Geo-Resilience 2023 Conference, Cardiff, Wales
D.G. Toll & M.G. Winter (Eds)
British Geotechnical Association, London. 2024
https://doi.org/10.53243/Geo-Resilience-2023-4-1

Energy Geostructures: An Investigation into the Barriers and Drivers, Focusing on the Industry's Perspective in the UK

Terry WINARTA

University of Cambridge, Cambridge, United Kingdom
Corresponding author: Terry Winarta (terry.winarta@arcadis.com)

Abstract

In the United Kingdom, the residential and commercial sectors, which energy consumption consists mainly for buildings and heating, accounted for 44% of the total final energy consumption and 24% of energy related CO2 emission. There is an increasing enthusiasm from designers and developers to use engineering structures to provide thermal exchange with the ground in recent years, called Energy geostructures. Energy geostructures are structure or infrastructure foundations used as heat exchangers within a Ground Source Heat Pump system. Carbon savings from such schemes and the energy associated with them is classed as renewable. Appetite in the industry is also growing, as indicated by the development of design methods in the UK and European countries and increasing numbers of model scale experiments. The intention of this research is to investigate the barriers and drivers in implementing the energy geostructure. Review of literatures on the development of energy geostructures were carried out, followed by barriers faced by geotechnical designers on their role in sustainable development and application of energy geostructures. Subsequently, existing policies and initiatives in the United Kingdom on renewable energy were assessed. indicating that the technology and theoretical application were adequately developed to support energy geostructures. The main barriers that were identified are the high capital cost in comparison with traditional gas heating system and other alternatives, general awareness and inadequate skills within the industry, organisational and administrative barriers within regulatory framework and organisations, and the availability of data required to implement project specific solutions. Various drivers have been identified and recent examples from European countries with higher level of industry maturity, including creating a level playing field between fossil fuel heating and electricity heating, introduction of financial incentives and establishing design tools and standards that will tighten the gap of skills and awareness in the industry. Following up from the findings in this paper, future research should expand on the implementation and strategy of the key drivers that have been identified.

Keywords: Energy Geostructures, Ground Source Heat Pump, Shallow Geothermal

1. Introduction

Global energy demand is estimated to double or triple as the global population rises and developing countries expand their economies. The United Nations projected that the world population will increase from 7.7 billion to more than 9 billion in 2050 (United Nations, 2019). This increase coupled with continued demand for the same limited natural resource will cause significant increase in consumption of energy. In the United Kingdom, the residential and commercial sectors, which energy consumption consists mainly for buildings and heating, accounted for 44% of the total final energy consumption and 24% of energy related CO2 emission (International Energy Agency (IEA), 2019).

One of the technologies to reduce carbon emission is the ground source heat pump (GSHP), a heat production and storage system that utilises shallow geothermal energy for the built environment. The GSHP is one the key technologies identified in the Renewable Heat Incentive (RHI) with 16% of residential renewable energy installations accounted to the system (IEA, 2019). Traditional GSHP system uses the borehole heat exchange mechanism to manage the thermal loads within buildings. However, there is an increasing enthusiasm from designers and developers to use engineering structures to provide thermal exchange with the ground in recent years (Bourne-Webb, Burlon, Javed, Kurten, & Loverdige, 2016). This application has been referred to variously as energy foundations, thermo-active ground structures (Brandl H. , 2006), geothermal piles and energy geostructures (Laloui & Sutman, 2019).

Energy geostructures are structure or infrastructure that are in contact with the ground utilised as geothermal heat exchangers within a GSHP system. Typically, these are the sub-structure of buildings such as foundations, underground basements, or tunnels. Dual use of the geostructures is achieved by equipping the structural elements with heat transfer pipes to the ground source heat pump system, contributing to the cooling and heating of buildings during summer and winter. Provided the system is designed and constructed appropriately, there will be long term financial and carbon savings from such schemes and the energy associated with them is classed as renewable (Soga & Rui, 2016).

Extensive researches were carried out for energy geostructures in geotechnical engineering field, primarily on the analysis and design methods (Bourne-Webb, Burlon, Javed, Kurten, & Loverdige, 2016), thermal loading (Rotta Loria, Bocco, Garbellini, Muttoni, & Lalou, 2019) and site investigation techniques (Loveridge, Low, & Powrie, 2017). Appetite in the industry is also growing, as indicated by the development of design methods in the UK and European countries and increasing numbers of model scale experiments (Loveridge, McCartney, Narsilio, & Sanches, 2020). Most of the literatures agreed that the fundamental theory and practical application of the energy geostructures are well developed. However, there is still little development of practical tools, design guidelines and standards for geoengineers and practitioners (Soga & Rui, 2016). Moreover, the added factors of higher capital cost of installing GSHP compared with its contemporaries along with the lack of visibility within the mainstream construction industry further resulted in the low uptake from clients on energy geostructures (Loveridge, McCartney, Narsilio, & Sanches, 2020).

