CITIZEN SCIENCE PLATFORM FOR RADON POTENTIAL ASSESSMENT AND RADON RISK AWARENESS

Paulo Meneses, Nuno Lopes, Patrícia Leite, Paulo Teixeira and Joaquim P. Silva
2Ai – School of Technology,
IPCA, Barcelos, Portugal
LASI – Associate Laboratory of Intelligent Systems,
Guimarães, Portugal

ABSTRACT

The WHO estimates that cancers caused by radon gas may account for 14% of all lung cancers. The concentration of indoor radon gas is a well-known public health threat and has been the subject of many scientific studies. The WHO has issued recommendations to encourage countries to act against radon exposure to reduce the associated cancer risks. However, despite the vast knowledge on this subject, the measures already taken and the information available, much of the population at risk remains unaware of what radon gas is and its impact on health. In this context, an approach has been designed to perform the pre-diagnosis of indoor radon potential based on the geographical location of the building, its construction characteristics, and its use profile. Recently, a model has been built that performs automatic classification of radon potential in indoor environments. This paper describes the development of a web platform integrating this model to enable citizens to obtain an assessment of the radon potential of the buildings where they work or live. The platform aims to promote radon measurements by the general population and raise awareness about radon risk. These measurements will generate new data that will be used to build more robust classification models.

KEYWORDS

Indoor Radon Potential, Citizen Science Platform

1. INTRODUCTION

Accumulation of radon gas inside buildings, often poorly ventilated, represents a known public health problem, widely reported by the World Health Organization (WHO). Indoor radon concentration is the second leading cause of lung cancer, after smoking. The WHO estimates that cancers caused by radon gas may account for between 3% to 14% of all lung cancers (WHO, 2009). Radon gas is a colorless, odorless, radioactive gas that results from the decay of uranium. It is most common in granite and shale soils and substrates, although it is also present in specific building materials such as concrete, brick and aggregates (WHO, 2009). Radon gas is approximately 8 times denser than air (Soltani-Nabipour, Khorshidi and Sadeghi, 2019), the reason for the highest concentrations being in basements and lower floors of buildings.

The concentration of indoor radon gas is a well-known concern for public health and has been the subject of many scientific studies. To minimize the health risks from indoor radon exposure, WHO recommends a reference level of 100 Bq/m3. Where this level cannot be achieved under country-specific conditions, the chosen reference level should not exceed 300 Bq/m3. In the European Community, the EURATOM Directive on Basic Safety Standards (BSS) states that reference levels for the annual average activity concentration in air should not exceed 300 Bq/m3 (European Union, 2013). In the United States, the Environmental Protection Agency (EPA) recommends remedial action in homes when radon concentrations are 4 pCi/L or higher, equivalent to 148 Bq/m3 (US EPA, no date).

Despite the WHO recommendations and the adopted radon legislation in many countries, the radon problem remains little known to the general population. In Portugal, no systematic measurements are performed in buildings to assess radon concentration levels. Only occasional studies are known, which in general include a few tens or hundreds of buildings. The most comprehensive recent study was conducted by the Portuguese Environment Agency (APA), in 2020, with the aim of obtaining data for the production of a radon exposure susceptibility map (APA, no date b). This was a nationwide radon gas monitoring campaign where passive radon sensors were used in 2224 buildings (APA, no date a). Following this study a radon susceptibility map was published by APA, where about one third of the territory of Portugal is considered to have a high radon potential.

The Portuguese government has recently approved the national radon plan which contains several measures to measure radon, prevent or remediate high concentrations in buildings and communicate the risks to the population (Presidência do Conselho de Ministros, 2022). The assessment of radon concentration inside buildings requires specific expertise involving the execution of a set of time-consuming tasks that may include radon potential assessment, short/long-term radon measurement, laboratory data analysis and technical reporting. Silva *et al.* (2022) proposed a radon potential assessment methodology, based on the analysis of historical data of a set of variables, to provide an estimate of the radon potential of a room of a given building, The radon potential classification model was based on the geographical location of the building, its construction characteristics and its use profile (Meneses *et al.*, 2023).

