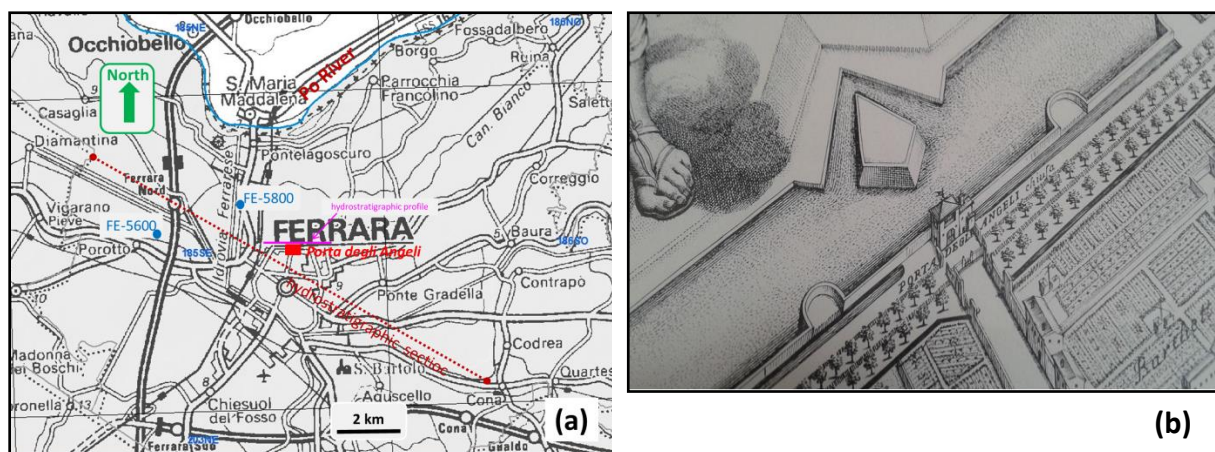


Figure 9 - a) Study area and position of hydro-lithostratigraphic section shown in Figure 10, b) Angel's Gate engravings of Andrea Bolzoni (1747)

From a geological point of view, Ferrara is located in the eastern sector of the Po alluvial basin entirely covered by Quaternary fluvial sediments (AGIP Mineraria, 1959; Pieri and Groppi, 1981; Castelarín et al., 1996; Regione Emilia Romagna-ENI-AGIP, 1998; Toscani et al., 2008). Pliocene and Pleistocene materials were deposited in different environments: marine, deltaic, swampy and alluvial conditions. Consequently, the Pliocene-Quaternary deposits are characterised by silty-muddy layers alternating with sandy and sometimes gravel lenses.

As revealed by geophysical prospecting and boreholes for hydrocarbon exploration, the deposits' thicknesses and distribution have been strongly influenced by the deep tectonic structures, most of which were active during the accumulation of the Pliocene-Quaternary sedimentary succession (Pellegrini and Vezzani, 1978; Gubellini and Russo, 1988; Albarello and Martinelli, 1994; Tinti et al., 1994). One of the most important of such tectonic structures is the Ferrara anticline, called 'Dorsale Ferrarese', where the Mesozoic carbonate units have been uplifted to a depth of less than 100 m (Figure 12; Pieri and Groppi, 1981; Cassano et al., 1986; Regione Emilia-Romagna-ENI-AGIP, 1998).

The influence of this shallow tectonic structure is crucial: a) being the source of a geothermal field with a temperature of about 100 °C (Casaglia geothermal reservoir) and b) by strongly modifying the geometry of the deep aquifer layers (especially aquifers A3 and A4, see Figure 12).

Based on historical and archaeological data, the present-day city of Ferrara was a widespread agricultural settlement. After the fall of the Roman Empire, due to cold and humid climatic conditions, a major rearrangement of the fluvial drainage network took place, leading to the development of two new distributary channels of Po di Volano and Po di Primaro. These channels diverged precisely at the future centre of the urban area of Ferrara.

On top of an alluvial fan along the hydrographic left of the Po River (a sandy morphological feature providing drained ground avoiding the stagnation of floodwaters), the first proto-urban structure was established (Figure 10), consisting of a Byzantine fortified village, developed in a linear way. It was about 240 m-long, with an area of 35,000 m².

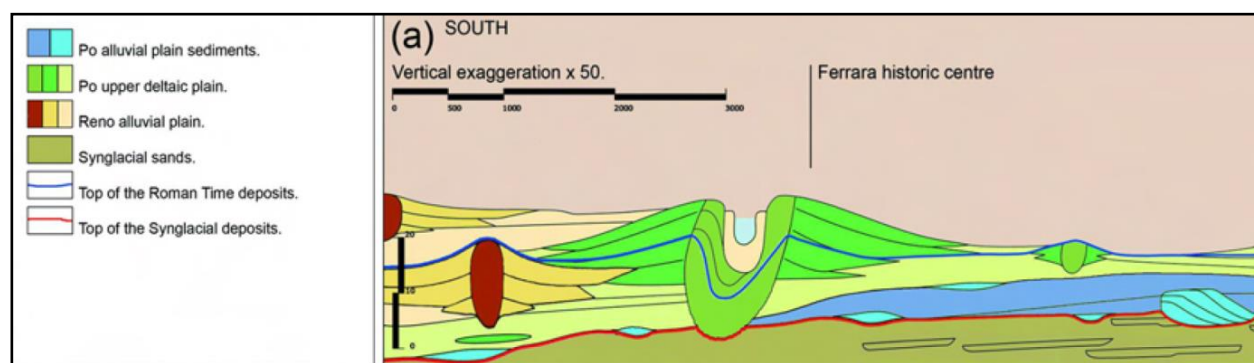


Figure 10 - Geological section showing the stratigraphic relationships between upper Pleistocene synglacial (18-25 ka BP) sands and Holocene (<10 ka BP) Po River deposits in correspondence of the Ferrara urban area, along a north-south profile (Stefani and Zuppiroli, 2010)

During the 11th century, the so-called “linear town” covered a levee sector more than 2 km-long with a width generally less than 100 m.

