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The Importance of Checking Indoor Air Quality in Underground Historic Buildings Intended for Tourist Use

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Abstract: This article demonstrates the importance of quantifying the air quality with radon gas level as indicator in any heritage building, especially those intended for the use of people. The tourist activity or historical guide represents a typology where people spend a certain time, that is to say, in no case do they spend the same amount of hours as in their homes or jobs. Different gases that may be present in the environment must be controlled. The Séneca Square shelter, in Alicante, is a very important place for the history of the city during the Spanish Civil War that has recently been rehabilitated for exposure to people. The source of most radon gas inside a building is the ground. Many countries, including Spain, in which the building regulations, regarding the accumulation of radon gas, do not specify in their technical codes, the maximum dose that a building can sustain so that it is not harmful to people, or, the measures required to correct excessive accumulation. The possible existence of radon is verified in any underground building, regardless of the characteristics of the soil (whether granitic or not), the importance of defining and unifying the regulations that specify the different levels of radon in any architectural constructions is evident. Most of the scientific agencies in the field of medicine and health, consider that radon gas is a very harmful element for people. This element in its gaseous state is radioactive and it is present in almost all soils in which buildings are implanted, with granitic types of soil presenting higher levels of radon gas. Non-granitic soils have traditionally been considered to have very low radon levels. However, this work, providing the results of the research carried out in the underground air raid shelter in Seneca Square in Alicante (Spain), demonstrates the relevant presence of radon in non-granitic soils. This research addresses the constructive typology of the underground building and the radon presence in its interior obtained using rigorous measurement techniques.

Keywords: healthy architecture; construction materials; environment; radon; underground building; heritage building

1. Introduction

The city of Alicante, being coastal, was one of the most exposed to the entry of both planes and boats to the peninsula during the Spanish Civil War [1,2]. For this reason, it is considered a very important city in the course of the war and its historical heritage of the time is a treasure that is currently being valued to be shown to the public. In addition, the port of Alicante is considered one of the last places of conquest of the winners and escape of the Republican side.

The shelters of the Spanish Civil War in Alicante are now part of a tourist route that is being set in motion. These buildings are of various types, but most are underground and unventilated. Therefore, the risk of high radon gas accumulations is high. The aim of this research is to demonstrate the risk of high concentrations of the gas in order to have it present in the future if it were to be destined to contain people over a long period of time.

1.1. Historical Heritage of the Spanish Civil War in Alicante

At the beginning of the war, the coast of Alicante has a privileged situation due to its remoteness from the capital, Madrid, and is a possible escape route. The two opposing sides had limited aviation and combat resources, but the intervention of both Germany and Italy helped in the early development of the battle for the future victorious side. The Soviet Union's aid to the Republican side was delayed until the end of 1936, when the rebels had already advanced and had taken several cities such as Albacete or Jaén [3].

When the means of war came from one side or the other, the participation of aviation grew and Alicante began to be a key strategic point; Figure 1 shows the impacts of aerial bombs on the city of which there is evidence. Among the areas bombed, is the Rabasa airfield, which currently houses the Campus of the University of Alicante with at least five confirmed bombardments, being one of the most important objectives for rebellious aviation. The city was equipped with anti-aircraft defenses during the first bombardments, in addition to four observation posts that had a phonolocator to determine the course of the planes by means of their sound, located in Cabo de las Huertas. The active defense of the city was completed with both fixed and mobile cannons to defend certain areas according to the needs of the conflict [4] .

On 8 August 1935, the Ministry of War decreed the creation of the National Committee for the Passive Defense of the civilian population against air and chemical attacks. The objective of this group was to take the necessary measures in the event of the outbreak of an armed conflict [5]. The committees would be chaired by the mayors of cities with more than 8000 inhabitants. In 1936 Catalonia pioneered the creation of a Passive Anti-Air Defense service, which in Alicante had its counterpart from July 1937. The task of this Local Board was to build shelters, as soon as possible, capable of protecting as many people as possible. Figure 1 shows the different shelters that were built in the city of Alicante during the Spanish Civil War combined with the bombs that are known.

The public shelters responded to the need to protect the population from possible attacks by using the topographical and geological characteristics of the terrain as a defensive element in order to save costs. The ultimate goal was to achieve the lowest possible cost per protected person ratio. From documents in the Alicante Municipal Archive (AMA), it is known that in 1937 there were 18 shelters for 8070 people and 15 pending construction for 9900 more people [6]. In 1938 there were 55 shelters with a capacity for 38,140 people and 37 more were planned that would have provided the city with a capacity for 108,590 people. There are currently some 90 shelters built during the war or in the development phase [7].

1.2. The Shelter of Seneca Square Construction and Restoration

The Spanish Civil War took place in Spain between 1936 and 1939, where two sides, the Republicans and the rebels fought to take control of Spain. The Civil War bomb shelters in Alicante are a singular type of architectural construction that conserves little information because they were developed without technical documentation arising from the urgent need to build shelters to protect the population [8].

The first reference to the Seneca Square shelter in the local press is written in the newspaper "Nuestra Bandera" on 25 August 1937, where it publishes a list of these defensive constructions as an existing shelter. Since it was located in an empty place, the type was of buried concrete slab. The people most likely to take shelter in it were the workers from the adjacent buildings, most of them were factory workers.