The intention of this research is to investigate the barriers and possible drivers to implement energy geostructure technology, focusing on the industry's opinion and perspectives towards the issue.

2. Energy Geostructures

The term energy geostructures have been collectively used to describe the incorporation of primary heat exchangers through foundation elements or into tunnel linings to utilise ground source heat pumps (Soga & Rui, 2016). The first application of heat exchange via foundation elements was in Austria and Switzerland; shallow foundation elements such as ground bearing slabs and shallow basement walls were first utilised for energy exchange, and these were quickly followed by bearing piles in mid 1980s, diaphragm walls (mid 1990s) and then tunnels (early-2000s). Various research on energy geostructures have emerged in recent years, such as energy ground anchors, base slabs, and shallow foundations (Loveridge, McCartney, Narsilio, & Sanches, 2020).

The efficiency of the GSHP is quantified by the coefficient of performance (COP) through examining the amount of energy input from electricity to operate the GSHP, and the energy that can be supplied to the building side (Laloui & Sutman, 2019). There are three possible GSHP operating modes, both heating and cooling, cooling, and heating only. The efficiency of a heat pump is strongly influenced by the difference between extracted and actual used temperature, and a value of COP higher than 4 should be achieved for economic reasons (Brandl H. , 2016). Various research has indicated that GSHP is able to achieve COP between 4 and 8 which is significantly higher compared with the COP between 2 and 3.5 for Air Source Heat Pump (ASHP) and traditional gas boilers, which has COP lower than 1 (Brandl H. , 2006).

Although this indicates that GSHP has higher efficiencies compared to ASHP or gas boilers, the relatively high capital cost of GSHP proves to be a barrier of adapting this technology, which might lengthen the payback period when compared to other alternative heating system. Moreover, the COP of ground source heat pump is highly dependent on the design and installation of the primary circuits as well as insulation of the building or structure. Hence, it is recognised that the theoretical COP of ground source heat pump might not be easily achieved on site due to these uncertainties.

General awareness regarding ground source heat pump and energy geostructures are typically low compared with other alternatives such as solar panels. There is a lack of visibility amongst potential end-users, legislators, and design professionals in the technology itself (Bourne-Webb, Burlon, Javed, Kurten, & Loverdige, 2016). This might be due to the complex process of design and installation of various components of energy geostructures that is usually taken by several different contractors and designers. The lack of general awareness and its complexity leads up to the common association of energy geostructures with high capital costs and novel technology (Loveridge, McCartney, Narsilio, & Sanches, 2020) although it is more efficient than other heat pump technologies. The high capital cost is mainly due to the drilling and ground works that are required to install the thermal exchangers. Hence, it should be noted that the high capital cost is only true for energy boreholes as the cost for drilling and ground works for energy geostructures are shared with the structural elements. Furthermore, most literatures that have been reviewed leans to the technical side of ground source heat pump and energy geostructures, rather than the wider issues within the industry to drive its implementation. This is noted as a gap in the current research.

This research intends to identify the barriers and potential drivers within the industry on increasing the uptake of this technology. The results of the research could then be taken as consideration in the development of further research within the industry.

3. Research Design

Mixed methods approach of survey questionnaires and semi-structured interview to selected participants were conducted. As energy geostructures is considered as a specialism within the industry, the limited number of available sources justified the use of qualitative data to investigate the causation of a particular topic (Burke Johnson & Onwuegbuzie, 2004). The interviews would be the best of these due to their versatility and the fact they can be shaped to gain the most valuable opinions possible from a variety of participants (Valentine, 1997). Semi-structured interview methodology was considered due to the unpredictable nature of the answers, resulting in following conversational trajectories to widen the scope of the interview would be important: which is a key benefit over a structured interview methodology (Cohen & Crabtree, 2006). Table 1 presents the list of interviewees that have participated in this research.

Table 1: List of Interviewees.