In the 12th century, the town expanded towards the outer edge of the body of the natural embankment, where the Romanesque cathedral was founded. Meanwhile, a few kilometres upstream of the city, the high seismicity and localised tectonic uplift caused a series of fluvial breaches, known as Rotta di Ficarolo, thus generating the detour of the Po River forming a northern branch relative to the town since then referred to as Po Grande.

During the following centuries, the land reclamation works made the growth of the urbanised area toward interfluvial clay-rich depressions possible. During Renaissance (end of the 15th century), a newly planned area towards the northern sectors of the old linear town represented a major expansion phase called Addizione Ercolea, which was designed by the architect Biagio Rossetti.

The expanded urban area then was surrounded on the north side by a new long stretch of fortified walls with a protective purpose from possible attacks by the Venetians, who were at war with the Este Family of Ferrara at that time. Moreover, in order to directly and quickly connect the castle containing the garrison with this external defensive structure a perfectly straight road was built (*Via degli Angeli*, nowadays Ercole I° d'Este Avenue), while at the end of the road the Angel's Gate was erected (Figure 9b).

In summary, all the processes described are reflected in the superficial lithology (Figure 11). In particular, the south-west sector of the city is characterised by the presence of the Po upper deltaic plain sediments, while in the northeastern sector, Po alluvial plain sediments prevail.

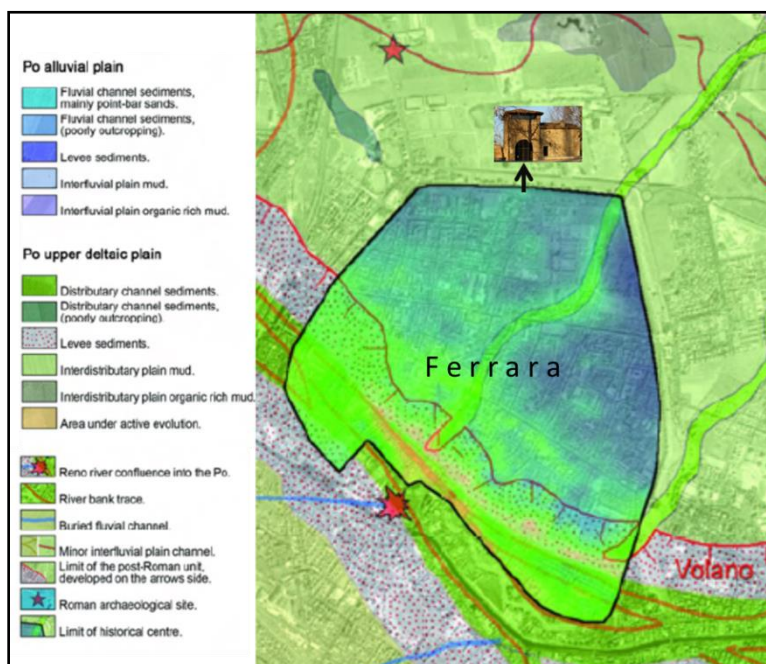


Figure 11 - Surface lithological map of the Ferrara area

On the basis of the available stratigraphic data and numerous penetrometric tests performed in the Ferrara area, it was possible to recognise the presence of the regional aquifer group called “A” developed within the uppermost 200 m of the Continental Quaternary Cycle (Qc), corresponding to the Upper-Emilian-Romagnolo lithostratigraphic system (Middle-Holocene-Pleistocene). The group consists of five major aquifer systems A0, A1, A2, A3 and A4 (Figure 12; Regione Emilia Romagna & ENI, 1998; Rapti-Caputo, 2000; Molinari et al., 2007).

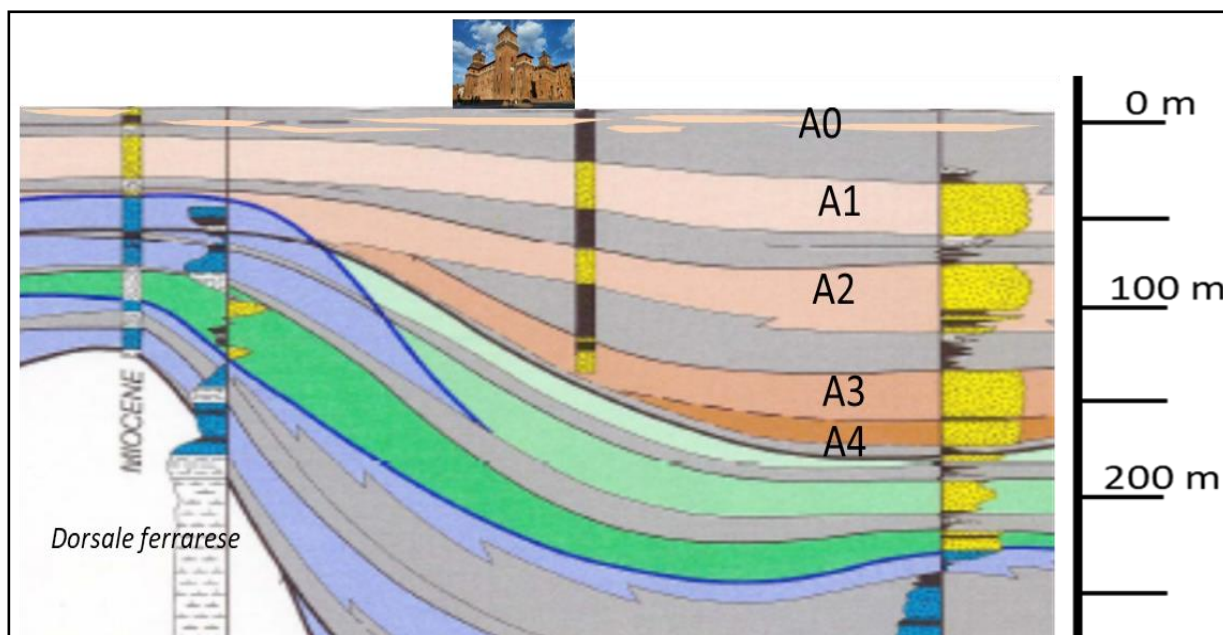


Figure 12 - Hydro-lithostratigraphic section. For location see Figure 9a (Regione Emilia Romagna & ENI, 1998)

The first three aquifer systems, A0, A1, and A2 are characterised by the aggradation of fluvio-deltaic and alluvial plain deposits with sediments originating from both the Po River and the Apennines streams. In particular, the coarser deposits (fine-to-coarse grained sands) are commonly associated with fluvial channels while the finer ones (mainly silt and clay) represent alluvial and/or swap environments.