This paper presents the development of the web platform that will enable the use of the radon potential classification model and contribute to increase the awareness among the general population about the health risks caused by radon. This is a citizen science initiative which aims to involve citizens in combating the radon problem, motivating them, whenever appropriate, to carry out radon measurements and communicate the results on the web platform. This approach aims to engage the population to carry out radon measurements on a large scale and promote the implementation of prevention and remediation actions. These measurements will help improve the platform and could be a tool for indoor radon monitoring.

The next section discusses the concept of citizen-science platform and describes previous work where these platforms have been used in the context of radon gas. Section 3 describes the architecture of the web platform, its features, and the stages of its implementation. The results and presented and discussed in section 4. The last section consists of the conclusion.

2. RELATED WORKS

Citizen science platforms have been providing large amounts of data to researchers to aid in answering research questions. Citizen science concerns the active engagement of the public in scientific research. Citizens actively contribute to science in data collection and/or sampling for scientific research (Bonney *et al.*, 2009; Silvertown, 2009; Dickinson, Zuckerberg and Bonter, 2010). Silvertown (2009) highlights three factors factor driving the growth of citizen science: (a) the existence of easily available technical tools for disseminating information about projects and gathering data from the public; (b) the increasing realization among professional scientists that the public represent a free source of labor, skills, computational power and even finance; and (c) a condition imposed by research funders upon every grant holder to undertake project-related science outreach.

2.1 Citizen Science Platforms

There are large citizen science projects running today. In the Zooniverse platform, participants are invited to participate in data analysis projects at a large scale. The participants have to follow a simple guide on how to perform the analysis to the data that is displayed using images, video or audio and a. Galaxy Zoo, the first project created in Zooniverse, mobilized 165000 participants to classify images of galaxies (Simpson, Page and De Roure, 2014).

Citizen science has been largely adopted in biological science with the objective of collecting and sampling observations in the field (Kullenberg and Kasperowski, 2016). iNaturalist is a citizen science platform for citizens to observe and identify natural species. The citizens take pictures of natural organisms and upload the images to the platform and other participants help to identify the organism (Nugent, 2018). iNaturalist is a multi-projects platform that can be used for multiple purposes. It supported a biodiversity project to teach secondary school students biology (Echeverria *et al.*, 2021).

The eBird project collects information about distribution and profusion of birds through submissions of observations by users. Data quality is assured by an automated filter and a regional network of editors (Sullivan *et al.*, 2014). Despite the initial slow growth, eBird platform grew rapidly after the changes that provided new services to the participants and increased appeal (Wood *et al.*, 2011). New features allowed participants to keep track and view their observations and compare them to other participants (Wood *et al.*, 2011). The biodiversity data generated is being used for a large variety of uses, fueling scientific publications (Sullivan *et al.*, 2014).

Generally, these platforms require the user's registration to turn into active participant. The participants provide their own observations and cataloging. These observations can be viewed by users without the need to be registered, Unregistered users can also read news blogs about insights and data analysis. Participants can submit comments on observations gathered by other participants and share their opinions on discussion forums. Participants can view and edit the user profiles, track their own contributions, see interactive observation maps, and read observations made by other users. Some of the most successful citizen science platforms, such as Zooinverse and iNaturalist, are multi-projects.

The geographical scope for the three mentioned platforms is global, meaning anyone with internet access can use the platform. Zooniverse doesn't have a target scope. iNaturalist and eBird are targeted to the fields of natural science and ornithology, respectively. Zooniverse collects data about the classification for images, text, and graphs according to the project guidelines. eBird and iNaturalist gather images submitted by users with locations, date, and the identified bird species. These platforms have defined data gathering and accessing policies. To download data on eBird and iNaturalist platforms, the user needs to be registered. Registration encourages communication between users and eBird staff, provide metrics about data usage, improve data products and ensure proper use of the data according to the terms of use policy (Sullivan *et al.*, 2014). In Zooniverse, data generated by the users can only be accessed by the respective project collaborators.

These platforms adopted protocols for data quality assurance and monitoring. eBird employs a two-stage verification system. In the first stage, submissions are automatically evaluated based on species count limits for a given location and given date. In the second stage, submissions are reviewed manually by local editors (Sullivan *et al.*, 2014). iNaturalist assures the data quality by checking if the observation has the date and time, a location, a photography, a supported identification by the platform, etc. Some observation attributes must be approved by the community.