Reference	Professional Background	Professional Sector	Experience in geostructures
P1	Ground Engineering	Engineering Consultancy	Feasibility Studies
P2	Ground Engineering	Engineering Consultancy	Academic Research
P3	Building Services	Engineering Consultancy	Detailed Design
P4	Ground Engineering	Engineering Consultancy	Schematic / Feasibility Studies
P5	Building Services	Engineering Consultancy	Detailed Design
P6	Ground Engineering	Engineering Consultancy	Detailed Design
P7	Ground Engineering	Academia	Detailed Design and Academic
P8	Geothermal Engineering	Engineering Consultancy	Cradle to Grave
P9	Ground Engineering	Contractor	Construction
P10	Financial Services	Management Consultancy	Schematic / Feasibility Studies
P11	Ground Engineering	Academia	Academic Research
P12	Piling Specialist	Contractor	Installation and Construction

A total of twelve semi-structured interviews were held with representatives from various background within the industry who have worked on energy geostructures. Each of the interviewees are from either Contractor, Engineer Consultants, or Academia and are specialists within the industry. Interviewees were selected to balance the possibility of contrasting interests and opinions. Results And Discussion

In general, the survey questionnaire indicated that professionals within the built environment have great awareness regarding UK's Net Zero Carbon target. Results of the semi-structured interview were coded to explore relevant key themes within the research question. Responses from the interviewees were coded based on a code manual that has been developed prior based on existing literature review, emphasising on whether the answers they have provided is either key advantages to energy geostructures, barriers or drivers. Based on the interview, recurring key themes regarding the potential barriers and drivers were identified and grouped together and presented in Table 2.

3.1 Perceptive Barriers

Three distinct type of end users were identified. The first is private and public developers, such as companies which develop residential and commercial development as the core of their business, and the property arm of local councils trying to provide affordable housing. Secondly, the government entities for infrastructure assets, that are responsible for the development and maintenance of their existing infrastructure, such as Transport for London, and Network Rail. Thirdly, existing homeowners, both in rural and urban area, who traditionally uses gas boilers as a heating mechanism and considering alternative heat sources.

The interviewees also identified that the application of energy geostructures is a project specific solution and limited to various factors within the project, such as reliance on the structural design of pile group solutions, geospatial location of the project as well as geological context within the underlying ground. The application of energy geostructures would ideally need to satisfy the suitability of the project within these three criteria to ensure that the investment applied will generate adequate return during operational period.

Finally, the interviewees identified that there is still inadequate skills and general awareness of energy geostructures within the built environment industry, either from the client, contractor, or geotechnical consultants. There are mainly four groups of professionals involved in an energy geostructures project: the designers, contractors, heat pump manufacturer and geothermal specialists. This is exemplified in Figure 1. In general, there is a lack of awareness with regards to energy geostructures between the contractors and designers. However, it is identified that the supply chain of ground source heat pump is relatively robust (Greater London Authority, 2018). Figure 1 presents the various stakeholders and designers which are involved in the design for energy geostructures.

Table 2: Results and Codes from Semi-structured Interview.

Key Themes	Perceptive Barriers	Potential Drivers
End user's perception	High capital cost, complicated administrative process, complexity in installations, complexity in building regulations, not efficient, traditional gas is still cheaper, lack of confidence, price of electricity	Financial incentives, simplify building regulations, level playing field between fossil fuel and electricity, subscription service for GSHP, improve industry skills, life cycle cost analysis, monetising carbon credits
Project specific solutions	Controlled by geological context, unknown ground condition, lack of ground investigation, reliance on structures design, dependent on substructures efficiency, project's location, programme dependent, space constrains	ground source viability maps, parametric tools, open data sharing, emphasis on technical standard and desk studies, collaborative approach in design, performance monitoring
Skills and Awareness in the Industry	Poor general awareness overall, poor installation skills, lack of interdisciplinary coordination, designers not involved in early planning, lack of technical guidance and standards, complex interface between designers	Mega projects as drivers, increase training in industry, core module in undergraduate studies, collaboration between academia and industry, better marketing