The unconfined or locally semi-unconfined aquifer system A0, mainly consists of lense-shaped sandy bodies originating directly from the Po River, usually as infilling deposits of abandoned channels and meanders or lateral banks. The exploitation of this aquifer body is performed by using numerous wells of about 1 m in diameter, excavated many years ago, to a depth of 7-8 m. The principal feeding source of this aquifer system is mainly through infiltration of precipitation and secondarily via lateral infiltration from the hydrographic network. The isotopic composition (δD and $\delta^{18}O$) of this aquifer strongly is affected by meteorological events, and the mean residence time of the water in the underground reservoir is of 2-5 years (Rapti and Martinelli, 2009).

There is a low permeability layer consisting of silt and clay locally alternating with peat, varying in thickness between 15 and 25 m and separating the unconfined aquifer from the underlying one (A1; Figure 12).

During the last glaciation (Alpine Würmian), associated with an eustatic lowstand, the study area was the site of widespread braided-river sedimentation. The uppermost Pleistocene sands (Figure 10; synglacial sands) are well developed in the urban area subsurface, where they form the confined aquifer, or along the axis of the major palaeo-rivers (semiconfined aquifer system A1). In the study area, only the aquifer A1-I is present, which corresponds to the more superficial aquifer body of the A1 system.

The depth to the sand top varies from 35-40 m in the depocentres, but it is only 15 m in correspondence of anticline culminations (Casaglia area, at the north-western border of town; Figure 12). Below the urban area, the top surface of the A1 rapidly decreases northwards from 32 to 13 meters deep.

The principal recharge sources of this aquifer are the alluvial fans and terrace deposits of both Apennines and Alpine origin and secondarily the River Po. Concerning the hydraulic parameters of this aquifer (A1-I), the mean hydraulic conductivity is 8×10^{-4} m/sec and the transmissivity about 3×10^{-2} m²/sec (Rapti-Caputo, 2000). The general flow direction is from NW to SE with a hydraulic gradient about 0.5‰.

From a hydrochemical point of view and based on analytical data related to borehole FE-5800 located about 2.2 km north-west of the Angel's Gate (Figure 9a) for the period 1988-2012 (ARPAe database), the average values of pH, temperature and electrical conductivity (at 20°C) of the aquifer are 7.6, 16 °C, and 2401 microS/cm, respectively. The concentration in chlorides presents oscillations between 125 to 1489 mg/l and sodium from 83 to 735 mg/l.

In addition, the tritium concentrations present variations from 2.5 to 15 ± 3.9 TU. The high tritium value, located near the Po River is due to mixing phenomena between the 'old' water of the confined aquifer A1 (about 40 ka) and the 'recent additions' from the hydrological channel network crossing the Ferrara plain (Rapti-Caputo, 2000; Rapti and Martinelli, 2009).

At the base of A1 aquifer system, a low permeability silt or silty clay layer, with a thickness varying between 15 and 20 m, hydraulically separates this confined aquifer from the underlying one (A2).

The permeable deposits of the A2 aquifer system (Figure 12) are the most important ones of the Ferrara Province. Similar to aquifer A1, this body also is recharged by the Apennines and Alpine alluvial fans, but it is hydraulically separated from the Po River. This system is subdivided into A2-I and A2-II aquifer (not present in the study area).

The A2-I aquifer, which corresponds to the upper part of the system, is of continental origin and presents the largest extension with respect to all the other aquifers in the Ferrara Province. The top of the A2-I is about 55-70 m below ground level and has a thickness about 15-25 m. The main flow direction, strongly influenced by the pumping (Ferrara industrial extraction zone, 30 l/s), is from WNW to ESE.

From a hydrochemical point of view and based on analytical data related to borehole FE-5600 located about 5 km west (Figure 9a) of the Angel's Gate for the period 1988-2012 (ARPAe database), the aquifer contains fresh water that is basic with pH values between 7.0 and 7.9.

The average temperature of the aquifer is about 16°C, and the mean electrical conductivity (at 20°C) value is 1166 microS/cm. The average concentration in chlorides is 74 mg/l and sodium 117 mg/l, while the mean values for calcium, magnesium and iron are 130 mg/l, 38 mg/l and 1064 microg/l, respectively.

The two deeper aquifer systems, A3 and A4, are developed in 225-400 ka old deposits mainly formed during the littoral and marine aggradation phases and are found at depths between 90 m and 180 m. The coarser materials (medium-grained sands) are interpreted as frontal delta or beach deposits, while the fine ones separating the aquifers (aquitard) represent lagoon, pro-deltas and platform environments. As shown in Figure 12, the geometry of aquifers A3 and A4 does not reflect the depositional geometry, but it is strongly influenced by the tectonic trend of the major structures (anticlines) affecting the area. These deeper aquifers show high salinity values.

In the preliminary phase, the definition of the conceptual local hydrogeological model mainly was based on stratigraphic data, integrated with shallow penetrometric information (Emilia Romagna Region archive).

Due to the lack of deep boreholes close to the site, the stratigraphic data were organised and elaborated along an east-west hydro-stratigraphic section, a few meters to the north and parallel to the walls of Angel's Gate.

Moreover, as the depth of the boreholes does not exceed 65 m for the definition of the deepest hydrogeological sequences, more distant boreholes have been taken into account reaching a depth of about 120 m.