User engagement is essential for the success of the citizen science platforms. eBird built a useful tool for bird watchers to use while doing science and added features designed to improve user-reward. Each participant can define a specific list of features to manage his/her own observations. eBird incentivizes participants to insert current and historic data by providing recognition for individual achievements. It also integrates a wide range of visualization tools participants can use to view the data (Sullivan *et al.*, 2014).

2.2 Initiatives for Combating Radon

In a recent research work, Meritxell Martell et al (2021) found several citizen science initiatives related to radon and studied eight of them. In all the initiatives, participants are involved in radon data collection. The Evict Radon project, promoted by the University of Calgary, Canada, provides a radon measuring kit to allow citizens to measure indoor radon concentration in their home. The citizens must order the measuring kit and, after the data measurement, send the kit back to the project team. In Ireland, the Environmental Protection Agency (EPA) implemented the RadNorm project which allows citizens to borrow radon measurement devices in the Wexford libraries network to monitor their indoor radon levels during a period of 3 months. Two of the initiatives, one in Italy and the other in Israel, aim to educate students on radioactivity and to raise their awareness while the students help to gather measurements data. The other four initiatives were developed in the United States, three of them promoted by universities. Two initiatives describe pilot projects set up in Massachusetts and New Mexico, using community-based participatory research in marginalized communities. In the first case, citizens participate in the problem definition and are engaged in data collection. In New Mexico, short-term indoor radon kits were used to measure indoor radon levels in 51 homes. Another citizen science initiative in Tennessee offers several services and assistance such as test kits for homeowners, technical information for universities, and specific materials for targeted audiences, such as real estate professionals, home builders, home inspectors and school officials. Finally, a transdisciplinary community-academic project in Kentucky addresses community concerns about lung cancer by identifying geological and atmospheric conditions that increase radon intrusion into homes. This knowledge is translated into greater residential awareness of risk, enabling home radon testing and report back, and growing access to affordable and adequate radon mitigation. The project engages residents of rural Kentucky communities and trains them to rigorously collect data and interpret findings.

According to Muki Haklay (2013), there are four levels of participation and engagement in citizen science projects: (1) crowdsourcing, basic level where citizens are data collectors; (2) distributed intelligence uses the cognitive ability of the participants as a resource; (3) participatory science, when the participants define the problem and implement a data collection method, previously devised with the help of experts; and (4) extreme citizen science, where professional and non-professional scientists are involved in all kind of scientific activities while matching the motivations and interests of the participants. Most of the identified initiatives were classified as crowdsourcing by Meritxell Martell et al (2021) because citizens just participate in data collection and are not engaged in the production of scientific knowledge. However, the researchers pointed out that citizen science projects have potential to contribute to radon research and provide benefits for all participants and society in general. Citizen science initiatives can be used to raise the poor public awareness about radon and contribute to national radon action plans and implementation of legal requirements. The development of citizen science initiatives including testing and radon mitigation may contribute to a reduction in radon related lung cancer.

3. MATERIALS AND METHODS

From the literature review, we have concluded that citizen science is very helpful to scientific questions that have large spatial or temporal scopes, such as the case of radon research.

3.1 Guidelines for the Development

Yadav and Darlington (2016) recommend that citizen science platforms should be designed to be cost effective, and easy to maintain. The platform should allow good interaction between scientists and citizens, offer security and trust, and have a good usability for the participants. One key aspect for getting the best of volunteers is having an engaging user experience (Simpson, Page and De Roure, 2014).

The ten principles of citizen science (Robinson *et al.*, 2019) are a good tool to assess the extent to which a citizen science initiative can contribute to radon research. These principles correspond to the shared view of the international community of citizen science practitioners and researchers about the characteristics that support high quality citizen science. According to these principles, citizen science projects actively involve citizens and have a genuine science outcome. Both the professional scientists and the citizen scientists benefit from taking part. Citizen scientists receive feedback from the project and may, if they wish, participate in multiple stages of the scientific process. If there are no legal or mandatory constraints, citizen science project data and metadata are made publicly available. The development of the Zooniverse platform was an iterative process and using real users was vital for project development evolving to a flexible platform for web developers leading to a wide range of projects (Simpson, Page and De Roure, 2014).The user must understand the project and the goal in a few minutes (Jennett and Cox, 2014).