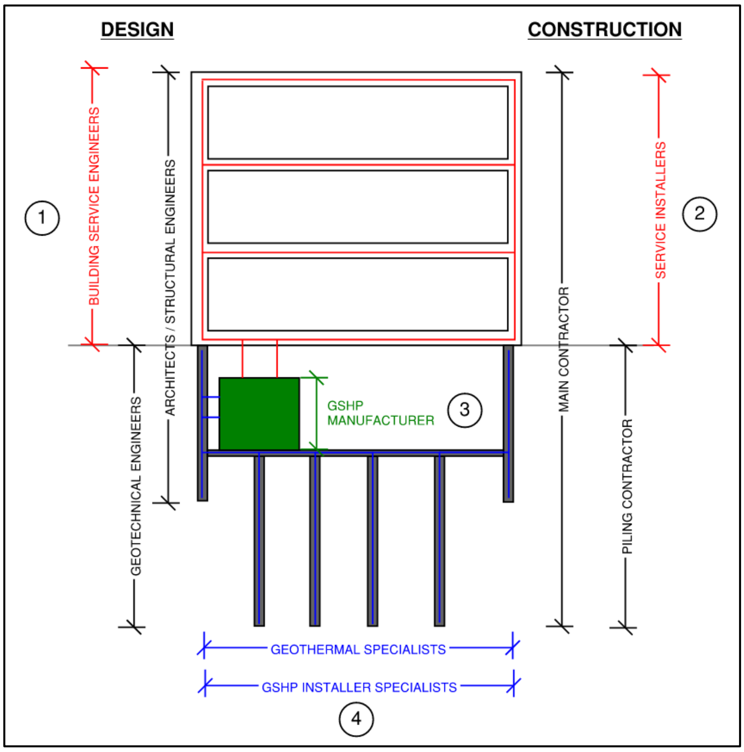

Figure 1: - Schematic Design and Construction Players for Energy Geostructures.

Amongst the designers, the accuracy of design and installation of heat pumps has been highlighted as a key concern in the industry. Appropriate design and sizing are seen as the key challenge related to installation. It is also understood that good quality installation of heat pumps is more difficult to achieve than gas boilers. Moreover, field trials also found that heat pump design and heat loss calculations at the chosen flow temperature and proportion of space heating were poorly understood amongst installers (Greater London Authority, 2018). In addition, there is also the lack of awareness of available specialists in the industry that would be able to provide their skills and experience in energy geostructures design, resulting in projects being abandoned at early stage as they deemed not feasible.

Secondly, the number and quality of installers is a barrier for widespread ground source heat pump deployment. This might be due to the lack of expert installers and project managers available for geostructures (such as piling) contractor, as the industry is predominantly dominated by civil engineering or structural engineering works. Interfacing between piling contractor, GSHP installer specialists and service installers will also need to be managed to ensure synchronisation in programme and space. Moreover, there are issues highlighted by the interviewee with regards to program management, temporary storage and site constrains for the installation of energy geostructures on site.

3.2 Potential Drivers

The potential drivers have been further grouped into two key themes, which are categorised as external and internal drivers, with definition presented in Table 3.

Table 3: Definition of External and Internal Potential Drivers**.**

Key Drivers	Definition
External Drivers	External driving forces that influence the feasibility, attractiveness, and general awareness of energy geostructures towards end users and players within the industry. These are usually implemented top down from the regulators and legislators, industry associations, and professional institutions.
Internal Drivers	Internal driving forces that occur and controlled within the industry to improve the skills and awareness. The internal drivers could directly influence the players within the industry and increase technical and design awareness.

Almost all the interviewees highlighted planning policy as one of the key drivers to unlock the potential of energy geostructures. The lack of clarity on how planning policies can support the adaption of alternative energy resources can be linked to the high capital cost and the lack of appetite by clients to adopt alternative solutions. The potential external drivers are grouped into four key themes and presented in Table 4.

Table 4: Potential key External Drivers.

Key Drivers	Suggestions of Potential Drivers
Building Regulations	Tighter building regulation, simplified regulatory framework, common tools, easier access, systematic approach from local authority and government
Financial Incentives	Grants, tax reductions, subscription service from installers, level playing field between cost of electricity and gas, lifecycle cost analysis to justify operational cost
District Heating	Holistic approach in design, smart heat grid system, exploitation of current infrastructures
Skills and Awareness of Contractors and Supply Chain	Mega projects, training, early involvement from contractor, innovative mindset, improving quality of installation and commissioning

Secondly, there is still inadequate knowledge and awareness of energy geostructures within the built environment industry. The internal drivers discussed in this section are identified as possible solutions that can be implemented by individuals and organisations within the industry without influences from external sources such as regulators, government, and end users. The potential internal drivers are grouped into four different themes, summarised in Table 5.

It was also identified that further alignment of ground investigation phases and TRoyal Institute of British Architects (RIBA) plan of work should be encouraged within the industry. This will allow geotechnical designers to be further involved in the decision making process earlier in the design stage, allowing the feasibility of energy geostructures to be identified earlier in the process. **Error! Reference source not found.** presents a proposed a pproach on the early involvement of various stakeholders identified in Section 0 combining the phases of ground investigation with RIBA plan of work.