In particular, based on the hydro-stratigraphic profile (Figure 13) consistent with the previous description, we can locally observe:

- a clayey layer with intercalation of peat and sand lenses (A0 aquifer) up to 15 m-deep;
- a confined sandy aquifer (A1) from 15 to 40 m of depth b.g.l., with variable grain size and thin clayey lenses;
- a clayey layer (thickness about 15 m);
- the second sandy confined aquifer (A2) from 55 to 80/82 m;

- in sequence, a low permeability clayey layer (thickness about 12-14 m);
- Finally, the confined A3 aquifer from 90-94 to 120 m of depth.

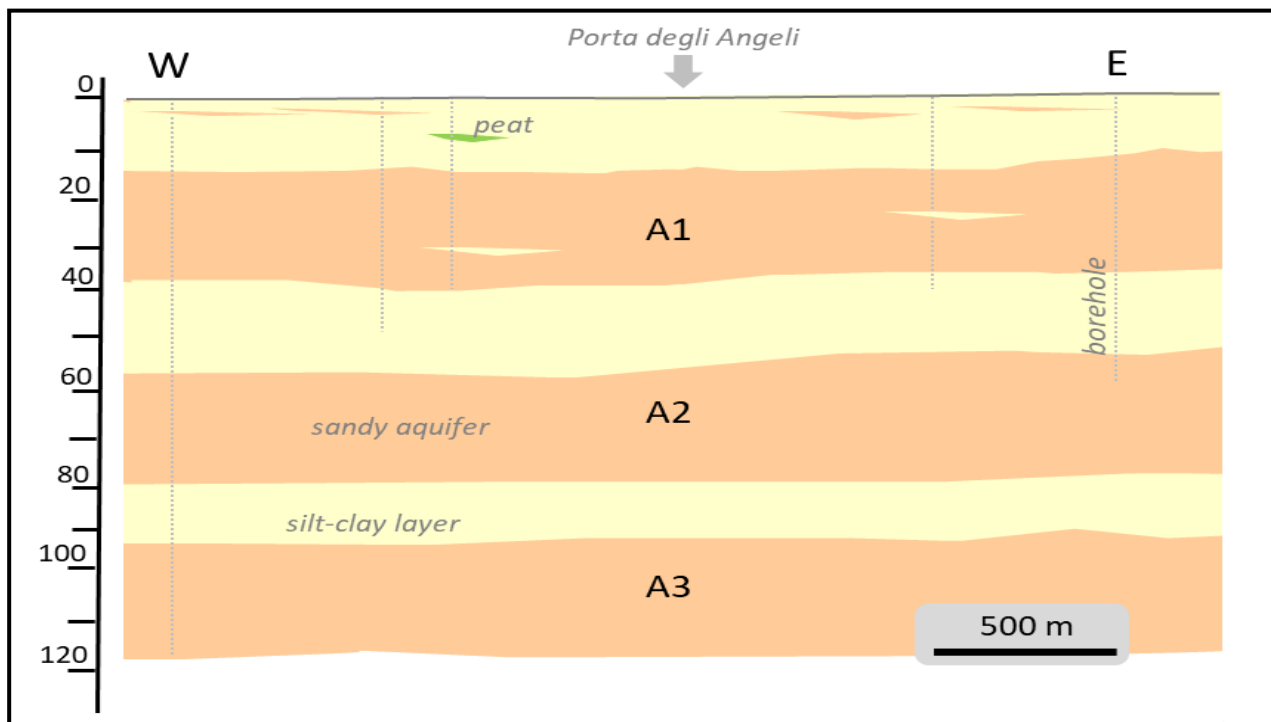


Figure 13 - Hydro-stratigraphic profile. For location, see Figure 9a

2 Monumental building in Croatia as recipient of GEO4CIVHIC virtual demo case

UNESCO pursued the objective of identifying - in cooperation with the responsible authorities in the country - a suitable destination and a significant case study to apply GEO4CIVHIC solutions through a well-instructed simulation exercise.

On 17 November 2015, the UNESCO General Conference adopted a Recommendation on the Protection and Promotion of Museums and Collections, their Diversity and their role in Society⁴. The Recommendation affirms that

Museums as spaces for cultural transmission, intercultural dialogue, learning, discussion and training, also play an important role in education (formal, informal, and lifelong learning), social cohesion and sustainable development. Museums have great potential to raise public awareness of the value of cultural and natural heritage and of the responsibility of all citizens to contribute to their care and transmission. Museums also support economic development, notably through cultural and creative industries and tourism. (Art. 2)

Within the norms and measures that the above-mentioned new Recommendation on Museums sets forth, the application of innovative sustainable energy technologies is especially relevant with regard to the following:

- Art. 22 states that Member States should adopt policies and take appropriate measures to ensure the protection and promotion of museums located in the territories under their jurisdiction or control, by supporting and developing those institutions in accordance with their primary functions, and in this regard develop the necessary human, physical and financial resources needed for them to function properly.
- Art. 26 encourages Member States to promote the development of standards, museum policies and national legislation.
- Art. 29 affirms that the functions of museums are also influenced by new technologies and their growing role in everyday life. These technologies have a great potential for promoting museums through the world, and Member States should strive to provide access to these technologies for museums in the territories under their jurisdiction and control.

⁴ UNESCO Recommendations are non-binding instruments in which the General Conference of UNESCO formulates principles and norms for the international regulation of any particular question and invites Member States to take whatever legislative or other steps may be required in conformity with the constitutional practice of each State and the nature of the question under consideration to apply the principles and norms aforesaid within their respective territories. These are therefore norms which are not subject to ratification but which Member States are invited to apply.

2.1 Description of the Museum of Croatian Archaeological Monuments

The Historical Complex of Split with the Palace of Diocletian was inscribed in the World Heritage List in 1979⁵. The site is one of the most important places on the Dalmatian coast, especially due to its high structural architectural integrity and preservation in contrast to other locations.



Figure 14 - External and interior of the MHAS

The Museum of Croatian Archaeological Monuments⁶ (MHAS) is a monumental building located just outside the historic city centre of Split. The Museum was proposed specifically by the Croatian Commission for UNESCO as a demonstration site. Though it is not part of the local World Heritage site, the MHAS is one of the oldest Croatian museums and the only museum in Croatia that was founded with the unique task to explore, collect, present and study the remains of tangible and intangible culture of the early medieval period, respectively from the 7th-15th centuries, in particular from the time of the early mediaeval Croatian State (from the 9th-12th centuries).