The maximum capacity of the shelter at Seneca Square (Figure 2), according to the Partial Plan (Spanish regulations) of shelters in the city, raised a capacity for 1200 people, although sources close to users at the time, assert that, in moments of alarm, about 2500 people sought shelter inside. During the years after the Spanish Civil War, when the Second World War started and the fear of the leaders of a possible nuclear war, the shelter at Seneca Square remained active and could protect the population in case of need at any time up to 1940, year in which it was closed and passed into oblivion.

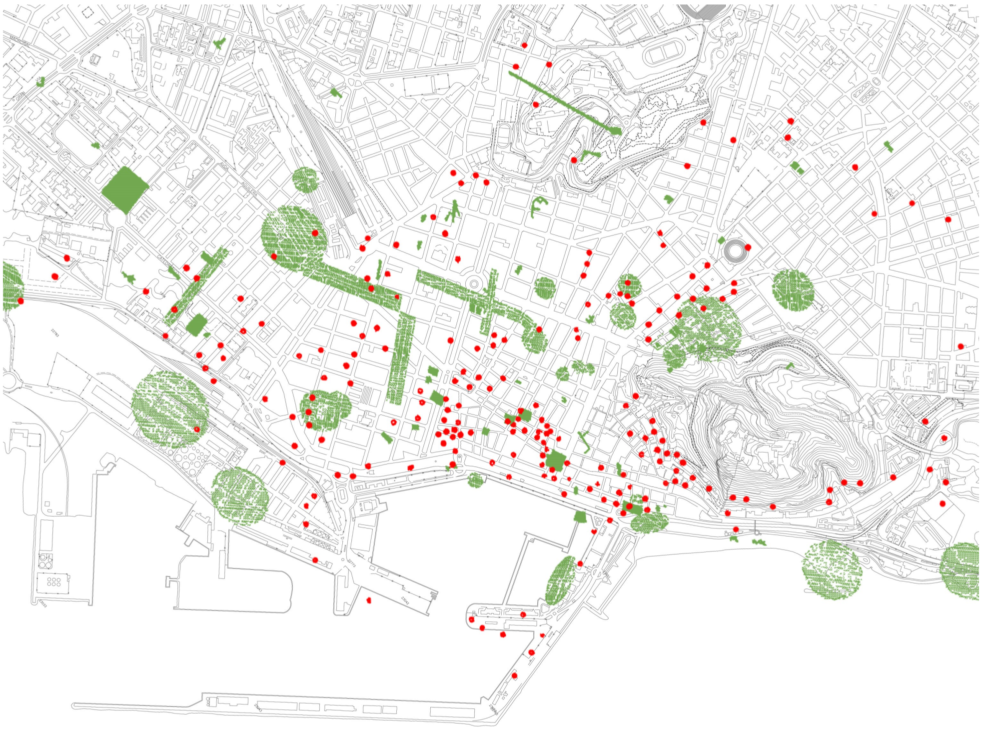

Figure 1. Image showing in red, the impact of the bombs dropped in Alicante during the Spanish Civil War and in green, the bomb shelters.

Figure 2. The inner corridor of the Seneca Square shelter.

At the beginning of 2000, in preparation for the project to rehabilitate Seneca Square in Alicante, the old air raid shelter of the Spanish Civil War was rediscovered. This place had been closed for decades and its state of preservation was unknown as its accesses were walled and hidden.

The shelter at Seneca Square is a passive defensive construction that, according to the recommendations of the municipal architect of 9 March 1937, was of the buried concrete slab type, and corresponds to an underground construction previously excavated, made with screed and walls of concrete masonry. For superior protection, it has a slab of 1.25 m high reinforced concrete with four layers of reinforcement. In the upper part of the shelter, there is a layer of 40 cm of soil and a layer of hard stone or masonry with mortar forming a ground shielding on the surface.

In the study carried out by Francisco Lozano Olivares and Marcos Lumbreras Voigt on the archaeological intervention prior to the enhancement of the shelter, the authors studied the structure of concrete slab buried under the remains of pavements from different periods and their corresponding basements [7].

The shelter volume is composed of a single body 51 m long by 12 m wide, not counting the two lateral arms of the 9 meter entrances, as shown in Figure 3. The concrete slab varies depending on the structural needs of each zone, between 60 cm and 180 cm at the accesses.

The inside of the shelter is distributed with a 43-metre-long corridor of 1.5 m wide from which the 38 cubicles are accessed (Figures 4 and 5). These spaces measure approximately 3 square meters. The inner width of the shelter, taking into account the corridor and the double row of lateral cubicles, is 5.4 m.

Figure 3. (**left**) View of the entire shelter from a neighbouring building in theaftermath of the demolition of the buildings that were built on top of it inthe post-war years. (**right**) View showing the inlaid vents in the concrete slab.