Some general design principles for citizen science are providing access to the data the users give, allow them to view it at any time, transparency with the data that it's collected, data sharing as much data as possible, modular development, each data point should have a unique identifier, design that appreciates time and lowers entry barriers to the users and secure data transmission and storage (Sturm *et al.*, 2018)

The collected data might have data quality issues and must be validated in some way. Data collection methods must be standardized, nevertheless very large sample sizes tend to lessen said issues (Silvertown, 2009; Dickinson, Zuckerberg and Bonter, 2010). Enhanced data quality can be achieved by providing a clear data collection protocol, simple data forms and support to participants (Bonney *et al.*, 2009).

3.2 Platform Development

A pre-diagnosis model was designed as a software tool for predictive diagnosis of indoor radon potential and radon awareness (Nunes *et al.*, 2022; Silva *et al.*, 2022). This paper describes the development of a web platform integrating this model to enable citizens to obtain an assessment of the radon potential of the buildings where they work or live. There are two main roles in accessing the platform: the user and the administrator. The user represents the citizen. The citizens will have access to the indoor radon potential estimation tool, and to the submission of radon measurements on the platform. The citizen is the one who provides the data to the platform. The administrator role will be assigned to researchers to give them exclusive access to user-entered data and model performance metrics. To bring some dynamic content to the web platform, the administrator will be able to publish news about radon-related issues.

The citizen science radon web platform will allow citizens to obtain an assessment of the radon potential of the buildings where they work or live. The platform aims to promote radon measurements by the general population and raise awareness of radon risks. These measurements will generate new data that will be used to build a more robust classification model. The functional requirements for the web platform were based on previous work that defined a pre-diagnostic model that allows a citizen to verify the need to perform an indoor radon assessment study based on a set of characteristics of the building and its location (Silva *et al.*, 2022). Thus, the platform should motivate citizens to obtain an estimate of radon potential by providing a form where the characteristics of the building and its geographical location are entered. At a later stage, the citizen should be able to consult the assessment and, if indoor radon measurements have already been performed at the site, insert the radon readings taken. The web platform shall provide clear and objective information on indoor radon. To avoid citizens feeling constrained in sharing sensitive data, radon potential estimates and subsequent submission of measurements can be performed without registration. Administrators will be able to view all assessments and citizen-entered measurements, check the model performance, and obtain metrics on the use of the platform.

REST architecture was used for the web platform, resulting in four main components, as depicted in Figure 1: Web server, API, classification model, and database. The database stores the radon measurements and the radon potential classifications. The API provides authenticated access to the data and execution of the indoor radon potential classification model based on location, building and room characteristics. The Web server runs the web application that provides citizen and administrator access to platform functionality in a graphical interface. This architecture implements separation of concerns and allows easy updating of application features.

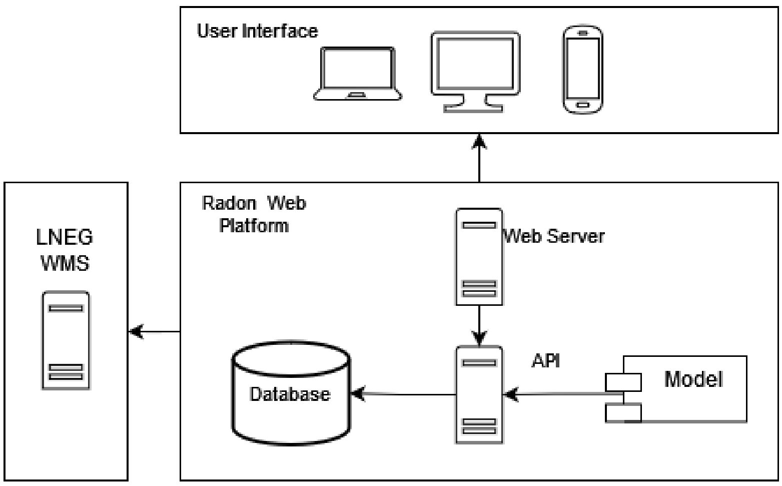

Figure 1. High-level architecture of the radon potential classification web platform

The platform must comply with the ISO/IEC 25010 standard. It should be easy to use and not require advanced computer skills. It should implement security measures to protect the data shared by citizens. It should be continuously tested for compatibility with the most used browsers, namely. Chrome, Firefox, Edge, and Safari, both on desktops and mobile devices.