The MHAS was founded under the name “First Museum of Croatian Monuments” in Knin in 1893. During World War II, fearing the threats of the war, it initially was moved to Sinj, later to Klis and finally to Split, where it is still located up to this date.

The MHAS’s inventory consists predominantly of exemplars of various jewellery, weaponry and objects of everyday use, as well as a large number of stone monuments that were part of the

⁵ <https://whc.unesco.org/en/list/97/>

⁶ All information and photos regarding museum taking from official MHAS website: <http://www.mhas-split.hr/english/language/hr-HR/museum/about-the-museum>

interior of early Croatian churches. With its collection of early medieval interlacing-ribbon and figural sculptures and a large number of early Croatian epigraphic monuments in Latin, the MHAS possesses currently one of the greatest collections of such kind in Europe.

The MHAS has an extensive inventory of early Croatian archaeological heritage with about 20,000 artefacts, out of which only 25% are displayed in a permanent exhibition, *inter alia*, the most significant and historically most valuable collection is the selection of epigraphic monuments from the 9th -12th centuries, depicting the engraved names of Croatian rulers, secular and ecclesiastic dignitaries. This part of the MHAS's archaeological collection, as the oldest Croatian "archive" (archive in stone), has in this respect a unique historical documentary value. Besides museological work, the MHAS conducts comprehensive archaeological excavations at early medieval archaeological sites, particularly in the south Croatian region between the Cetina and Zrmanja Rivers, i.e. in the cradle of the early medieval state of Croatia, and deals extensively with exhibition and publication activities.

The building of the MHAS was constructed from 1972 until 1976. A suitable building was erected that the Museum had been lacking since its founding in 1893, and the permanent exhibition was opened later in 1978. The project was entrusted to an academic architect Mladen Kauzlarić, and after his death it was elaborated by Zvonko Vrkljan and Sena Gvozdanović. The Museum's permanent exhibition was directed by the architect Ante Svračić and academic painter Frane Delalle.

The architectural complex of MHAS is characterised by the grouping of functional elements of pure volumes within the complex and their integration with nature. The intertwining of nature and architecture is visible by the positioning of simple volumes on the lot in a way that forms multiple green surfaces. The Museum consists of the following basic spaces: an office building and building with the exhibition, the Museum workshops and event space. The idea of integration is present between outer and inner spaces, as well as between mutual inner spaces. Connecting the Museum to a given place and nature was accomplished with use of a longitudinal planted greenery along the southern façade of the building facing the street and a modern horizontal line towards the sea. The area around the Museum's complex, which is arranged as a park, has life-sized foundations of typical Old-Croatian churches, as well as placements of stecći that are grouped effectively making this space to be an exhibition in the open air. These are in the eastern terrace-shaped section of the park. Here, also is a projected access to the administration building as well as an additional access to the main building. Positioned on the northern side of the lot is a planted green area with a small pine forest and an entrance to the administration building. On the western side of the complex, a cascade garden is located with a connection to the Museum parking area. On this same side is a service access for vehicles that has a connection to the workshops and depos. A lapidarium, which as a semi-open space, has the role of linking the Museum park and building with the exhibition; closing this outside space within the building and acting as an inner courtyard which creates a division between the main building with the exhibition from the workshops and exhibition hall; and having green borders of volumes, transparent walls with fanlights and big windows as framed views from the gallery towards the sea.

The idea of integration continues within the enclosed space, between the central spaces for the permanent exhibition. This acts like a square, occupying almost the entire area of the first floor of the building, displays the Museum exhibition and is connected through the gallery to the second floor on which the permanent exhibition continues. The load-bearing system consists of

reinforced concrete pillars measuring 80 x 80 cm. This type of support system allows for an independent façade that makes a connection possible of the volumes with a dark glass, which is a particularly expressive tool of modernist architecture. The second plan behind the pillars supports the lifting of the building from the terrain, and, while on the second level, it completely works as a dematerialised surface between two powerful horizontals.

As well as an exceptionally valuable museum fundus of national significance, the MHAS is architecturally representative of a first class monument of modernism.

The Museum has been listed on the Register of Protected Cultural Heritage of the Republic of Croatia since 2011.

While most direct efforts were put on the search for a real case study of the project, due to its prominent importance, UNESCO relied on the Croatian Commission for UNESCO, a national based entity under the authority of the Ministry of Culture, to select the virtual case to be assessed and performed within the framework of the project. The Museum of Croatian Archaeological Monuments (MHAS) was therefore, identified through an internal selection processed by the country’s domestic authorities against the criteria provided by the project partners. Such a long consultation initiated after the kick off meeting in April, and ended up with an official communication provided to UNESCO by the Secretary General of the Croatian Commission for UNESCO, as from the annex II, hereby attached.

The identification of the building and the relevant information received by its management authority are just a preliminary step toward a full fledge implementation of the virtual case study which will require in field visit and assessment by the project team in the upcoming future.

2.2 Hydrogeological setting

The central Dalmatian flysch is a part of a larger flysch basin, which stretches from Gorizia in Italy all the way to Albania.

The Pyrenean orogenic phase of the Eocene epoch is defined as one of the most important phases during the Alpine orogeny. Tectonic movements in this geological period, together with movements in subsequent periods, have resulted in the formation of current geological structures at the eastern coast of the Adriatic Sea.

In terms of geodynamics, primary geological structures significantly have been altered by subsequent thrust tectonics. These tectonic movements have resulted in a local narrowing of flysch sedimentary basins in the Adriatic belt and sporadic occurrences of these rocks on the surface, which is especially prominent in central and southern areas of Dalmatia. In central Dalmatia, the flysch rock mass can be found in areas around the towns of Trogir, Kaštela and Split, and these areas are defined in the Basic Geological Map as clastic and carbonate formations of Eocene flysch (Figure 15).