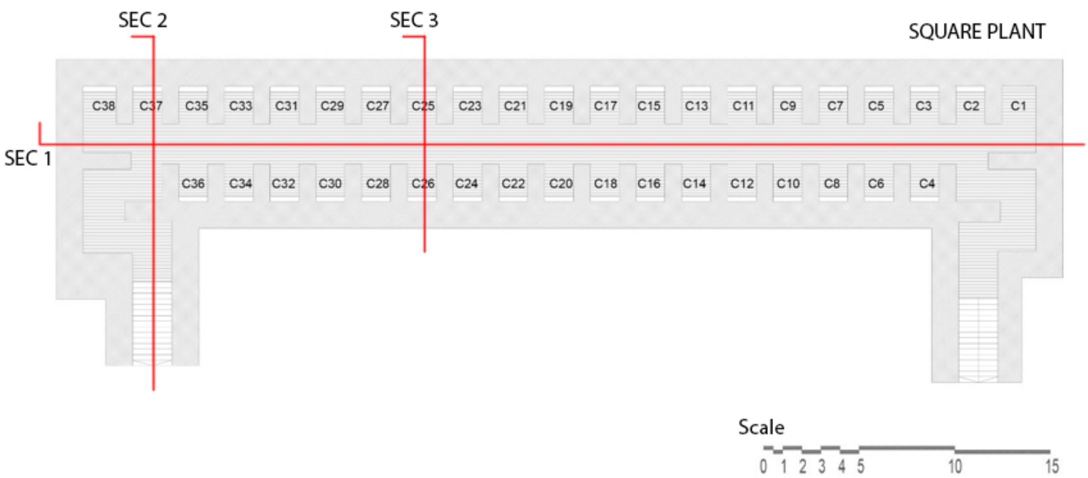

Figure 4. The plan shows the 38 cubicles connected by the central corridor thatends at the two main zigzag-shaped entrances.

The original construction had two zigzag-shaped entrances to mitigate the damage to a possible direct bombardment on the shelter and, in this way, to facilitate the evacuation of people as indicated by the recommendations of the city architect of the day. The accesses save the 3 m of drop with some steps, of reinforced concrete, of 16 steps in 4.9 m of floor (Figures 6 and 7) .

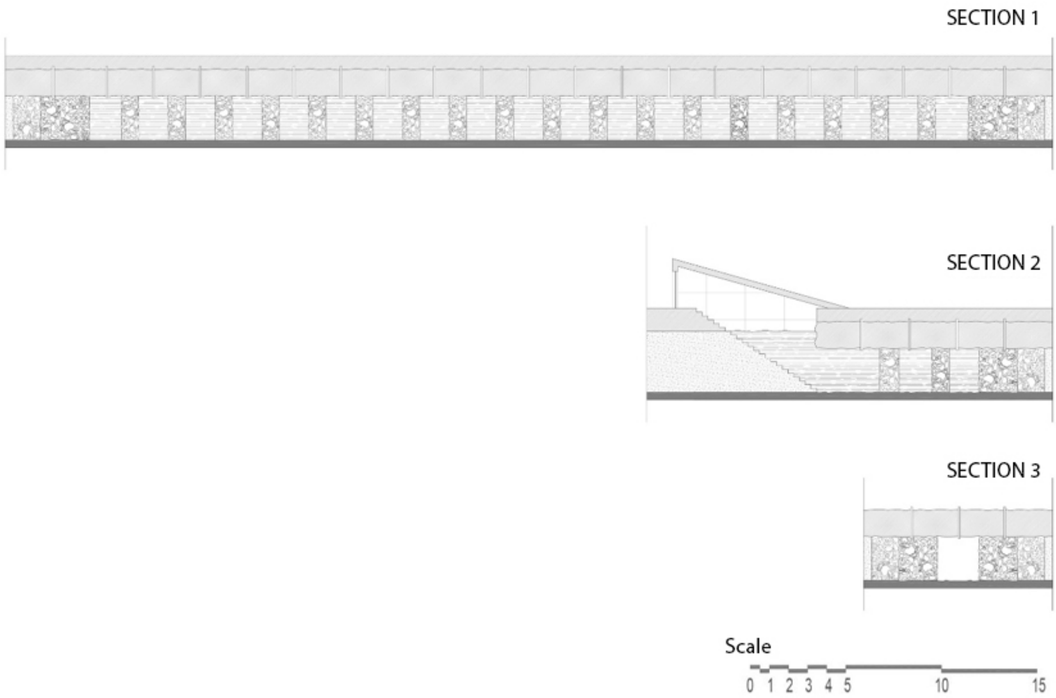

Figure 5. Sections of the shelter.

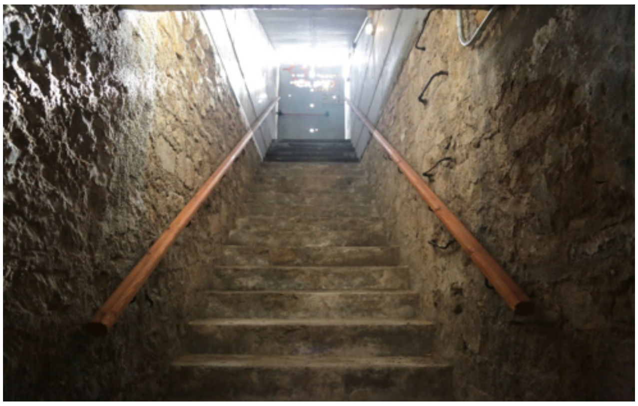

Figure 6. South Access.

Figure 7. North access in zigzag form and rebuilt cubicle with period furniture.