The platform requires access to the LNEG map server to access the radiological map of Portugal and obtain the gamma value for the location selected by the citizen, which is an essential input for the model (Laboratório Nacional de Energia e Geologia, 2014). The radon potential estimation model runs through the RnHealth API. It will receive as input the location coordinates, the building construction year and the building number of floors, wall and floor materials of the room, the room floor and the number of floors below, thermal adaptation, and ventilation scheme. With these characteristics, the model estimates an indoor radon potential at the low, medium, or high level.

The platform was deployed into two containers: Mongo Container and RnHealth Platform Container. This design provides the isolation of the database from the web platform, so the web platform can be updated without compromising the database. The NoSQL database keeps flexibility to store arbitrary metadata as the platform evolves without having to be concerned with what exactly is stored (Simpson, Page and De Roure, 2014). The three services of the application used different technologies. The Mongo Container is a preloaded data image of a Mongo Database. The Rn Platform container supports the execution of two services: Rn API and RnHealth Web. The Rn API is running a Uvicorn server, a implementation of an asynchronous server gateway interface (ASGI) for python. The RnHealth Web service is running the Nginx open-source HTTP web server.

4. RESULTS AND DISCUSSION

The web platform is already online for functional testing by the researchers to ensure the functionality of the platform and to verify that the new radon readings data recorded through the platform are consistent with metadata from the dataset used to build the radon potential classification model. Figure 2 shows the form created to submit a radon potential estimation request on the web platform. The citizen can select the location of the building by clicking on the map and placing a marker on the building or in its vicinity, and all the fields required as input to the estimation model. Most of the fields in the form are drop-down lists with options that help the user experience.

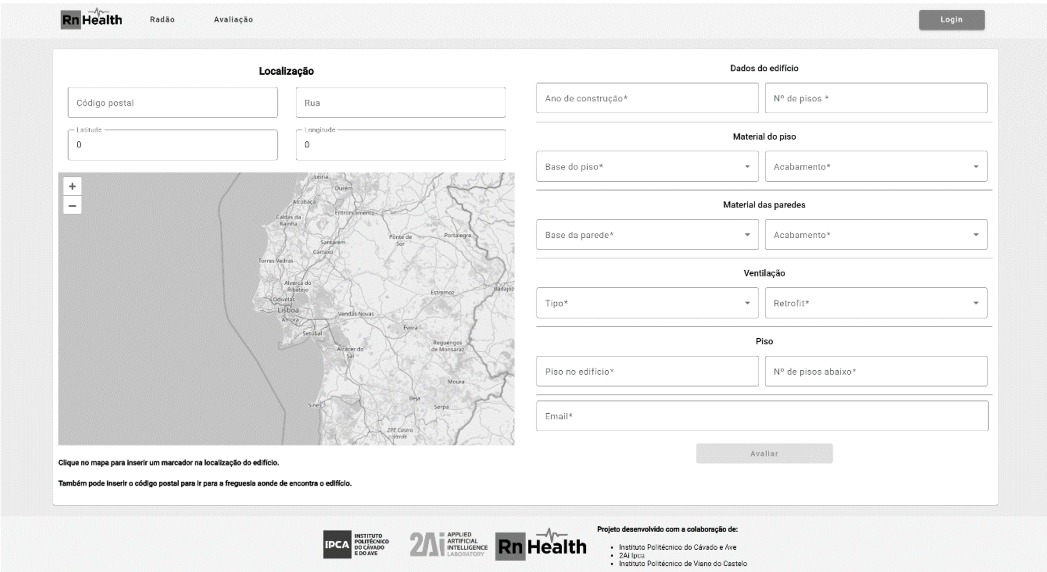

Figure 2. Submission form for radon potential estimate

After the citizen fills the form and submitting it, it will receive in their email a link to access the estimate, for later access and feedback, and the page will show the result of the submission with the indoor radon potential estimate and recommended actions. The citizen can submit feedback by accessing the link sent to the email. This feedback should be an indoor radon assessment reading during a certain period to confirm or deny the estimate.