On the north side, flysch formations are mostly in normal fault contact with Cretaceous limestone of Mount Kozjak, while on the south side they spread under the Adriatic Sea. According to lithological characteristics, flysch dominantly consists of clastic sediments classified as limestone breccia, conglomerate, calcirudite, calcarenite and biocalcarenes calcareous siltstone. Marl usually manifests as final members in the flysch series, with the

registered occurrence of minerals quartz, illite, muscovite, plagioclase, microcline and montmorillonite.

The city of Split has been developing continuously since the construction of the Diocletian Palace (287–305) to the present time. Detailed engineering geological investigations, with the recorded documents, have been performed since 1970.

Flysch formations in Split area consist of breccia, conglomerate, sandstone, detrital limestone and marl with a varying CaCO₃ content. The same members of flysch sequence is divided into: coarse-grained (phaneritic) and fine-grained (argillaceous), wherein coarse-grained members are usually represented by calcirudite and calcarenite, breccia, conglomerate and sandstone, while argillaceous members are represented by marl and siltstone.

Due to their mineral composition, phaneritic layers are more resistant to weathering than argillaceous layers, whose weathering intensity can be noticed on a day-to-day basis. Because there is such a diversity of members in flysch sequence, and, consequently, in their mechanical properties (strength, resistance to weathering, etc.), the problems of durability, differential weathering and local rock falls are particularly pronounced inside cuts in flysch rock mass.

The data available are here reported on the basis of available data from geotechnical reports about stratigraphical units (their lithological composition and physical and mechanical properties) and limited field surveys. Zones with different ground conditions regarding rock properties are delineated in the form of lithological complexity and engineering geological mapping units for medium-scale maps. The area of the city of Split, built of foraminifera limestone (E_{1,2}), clayey glauconitic limestone (E_{1,22}) and flysch sediments (E_{2,3}), is divided into five lithological complexes, which present a unique combination of individual lithological types for which it is possible to indicate general behaviour of the whole. The data also provide a short review of other environmental conditions (active geomorphological processes, hydrological and hydrogeological conditions, as well as seismic conditions), which are intended as a guide to the sort of environmental data that could be collected by more detailed studies during the course of the zoning process.

Introduction of studied area

The city of Split is located in the central part of southern Croatian region called Dalmatia (Figure 15). The area under study lies between geographic longitudes 16°30' and 16°32'. The southern coastal boundary is approximately at 43°30' northern geographic latitude, while the northern boundary is at 43°32' northern geographic latitude. The size of the investigated area is approximately 25 km². The area of Split is highly urbanised and, as seen in Figure 15, the coastal area is well-developed and predominantly planned in an orderly manner.

Geological, engineering geological and hydrogeological investigations have been carried out in the Split region for several years with the objective of obtaining data on the composition and physical and mechanical properties of rocks, tectonics, hydrogeological and geomorphological phenomena and conditions necessary for construction on rock surfaces. Engineering geological mapping, geophysical investigations, excavations, exploration boreholes and laboratory/in situ testing of borehole samples yielded a great number of data, which, after a detailed analysis, provided information on ground conditions of the terrain on which Split was built and has been developing.

Sufficient reliable data were collected in the western part of Split on the Marjan Peninsula and in an area with new residential buildings in the eastern area of Split. Only some less numerous data were collected in the old city centre, i.e. the central part of the city. These data were included in more than 500 studies and reports referring to investigations carried out since 1960. It should be noted that in the earlier years the investigations were conducted sporadically, while after 1970 they became more systematic and comprehensive. These investigations became more intensive after the realisation that extensive surveys and studies of the terrain are crucial for safe design and construction.

Despite the long tradition of engineering geological mapping (Anon, 1972) and the existence of a great number of geotechnical investigation reports which depicts ground conditions at locations of particular site investigation, there is a lack of an urban engineering geological map of Split.

The only available map is a geological map in the scale 1:100.000 (Marinčić et al., 1971). Moreover, this map is a chrono-stratigraphical map, and it does not depict changes in lithological composition, which is necessary for the planning of detailed engineering geological or geotechnical investigations. For this purpose and for the purpose of land use planning, an urban engineering geological map (Dearman, 1991) or applied geological map (Smith and Ellison, 1999) of the city of Split is required.

This deliverable reviews engineering geological conditions in the area of Split by compiling available data about stratigraphic units, their lithological composition and physical and mechanical properties. It illustrates criteria for the delineation of main engineering geological mapping units on the basis of rock/soil properties, which are in the range of lithological complex (i.e., engineering formation, UNESCO/IAEG, 1976; Dearman, 1991). The aim was to identify zones with different ground conditions in terms of presentation and utility for future applied mapping studies for planners, developers and construction practitioners.

Lithological complexities derived on the engineering geological map of Split in the scale 1:25.000 satisfy the following attribute of homogeneity defined in Dearman (1991): specific grouping of certain lithological types and their spatial arrangement. The deliverable also provides a short review of other environmental conditions (active geomorphological processes, hydrological and hydrogeological conditions, as well as seismic conditions), which are intended as a guide to the type of environmental data that could be collected by more detailed studies during the course of the zoning process.

Review of past investigations

The first geological investigations of the wider Split area date back to the Austro-Hungarian monarchy and have continued to the present. However, engineering geological, hydrogeological and geophysical investigations began after World War II, primarily in a search for oil and later for construction purposes. For the most part, results of these early investigations are stored in the archives of companies and research institutions. All papers produced from these investigations include lithological features of the sediments, their physical and mechanical properties, chemical compositions and results of slope stability analyses and requirements, which must be satisfied before carrying out engineering works on rocky terrain.

The official geological map of the Split area is the Basic Geological Map of SFRJ 1:100.000, the Split Sheet (Marinčić et al., 1971) published together with an accompanying report on the Geology of Split Sheet (Magaš and Marinčić, 1973).