The thickness of the shelter varies according to the structural needs of each part; the perimeter, 1.8 m in some areas, is made of reinforced concrete of a mixture very resistant to traction, that is, with a fine gravel size. The concrete mix between cubicles, such as the 1.2-metre-thick slab armament, was made of cyclopean concrete [9]. This type of concrete was used in the past for its savings and had no control at all with large stones that reached 50% of the total content.

The basement has 20 cm of ground tamped down, on which a base of leveling gravel is laid, leaving a free height inside the shelter between 2.2 and 2.3 m. The total height of the shelter taking into account the foundation and the upper slab is about 3.7 m. The construction stands out for its great solidity since it has supported for more than 50 years the thrust of the basement of a five , the mixtures of cyclopean concrete and be at level 0 (Figure 8).

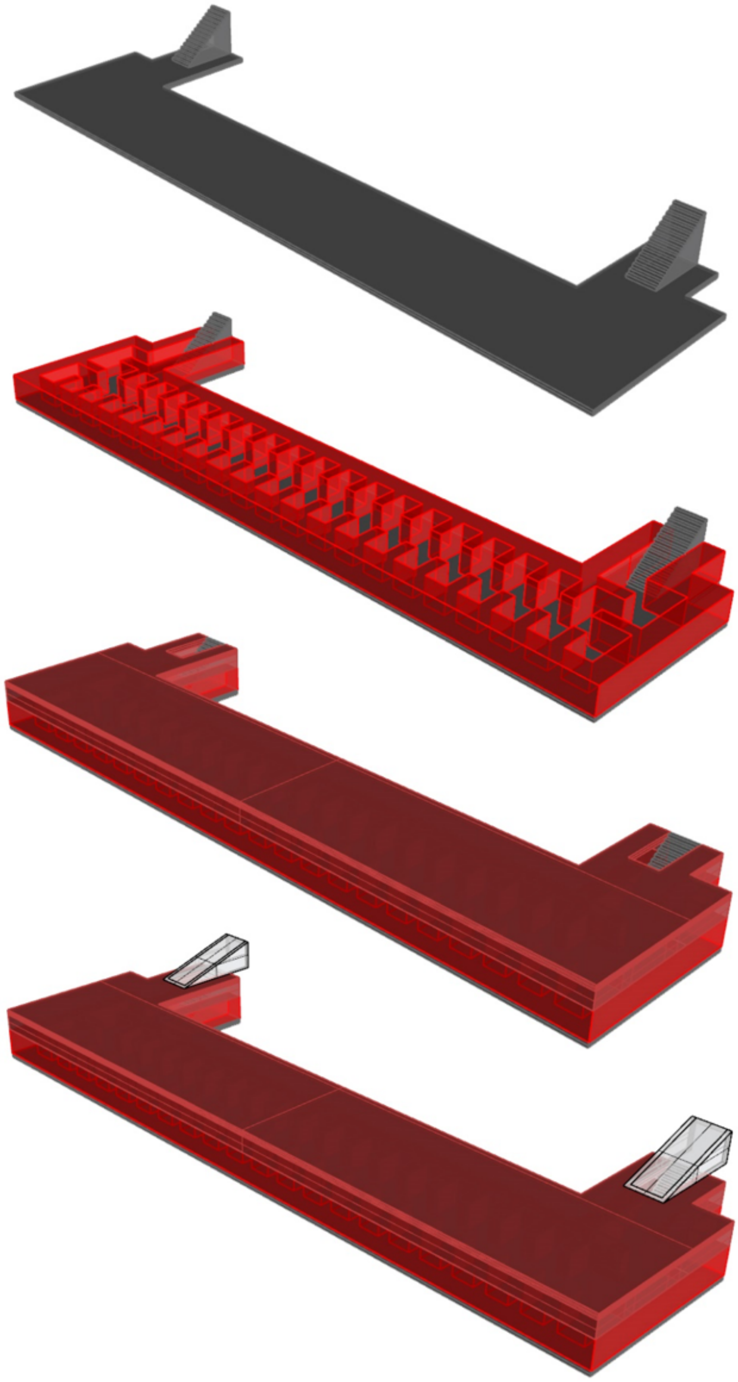

Figure 8. 3d reconstruction of the shelter.

The shelter had 65 ceramic vents (Figure 9), measuring between 7 and 140 cm, which crossed the concrete slab and ventilated the interior along the central corridor connecting the cubicles. The layer behind the concrete slab consisted of compacted earth to cushion the effect of the bombs.

Figure 9. Interior view of the old vents.

In 2008, the City Council of Alicante launched a call for proposals for the construction of the new Seneca Square, giving the option to remove the Bus Station and adjacent buildings [10]. This project had a starting premise: to build an underground car park and to improve the four streets that made up the block. At that time, the historical value of the underground city was not obvious and there were favorable reports that facilitated the demolition of the area, as it had greatly deteriorated (in Figure 10 left). In addition, in the old bus station there was a series of murals by Gastón Castelló which could have been lost if the reform project had been carried out (in Figure 10 right) [11].

Figure 10. (**left**) View illustrating the appearance of Seneca Square until 2011when the 1944 buildings of architect Felix de Azúa and two of the three busstation canopies were demolished. (**right**) Painting by Gastón Castelló at the BusStation.

88 proposals from different architects were submitted to tender for the reform project, but none of them considered the shelter and few respected the natural conditions of the square, such as the trees. The winning project was that of the architect Roberto Santatecla Fayos, but as he did not reach an agreement with any construction company, his plan could not be carried out.