The web platform administrator has access to a dashboard that monitors the performance of the classification model and provides data about the radon potential assessments performed and the respective readings entered by citizens. The data provides detailed information about the geographic areas where the web platform is used and about the involvement of citizens through the ratio of the number of recorded radon readings to the total number of assessments performed. The indicators on the performance of the radon potential classification model allow researchers to decide whether the model needs to be rebuilt using our collected data.

This platform will need to be continuously updated, both in improving the performance of the radon potential classification model and the functionalities offered, to increase citizen participation and further their involvement. It is intended that this action will have a very positive impact on increasing public awareness of the health risks of radon inside buildings and significantly increase the number of buildings in Portugal where radon concentration measurements have been performed. The indoor radon concentration measurements that will result from this initiative will contribute to the increase of indoor radon data available for future scientific research.

5. CONCLUSION

The radon potential assessment web platform will allow citizens to obtain estimates from the radon potential classification model and provide new data for research. The development of the web platform is already online but restricted to the research team. After the testing and validation, the web platform will be opened to the citizens, and dissemination initiatives will be developed.

The performance of the current classification model needs to be improved. The dataset used in the construction was small and very unbalanced. Therefore, the estimates provided by the model should be carefully presented to citizens. New data collected by citizens will help to obtain much better performing models. The researchers are confident that the estimates of radon potential, combined with information on radon health risks, will increase citizens' awareness of radon health risks, trigger many measurements, and promote mitigation actions. This initiative will have a positive impact on the reduction of the radon health risks.

ACKNOWLEDGEMENT

This research was funded by the project TECH (Technology, Environment, Creativity and Health), Norte-01-0145-FEDER-000043, supported by Northern Portugal Regional Operational Programme (NORTE 2020), under the Portugal 2020 Partnership Agreement, through the European Regional Development Fund (FEDER).

REFERENCES

APA (no date a) *Campanha nacional de monitorização do gás radão 2020 | Agência Portuguesa do Ambiente (APA)*. Available at: https://apambiente.pt/prevencao-e-gestao-de-riscos/campanha-nacional-de-monitorizacao-do-gas-radao-2020 (Accessed: 29 May 2023).

APA (no date b) *Mapa de suscetibilidade ao radão | Agência Portuguesa do Ambiente (APA)*. Available at: https://apambiente.pt/prevencao-e-gestao-de-riscos/mapa-de-suscetibilidade-ao-radao (Accessed: 29 May 2023).

Bonney, R. *et al.* (2009) 'Citizen science: A developing tool for expanding science knowledge and scientific literacy', *BioScience*, pp. 977–984. Available at: https://doi.org/10.1525/bio.2009.59.11.9

Dickinson, J.L., Zuckerberg, B. and Bonter, D.N. (2010) 'Citizen science as an ecological research tool: Challenges and benefits', *Annual Review of Ecology, Evolution, and Systematics*, 41, pp. 149–172. Available at: https://doi.org/10.1146/annurev-ecolsys-102209-144636

Echeverria, A. *et al.* (2021) 'Learning Plant Biodiversity in Nature: The Use of the Citizen–Science Platform iNaturalist as a Collaborative Tool in Secondary Education', *Sustainability*, 13(2), p. 735. Available at: https://doi.org/10.3390/su13020735

European Union (2013) *COUNCIL DIRECTIVE 2013/59/EURATOM*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013L0059 (Accessed: 15 April 2023).

Haklay, M. (2013) 'Citizen science and volunteered geographic information: Overview and typology of participation', in *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*. Springer Netherlands, pp. 105–122. Available at: https://doi.org/10.1007/978-94-007-4587-2_7

Jennett, C. and Cox, A.L. (2014) *Eight Guidelines for Designing Virtual Citizen Science Projects*. Available at: http://citizencyberlab.eu/

Kullenberg, C. and Kasperowski, D. (2016) 'What Is Citizen Science? – A Scientometric Meta-Analysis', *PLOS ONE*, 11(1), p. e0147152. Available at: https://doi.org/10.1371/JOURNAL.PONE.0147152

Laboratório Nacional de Energia e Geologia (2014) *Geoportal LNEG*. Available at: https://geoportal.lneg.pt/mapa/?mapa=CartaRadiometrica (Accessed: 15 April 2023).