Table 5: Potential Key Internal Drivers.

Key Drivers	Suggestions of Potential Drivers
Bridging the Awareness Gap	Industry-academia partnership, investment in research and development, knowledge sharing
Technical Standards and Guidance	Improving desk studies, collaborative approach in ground investigations, early involvement, updating technical standards and design guidelines
Innovative Tools	Viability maps, parametric tool, lifecycle assessment, carbon calculator for emission and operation
Open-sourced Data Sharing	Targeted ground investigation, data sharing between practitioners, transparency of information, shared monitoring data

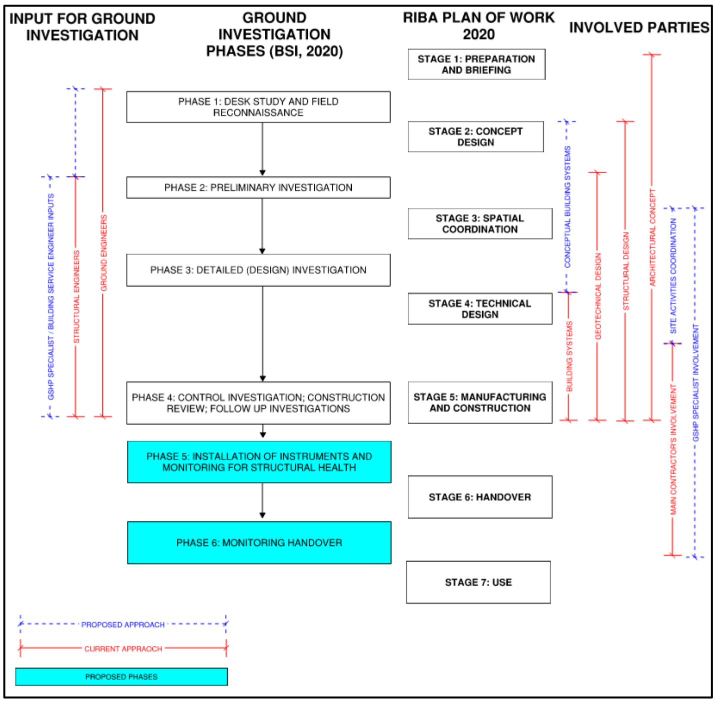

Figure 2:Proposed Flowchart to Encourage Interdisciplinary Collaboration.

Tools to support the planning application should be developed to enable this process, adapting from tools that are already available in other engineering disciplines such as parametric design, lifecycle assessments and carbon calculator. Furthermore, open sourced data sharing are encouraged and identified as one of the major driver to remove the perceptive barriers of inadequate available information. Figure 3 presents a proposed desk study framework for geotechnical engineers to support planning application for the applicability of energy geostructures in projects.

4. Conclusion

The Net Zero Carbon target forms the backdrop that cascades the drive for sustainability down to government, industry, and consumers. Nevertheless, the implementation of energy geostructures in the United Kingdom has not been developed to match its potential to provide a decentralised source of energy. Research comprising of literature review, quantitative and qualitative survey has been carried out to understand the barriers and drivers of implementing energy geostructures. The findings of the research are summarised in Figure 4. Following up from the findings in this paper, future research should expand on the implementation and strategy of the key drivers that have been identified. It may also prove pertinent to review the electricity generation in the United

Kingdom in a wider context. As ground source heat pumps are reliant on electricity to generate heat from the ground to the built environment, the implementation of energy geostructures alone will not be able to reduce the country's carbon emission due to reliance on fossil fuels. Moreover, with the rising fuel costs and the country's dependency in importing fossil fuel, it is important for electricity generation to shift locally.