The contest was abandoned and gave rise to a second competition in 2013, with no intention of creating an underground car park, which made it possible to rescue the shelter and add value since two registers were found that had access to the old shelter. These entrances were walled up in the 1940s when blocks of flats were built next to the station. The aim of the proposed renovation was to recover the old city square and the planned demolition of the houses. From that moment on, the procedures to consider the value of the shelter were initiated.

The reforms were carried out from 2011 onwards in the entire block of the old bus station, demolishing the buildings of Félix de Azúa and building a new square that valued the shelter, as it is now known (Figures 11 and 12) .

Since 2015, you can visit the shelter of Seneca Square [12], next to the Interpretation Centre of the Spanish Civil War air-raid shelters, a place focused on presenting the history of Alicante through its shelters.

Figure 11. Panoramic view of the new square.

Figure 12. North entrance to the shelter.

1.3. Radon Gas in Alicante

Radon gas is produced as a result of the disintegration of uranium contained in rocks [13]. Radon flows from the soil and is mostly concentrated in closed areas [14], so it is highly recommended that homes and workplaces are properly ventilated [15]. Three quarters of the radioactivity in the environment comes from natural elements [16]. Radon is the largest source of natural radioactivity [17] and the public health problem that it generates concentrations both inside buildings and in drinking water makes it necessary to consider it for evaluation [18].

Radon disintegrates due to the so-called ionizing radiation because when it penetrates matter, it usually pulls electrons from the surrounding atoms by a process known as ionization [19]. If the matter is a biological structure with a high water content, the ionization of water molecules can give rise to so-called free radicals with a high level of chemical activity, enough to alter important molecules that are part of the cells of living organisms [20]. These alterations may include chemical changes in DNA, the basic organic molecule that is part of the cells that make up our body [21]. These changes may lead to biological effects, including abnormal cell development [22]. These alterations can be more or less severe depending on the dose of radiation received [23]. The main effect of the presence of radon in the human environment is the risk of lung cancer [24]. The radioactive gaseous element known as radon is present in almost all construction materials, and in the soil where buildings are implanted [25].

There are two types of radon measuring devices: active and passive. The first ones, require electricity and allow a continuous record of the concentration and fluctuations of radon gas during the measurement period [26]. Passive do not require electric power to operate in the sampling environment. These methods use a vessel of known volume exposed over a certain period of time with an electrically charged resistor [27,28].

Ionic Chambers of Electretes (ICE) have been used to carry out this research. ICEs are passive devices that function as integrative detectors to measure the average radon gas concentration during the measurement period. The electret functions both as a generator of an electric field and as a sensor in the ion chamber. The radon gas enters the chamber by diffusion through an inlet equipped with a filter without allowing the rest of the elements produced during the disintegration process to pass through [29]. Radiation emitted by radon and its disintegration products formed inside the chamber ionize the air contained inside the chamber reducing the voltage of the detector surface [30]. Subsequently, a calibration factor relates this voltage drop to the concentration of radon in the space and time studied.

In isolated constructions or on the ground floor of buildings, the most important source of radon is the radium present in the ground. The radon concentration in the ground is generally between 10 and 50 Bq/m^3, although it can reach much higher values. The average value is around 40 Bq/m^3. The amount of radon that enters an interior from the ground depends mainly on the concentration of radium-226 in the subsoil and its permeability.

In most countries there are predictive maps of radon levels, elaborated mainly by the igneous compositions of the soil [31]. For example, Sweden has developed maps based on the measurement of the geogenic potential of radon, which indicates the risk level by zone, estimated from the concentration of radon in the ground at 1 meter deep [32,33]. Likewise, the usefulness of methods based on other variables, such as soil radio-226 concentration or uranium equivalent has also been tested. In the case of France, for example, the national map has been compiled from geological maps and average uranium content of each geological unit [34]. The German map [35] has also been developed using the geogenic potential of radon as well as the Czech map [36]. All the radon gas predictive maps consider that granitic soils are the most risky in terms of their concentrations [37], considering the clayey soils as having a low presence of radon gas. In Spain, the Technical Building Code (CTE), in February 2018, does not yet contemplate the dose of radon that can contain at most one building and how to control it [38].

The Spanish Mediterranean coast, where the city of Alicante is located, is mainly clayey [39]. In the city center of Alicante (Spain), there is an underground air raid shelter at Seneca Square, built in 1937 during the Spanish Civil War (1936-39), and restored in 2011 in order to be part of the city's museum tours. The shelter has been studied in different aspects: the constructive typology of the underground building, its historical context, and the presence of radon inside was measured using rigorous measurement techniques. The results obtained from the measurements make the shelter a paradigm to demonstrate the relevant presence of more than 100 Bq/m^3 of radon in the interior of an underground building in non-granitic soil [40].

1.4. Importance of Radon Gas Measurement in Heritage Buildings Intended for Tourist Use

In a building, the main sources of radon are the soil on which it sits and the materials used in its construction [41]. In addition, it can enter with fresh air, supply water and gas for domestic use, although the latter, except in some specific cases, are considered to be minor sources. As it is a gas, its concentration in an indoor environment also depends on certain practices and habits that favour its accumulation, especially the lack of ventilation, accompanied by tightness in construction, generated by energy saving policies, according to NTP 440: radon in indoor environments [29]. Figure 13 shows the most typical radon sources and priority entry routes.