Martell, M. *et al.* (2021) 'Evaluation of citizen science contributions to radon research', *Journal of Environmental Radioactivity*, 237. Available at: https://doi.org/10.1016/j.jenvrad.2021.106685

Meneses, P. *et al.* (2023) 'A Pre-Diagnosis Model for Indoor Radon Potential Assessment', *2023 11th International Symposium on Digital Forensics and Security (ISDFS)*, pp. 1–6. Available at: https://doi.org/10.1109/ISDFS58141.2023.10131887

Nugent, J. (2018) 'iNaturalist Citizen science for 21st-century naturalists'. Available at: https://www.proquest.com/docview/2009534937 (Accessed: 24 April 2023).

Nunes, L.J.R. *et al.* (2022) 'Designing a Multicriteria WebGIS-Based Pre-Diagnosis Tool for Indoor Radon Potential Assessment', *Applied Sciences*, 12(3), pp. 1–16. Available at: https://doi.org/https://doi.org/10.3390/app12031412

Presidência do Conselho de Ministros (2022) *Resolução do Conselho de Ministros n.º 150-A/2022, de 29 de dezembro, Diário da República n.º 250/2022, 1º Suplemento, Série I de 2022-12-29*.

Robinson, L.D. *et al.* (2019) 'Ten principles of citizen science', in *Citizen Science*. UCL Press, pp. 27–40. Available at: https://doi.org/10.2307/j.ctv550cf2.9

Silva, J. *et al.* (2022) 'A pre-diagnosis model for radon potential evaluation in buildings: A tool for balancing ventilation, indoor air quality and energy efficiency', *Energy Reports*, 8, pp. 539–546. Available at: https://doi.org/10.1016/j.egyr.2022.02.100

Silvertown, J. (2009) 'A new dawn for citizen science', *Trends in Ecology and Evolution*, pp. 467–471. Available at: https://doi.org/10.1016/j.tree.2009.03.017

Simpson, R., Page, K.R. and De Roure, D. (2014) 'Zooniverse: Observing the world's largest citizen science platform', in *WWW 2014 Companion - Proceedings of the 23rd International Conference on World Wide Web*. Association for Computing Machinery, Inc, pp. 1049–1054. Available at: https://doi.org/10.1145/2567948.2579215

Soltani-Nabipour, J., Khorshidi, A. and Sadeghi, F. (2019) 'Constructing Environmental Radon Gas Detector and Measuring Concentration in Residential Buildings', *Physics of Particles and Nuclei Letters*, 16(6), pp. 789–795. Available at: https://doi.org/10.1134/S154747711906030X

Sturm, U. *et al.* (2018) 'Defining principles for mobile apps and platforms development in citizen science', *Research Ideas and Outcomes 4: e23394*, 4, pp. e23394-. Available at: https://doi.org/10.3897/RIO.4.E23394

Sullivan, B.L. *et al.* (2014) 'The eBird enterprise: An integrated approach to development and application of citizen science', *Biological Conservation*. Elsevier Ltd, pp. 31–40. Available at: https://doi.org/10.1016/j.biocon.2013.11.003

US EPA (no date) *What is EPA's Action Level for Radon and What Does it Mean?*, *Radon*. Available at: https://www.epa.gov/radon/what-epas-action-level-radon-and-what-does-it-mean (Accessed: 15 April 2023).

WHO (2009) *WHO Handbook on Indoor Radon: A Public Health Perspective*. Edited by H. Zeeb and F. Shannoun. World Health Organization.

Wood, C. *et al.* (2011) 'eBird: Engaging birders in science and conservation', *PLoS Biology*, 9(12). Available at: https://doi.org/10.1371/journal.pbio.1001220

Yadav, P. and Darlington, J. (2016) 'Design Guidelines for the User-Centred Collaborative Citizen Science Platforms', *Human Computation*, 3(1), pp. 205–211. Available at: https://doi.org/10.15346/hc.v3i1.15