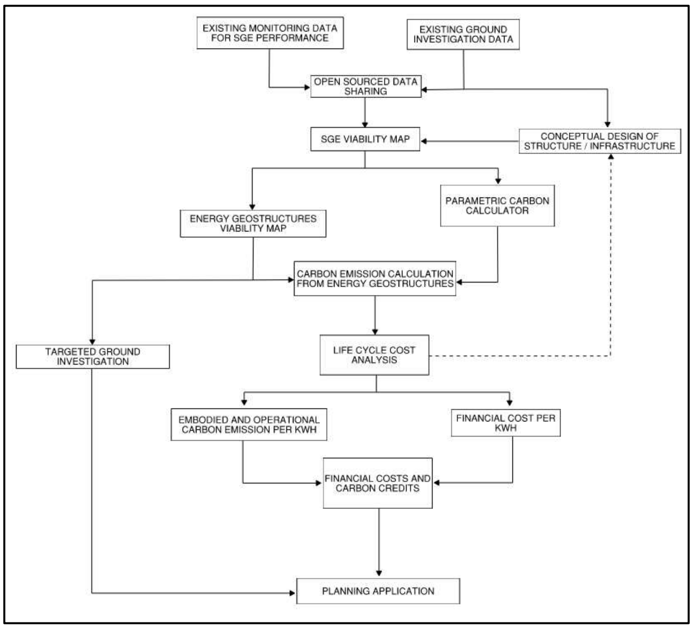

Figure 3: Proposed Desk Study Framework for Planning Application Related to Energy Geostructures.

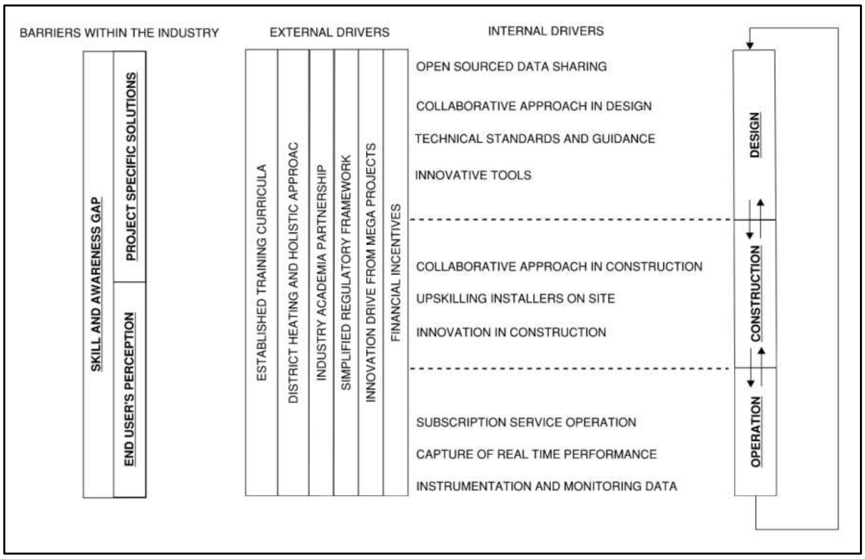

Figure 4: Summary of Barriers and Drivers in the Implementation of Energy Geostructures.

References

Bourne-Webb, P., Burlon, S., Javed, S., Kurten, S., & Loveridge, F. (2016). Analysis and design methods for energy geostructures. Renewable and Sustainable Energy Reviews, 402-419.

Brandl, H. (2006). Energy foundations and other thermo-active ground structures. Geotechnique, 81-122.

Brandl, H. (2016). Geothermal geotechnics for urban undergrounds. Procedia Engineering, 747-764.

Burke Johnson, R., & Onwuegbuzie, A. (2004). Mixed methods research: a research paradigm whose time has come. Educational researcher, 14-26.

Greater London Authority. (2018). Low carbon heat: heat pumps in London. London: Etude.

IEA. (2019). Energy Policies of IEA Countries United Kingdom 2019 Review. IEA.

Laloui, L., & Sutman, M. (2019). Energy geostructures: a new era for geotechnical engineering practice. Geotechnical Engineering Foundation of the Future (pp. 1-3). Reykjavik: XVII ECSMGE 2019.

Loveridge, F., Low, J., & Powrie, W. (2017). Site investigation for energy geostructures. Quarterly Journal of Engineering Geology and Hydrogeology, 159-168.

Loveridge, F., McCartney, J. S., Narsilio, G. A., & Sanches, M. (2020). Energy geostructures: A review of analysis approaches, in situ testing and model scale experiments. Geomechanics for Energy and the Environment.

Rotta Loria, A. F., Bocco, M., Garbellini, C., Muttoni, A., & Lalou, L. (2019). The role of thermal loads in the performance-based design of energy piles. Geomechanics for Energy and Environment.

Soga, K., & Rui, Y. (2016). Energy geostructures. In S. J. Rees, Advances in Ground-Source Heat Pump Systems (pp. 185-221). Cambridge: Woodhead Publishing.

United Nations. (2019). World Population Prospects (Highlights). New York: United Nations.