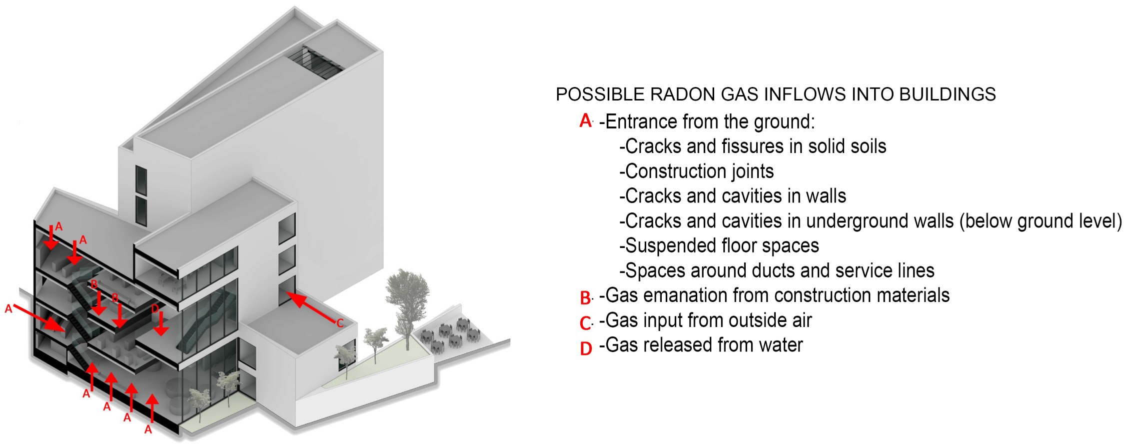

Figure 13. Sources and routes of entry of radon gas into a building.

Radon has been considered carcinogenic by the World Health Organization (WHO) since 1998, according to the International Agency for Research on Cancer (IARC) and the U.S. Environmental Protection Agency (EPA), which classify it as carcinogen first level [42]. The main adverse effect of inhaling radon and its breakdown products is the risk of lung cancer [43].

Despite the fact that the presence of radon is quite relevant in many territories, posing a certain risk to the health of a good number of citizens, regulation of this gas is very recent or even non-existent in certain countries [44]. The intense concern about radon present in the United States has been slow to spread throughout Europe, but little by little this phenomenon is beginning to be considered with the existence of different international and European organizations in charge of the study and control of radioactivity [45]. Organizations that, for some years now, have been concerned about this issue through the generation of documents urging the different countries to adopt concrete measures regarding radiation and advising a specific legislative development for each of them, generating a progressive standardization [46].

The shelters of the Spanish civil war, most of which are buried, are considered to be at risk of high gas accumulation, and should therefore be controlled when their purpose is the transit of people.

2. Methodology for Measuring Radon Gas in the Shelter

For the data collection phase of the study carried out at the Seneca Square shelter, the measurements were made between 18 and 28 January 2016. This process included the entire length of the shelter, separating the chambers into the previously mentioned cubicles in order to measure the amount of radon generated in the different areas within the same room. The measurement zones of the study correspond to the cubicles, as shown in the Table 1 and the positions of the cameras are shown in Figures 14 and 15.

The design of the shelter acts as a single room, with all the cubicles connected by the central corridor, with no possibility of ventilation by means of the old vents, which are walled up, the only way of possible air renewal coming from the accesses, that make it slow and uniform. The shelter is interesting to measure the amount of radon generated inside for different reasons: the location 5 m below level 0, the low ventilation, the structure, the construction materials used and the situation.

Table 1. Association of measurement zones and corresponding cubicle.

Zone	Cubicle
Zone 1	Cubicle 5
Zone 2	Cubicle 6
Zone 3	Cubicle 15
Zone 4	Cubicle 35
Zone 5	Cubicle 22

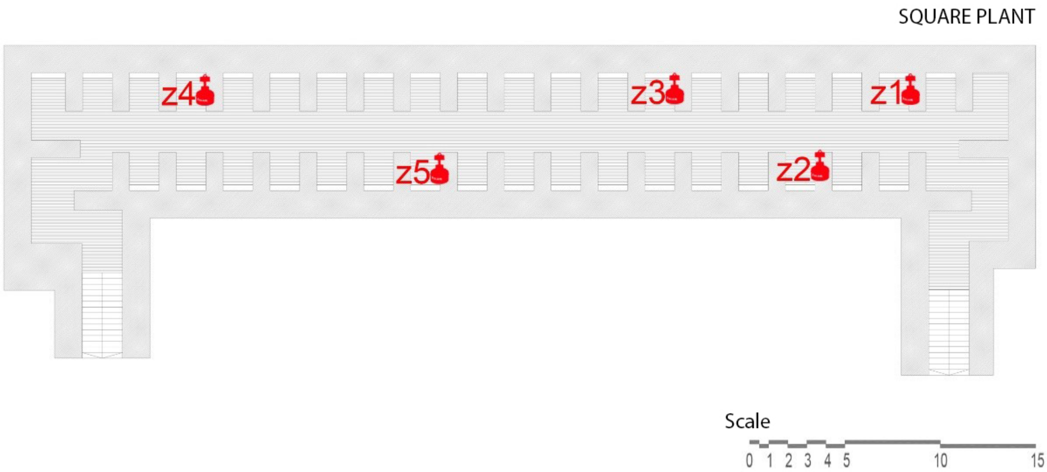

Figure 14. Plan of the Seneca Square shelter with the layout of the measurement zones.