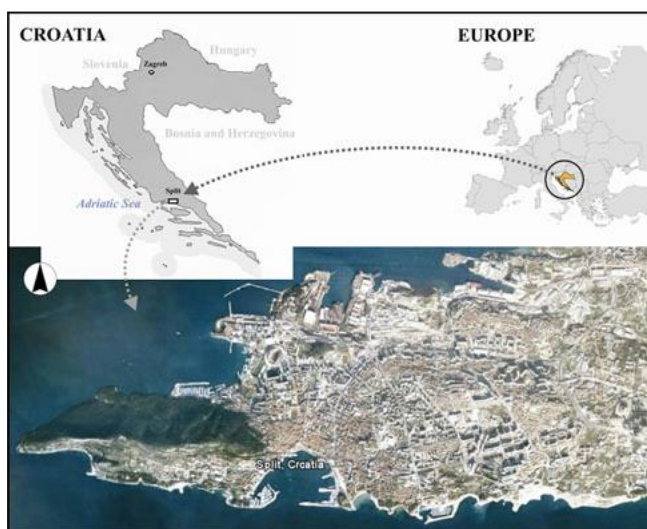


Figure 15 - Location of the studied area in the city of Split, Croatia (from Google Earth)

An understanding of structural geological characteristics is very important for engineering rock mass description and classification. Interpretations of structural tectonic relations in the area of Split prove to be very useful in open pit excavation design. This makes it possible to avoid negative effects of unforeseen ground conditions to be encountered during the construction exploitation phases.

Engineering geological conditions encompass a set of environmental conditions, which are the result of characteristics of rock and soils, geomorphological conditions and active geomorphological processes, hydrological and hydrogeological conditions, as well as geodynamic phenomena, such as earthquakes. Mapping of engineering geological conditions require zoning according to numerous engineering geological and environmental thematic data. The most important part of this work is the compilation of stratigraphic and lithological data from existing small-scale basic geological maps (Marinčić et al., 1971) and using data from borehole and outcrop investigations to derive a medium scale (1:25.000) engineering geological map in the scale (Figure 16). Cartographic rock units presented in this map (Figure 16) can be considered as basic engineering geological units, in rank of lithological complexes (UNESCO/IAEG, 1976). Among data about rocks, a short presentation is made of the most relevant environmental conditions related to surface and subsurface water and natural processes.

The area of the city of Split is formed of Foraminiferal limestone (E1, 2) and clayey glauconitic limestone (E1, 22) on the northern slope of the Marjan Peninsula. The clayey glauconitic limestone is intermediary sediments between Foraminiferal limestone and flysch sediments (E2, 3) that built most of the investigated area represented in Figure 16.

The youngest sediments are of Quaternary age (Q) produced by weathering of limestone and flysch, which randomly cover the Eocene age rocks (Marinčić et al., 1971; Magaš and Marinčić, 1973). Figure 16 shows spatial distribution of main bedrock stratigraphical units classified into five lithological complexes.

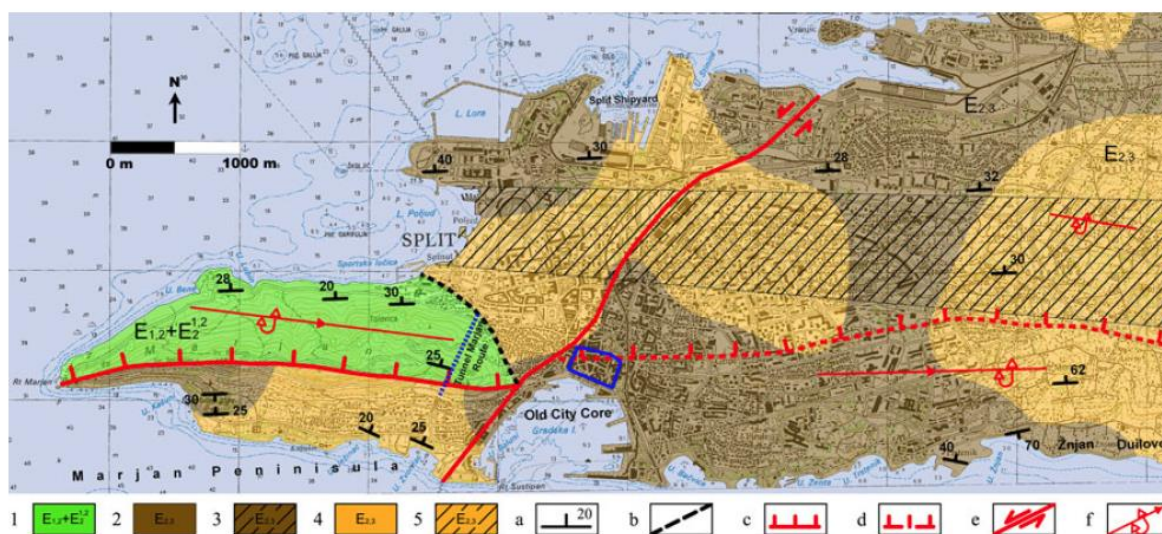


Figure 16 - Engineering geological map of lithological complexes in the scale 1:25.000. 1: complex of limestone, Foraminiferal limestone ($E_{1,2}$) and clayey glauconitic limestone ($E_{2,2}$); 2: complex of thick-bedded flysch, marls and calcirudite with subordinated content of clayey limestone, breccia and calcarenite ($E_{2,3}$); 3: complex of thick-bedded flysch with limestone olistolith blocks ($E_{2,3}$); 4: complex of thin-bedded flysch, marls and calcarenite with subordinated content of clayey limestone, breccia and calcirudite ($E_{2,3}$); 5: complex of thin-bedded flysch with limestone olistolith blocks ($E_{2,3}$)

Quaternary sediments are represented by calcitic silty clay and coarse gravel, cobbles and boulders. Clay is originated from marls, which are extremely influenced by atmospheric weathering. The thickness of the weathering zone, which covers the flysch rock ($E_{2,3}$), varies from a few centimetres to a few meters. Gravel, cobbles and boulders originated from mechanical disintegration of limestone on the Marjan Peninsula forming talus material on its slopes. Physical and mechanical properties of limestone and flysch sediment Foraminiferal limestone on the northern slope of the Marjan Peninsula have been extensively studied by in situ and laboratory tests during the surveys carried out for the construction of the Marjan Tunnel.