Figure 15. Image of the chamber in a cubicle.

The measurement system of this shelter, in addition to providing data on the amount of radon present, served as a reference to evaluate the deviation of the equipment, according to the type of cameras and electrets used in each place, used in parallel studies. With this objective in each measurement point, four samples were taken, resulting from the combinations shown in the Table 2.

The ten days that the equipment was inside the shelter, contributed data from the whole of this one in five different zones, with the four combinations of the equipment used for the study. The total number of samples collected was 40, being the typology Camera-Electrete, Short-Short of the Eperm System, repeated four times in each of the places giving consistent results in the different measurements.

Table 2. Combinations of camera and electrete tested.

Camera Type	Electrte Type
Short Camera	Short Electrete
Short Camera	Long Electrete
Long Camera	Short Electrete
Long Camera	Long Electrete

As far as the climatology during the measurements is concerned, it was necessary to monitor the conditions of the external climatic parameteres and any presences of toxic and polluting gases [47,48]. The rainfall only occurred on 15 and 16 January, with 8 mm between the two days, which did not have a major effect on the ionization of the site and therefore, did not affect the presence of radon gas. The temperatures reached outside during the study fluctuated between 23 °C maximum and 1 °C minimum during the early morning of 17 January, although this fact did not affect to a great extent the interior of the shelter because it maintains an average of 16 °C in a practically uniform way since it is underground [49].

3. Results Analysis

The results obtained in the different measurements are compared with the 100 Bq/m^3 and 300 Bq/m^3 recommended by the European directive 2013/59/EURATOM of the year 2014 suggested as maximum recommended by the European Commission for Atomic Energy [50]. 100 Bq/m^3 is considered as the first threshold from which permanent monitoring of the gas, presence measurement and the level of 300 Bq/m^3 are considered as the threshold from which, mandatory ventilation increase measures must be taken.

For the representation of the results, a summary Table 3 shows the different measurement zones and the values of the mean environmental concentration obtained from radon gas, in Bq/m^3.

Table 3. Summary mean values of radon concentrations in zones.

Zone	Samples	Mean Radon Concentration (Bq/m^3)
Zone 1	8	79.47
Zone 2	8	150.61
Zone 3	8	130.48
Zone 4	8	64.87
Zone 5	8	70.68

From the data extracted in the study, the concentration of radon gas inside the shelter is interpreted, conditioned by the ventilation differences produced by the air currents caused mostly by the ventilation generated by the opposing entrances. On the other hand, radon results can be variable within the same room of the same building. For this reason, variations in the measurements are obtained between zones [51,52].

Figure 16 shows a scatter plot of all measurements made in the different test zones. The box diagram shows the median and quartiles of the data, marking their outliers. The values obtained in the different measurement areas are below the threshold of 300 Bq/m^3, established within this study as a value from which urgent corrective measures need to be taken, fundamentally improving ventilation, this action is not necessary in the shelter. Zones 2 and 3 are above 100 Bq/m^3, a value from which, as a precautionary measure, the presence of radon gas in buildings used by people should be monitored, to ensure that they do not result in accumulations exceeding 300 Bq/m^3. Figure 17 shows the heat graph (two-dimensional representation of data in which values are represented by colors) of the results obtained in the measurement.

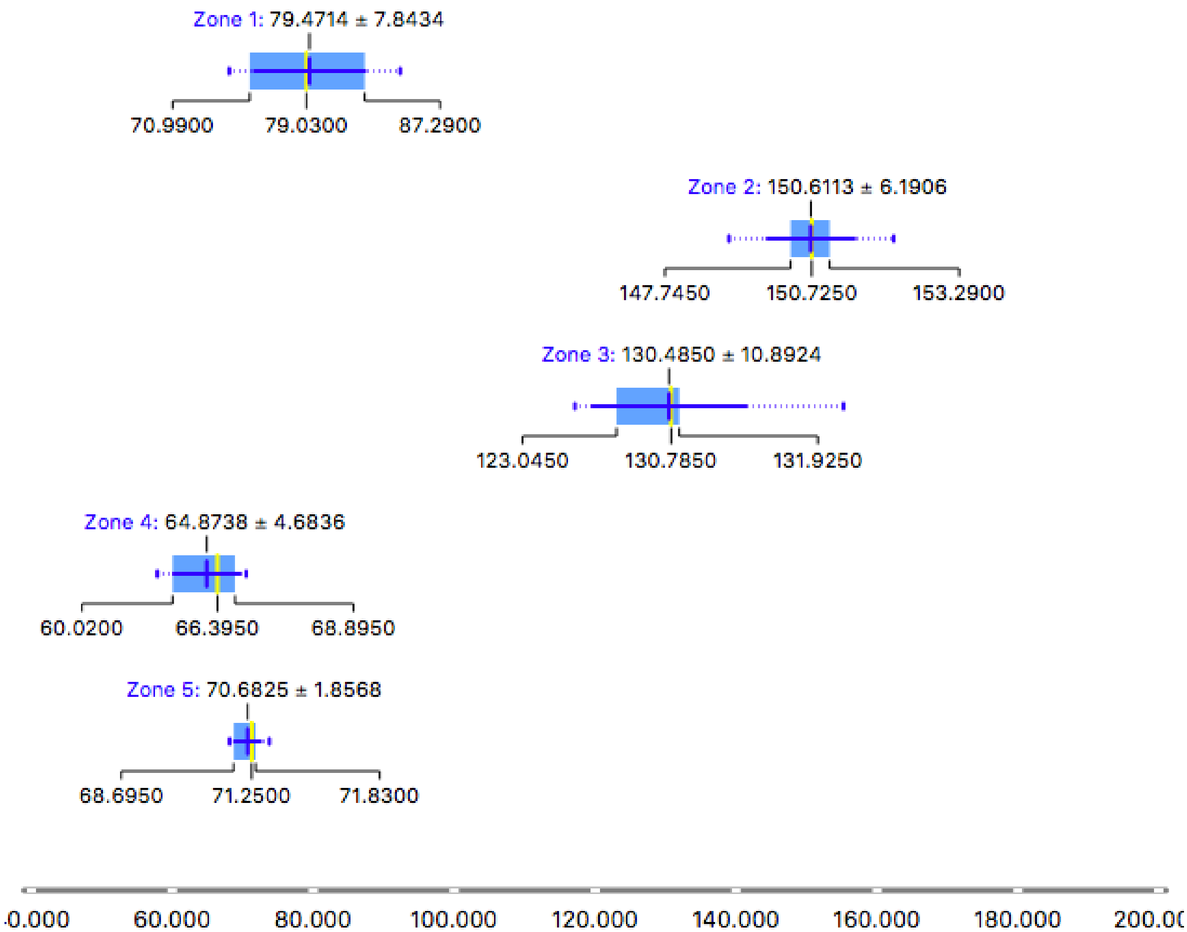

Figure 16. Box Plot zones measures.

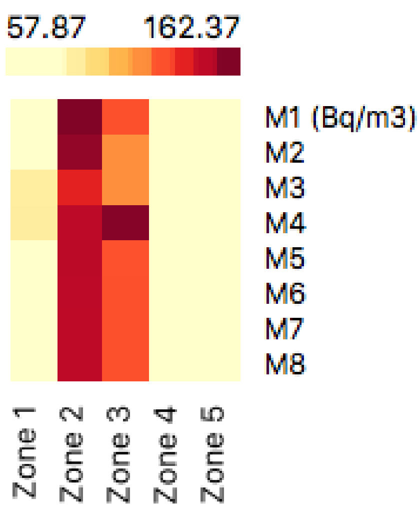

Figure 17. Heat graph of the results obtained in the measurement.

4. Conclusions

The article has used the anti-aircraft shelter of Seneca Square in Alicante (Spain) as a paradigm to demonstrate the presence of radon gas in underground constructions located in clay soils (not granitic) that are usually considered low risk in terms of potential presence of the gas. The southern Mediterranean coastline where Alicante is located is considered a low or very low risk area within the Spanish map of natural radiation.

In order to extract the conclusions, Directive 90/143/EURATOM has been used as a purpose, where the European Union recommends a target radon gas level in the design phase of 100 Bq/m^3 maximum for newly built buildings and an immediate level of action from 300 Bq/m^3 for interior spaces from which remedial measures should be carried out in existing buildings. Although these values should not be taken as safe when they are less than 100 Bq/m^3, they can be interpreted as a border from which to start giving attention and try to minimize the values obtained by incorporating a more efficient form of air renewal and establishing more effective constructive methods to accumulate less radon gas. Radon has been considered carcinogenic by many agencies, which classify it as carcinogen first level. The main adverse effect of inhaling radon and its breakdown products is the risk of lung cancer.

The maximum quantities of radon obtained within the shelter are 150.61 Bq/m^3, exceeding the first threshold (100 Bq/m^3) corresponding to periodic and precautionary monitoring of measurements. These measurements demonstrate the presence of radon gas with relevant concentrations in clay soils that are usually considered low risk in preventive maps. These results urge countries to incorporate radon control in their building codes, especially in constructions with high soil contact and regardless of whether it is granitic or not.

Predictive maps must be concertized in their application by means of technical building codes, but in most countries, including Spain, the Technical Building Code still does not specify the dose of radon that can be contained at most in a building and how to eliminate it.

It has been well documented that radon gas is harmful to human health and has become a highly carcinogenic element and therefore, new regulations must incorporate this aspect as a control element. In view of the results presented in this article, it is clear that there is a need for compliance with measures (constructive, ventilation, etc.) to limit the presence of radon gas in buildings, especially in enclosed spaces used by people. Radiological studies on exposures to radon in underground workplaces and leisure areas (including public car parks, mines, subways, museums, tourist caves, etc.) should be mandatory in all cases. All this regardless of the type of land on which the buildings are built and the type of materials used.

The presence of radon gas in the Plaza Seneca shelter studied in the article must be controlled due to its heritage importance to the city. The values obtained in the study demonstrate an accumulation of medium importance, it must have a follow-up. If the shelter is to be used for other purposes, elements of continuous gas testing should be implemented. In the future and for greater security, this type of building must have ventilation systems as they are intended to house people: technical employees, guides, visitors.

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