From a drilling point of view, Foraminiferal limestone is very favourable ground for construction purposes; although, unforeseen conditions like solution cavities (size of a few meters or dozens in span) are inevitable in limestone rock masses. Compared to Foraminiferal limestone, clayey glauconitic limestone is less favourable, because of a higher porosity and lower $CaCO_3$ content, which results in lowering drilling resistance parameters. Clayey glauconitic limestone with calcirudite, calcarenite and breccia have a comparable behaviour. It should be stressed that their spatial distribution is very limited. They build only a tight zone between Foraminiferal limestone and flysch. Consequently, clayey glauconitic limestone is less important in the investigated area.

Marls are classified in terms of hardness in according to $CaCO_3$ content, which is very important for engineering behaviour of marls. Marls with lower $CaCO_3$ content have a lower resistance to drilling penetration. If not protected from drying and wetting processes, a weathering of marls occurs in engineering time (Fookes et al., 1988), not in a geological one like weathering of limestone.

Hydrogeological and hydrological conditions

According to hydrogeological properties, the Split area is characterised by sediments of high permeability, sediments with some vertical and lateral changes in permeability in the form of presence of partly impermeable sediments, partly impermeable sediments and impermeable sediments.

Sediments of high permeability include Foraminiferal limestone, which build the northern slope of the Marjan Peninsula. Their porosity is secondary (joints and solution cavities). Water is not possible to be retained in those areas even after abundant and long-lasting rainfalls.

The sediments with vertical and lateral changes in permeability include Quaternary sediments represented by calcitic silty clay and coarse gravel, cobbles and boulders. Their porosity is primary (intergranular), and the permeability varies depending upon the clay content.

Partly impermeable sediments include clayey glauconitic limestone. Their porosity is secondary (joints and solution cavities), and their permeability varies depending on the degree of their karstification and type of joint infilling.

The impermeable sediments are flysch sediments. In flysch marls, water can infiltrate through thin, clear joints in shallow subsurface zone. The clayey limestone, calcirudite, calcarenite and breccia of flysch, although essentially permeable (joints and solution cavities), are also treated as impermeable due to their position (these sediments are interlayered with marls) in flysch. In the investigated area, groundwater level has not been recorded in flysch sediments. However, some small parts of the area reveal the isolated phenomena of perched groundwater, which fills the deposits originating from flysch weathering in the depressions above the impermeable flysch. Also, some small and periodical springs can be found in the investigation area. They are always placed at the contact area between flysch calcarenite (or calcirudite) and marls or at the contact area between clayey glauconitic limestone and flysch. Several submarine springs are recorded in Kastela Bay near the northern slopes of the Marjan Peninsula (Alfirević, 1966, 1969; Fritz and Bahun, 1997). Similar phenomena were recorded along the entire southern coast of the investigated area. An analysis of structural-geologic and lithological characteristics of flysch showed that groundwater appears in those areas consisting of calcirudite and/or calcarenite of flysch and of highly tectonised marls.

The depth of groundwater flow varies, and it depends upon the layer thicknesses, frequency of joints, orientation and its surface conditions. The general direction of the groundwater flow is from the east towards west, through the partly karstified calcirudites and/or calcarenites of flysch flow to the old city core. This undoubtedly has been proven by deep excavations for the railroad through Split (Bojanić et al., 1986). The second general direction is flow from west to east to the old city core through the karstified limestones on the Marjan Peninsula. Water also flows along the faults and joints in the southwest, i.e. northeast direction.

Conclusion

The work been undertaken by UNESCO and W 5.1 partners sought to lay a suitable testing ground for GEO4CIVHIC shallow geothermal solutions, which required the identification of both virtual and real testing cases on which to work. The selection of the cases was essential to provide an exemplary assessment to which the geothermal energy system brought forward by GEO4CIVHIC is able to meet multiple and demanding targets.

Firstly, the purpose was to secure the coexistence between heritage-significant conservation in interior/exterior features of built heritage and affordable geothermal infrastructure along with its maintenance. Secondly, the goal was to contribute to curbing CO₂ emissions and operating costs for the beneficiary hosting sites that have to cope with scant financial resources with particular evidence in southern Europe, such as those of Italy and Croatia. In these countries, the running costs of heating or cooling (if existent) in monumental buildings, such as built heritage and museums, become overwhelming and highly impacting for the overall budget due to the high energy demand and, as applicable in several circumstances, also dictated by the very nature of the artefacts displayed.

Despite this, WT was not meant to provide evidence of the overall impact of a GEO4CIVHIC solution, and; therefore, the above-mentioned targets are quantifiable yet. The methodology used for the conduction of the preliminary assessment suggests a most likely successful achievement. For instance, the sharing of hydrogeological information and the empirically-based evidence provided have clearly highlighted that the geological characteristics of the underground and the local thermal conductivity in the soil have a potential for a very high energy return per investment for shallow geothermal solution in the areas of Ferrara and Split.

The process of consultation involving a set of fundamental end-users, for each site, starting with the management authorities, inclusive of upper level ministries and local technical experts, have brought us to identify the most interesting and suitable areas to physically host GEO4CIVHIC solutions according to the next WP/WT.

As far as UNESCO is concerned, an additional asset of the undertaken activities is inherent to their relevance with regard to museums, with special reference to the Recommendation concerning the Protection and Promotion of Museums and Collections, their Diversity and their Role in Society, approved by the UNESCO General Conference on 17 November 2015. Within the Recommendation on Museums, the application of innovative sustainable energy technologies, as those promoted by Cheap-GSHPs are especially relevant with regard to Art. 29, affirming that *the functions of museums are also influenced by new technologies and their growing role in everyday life. These technologies have a great potential for promoting museums through the world, and Member States should strive to provide access to these technologies for museums in the territories under their jurisdiction and control.*

With this spirit, UNESCO will pursue with its most dedicated energies and resources the objective of turning the hereby assessment into successful practices. This shall be done with the strategic vision to possibly inspire other sites, including UNESCO-designated ones, both within and outside Europe, which may find GEO4CIVHIC solutions suitable to their settings and challenges in an attempt to bond different stances such as innovation in sustainable energy, conservation of built heritage, climate change mitigation policy and energy poverty reduction in an encompassing, comprehensive fashion.

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