Enhancing the use of energy geo-structures by integration with other energy sources for heat storage

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Introduction and motivation

Today, climate change represents a dramatic challenge for the entire world society, leading to an increase of **mitigation** and **adaptation** strategies promoted by the European Union. Technological advances are required, particularly in the **heating** and **cooling** sector, since it represents a huge share of the world energy consumption (IRENA, 2020).

Among the current technologies for clean thermal energy production and storage, **shallow geothermal energy** takes advantage of the underground as a heat tank that can be tapped into for heating in winter and where buildings excess heat can be stored in summer. However, if more shallow geothermal systems are closely installed (e.g. in densely inhabited areas), thermal interferences could occur, leading to the depletion of the resource.

Fig. 1: Examples of energy geostructures: a) in rendering (Alvi et al. 2022); b) under construction (Barla et al. 2023).

In the last decades, **energy geostructures** (like energy tunnels, Fig. 1a, and diaphragm walls, Fig. 1b) have emerged as systems that manifest a huge potential for the heat storage and recovery from the surrounding soil and rock mass, mainly adopted in new constructions but also for thermally efficient retrofitting projects.

The research of this Ph.D. is dedicated to the investigation of the **integration** of **new technologies** to improve the energy efficiency of energy geostructures (i.e. with shape stabilized phase change materials and solar energy) and the **storage capacity** of the **subsoil**.

It will also consider the possibility to **mitigate thermal interferences** between new and existing shallow geothermal systems, that could hamper the heat exploitation from the ground source.

Objectives

- **Enhancing** the **heat storage capacity of the subsoil** and the shallow geothermal exploitation (through energy geostructures), introducing innovative materials, for example phase change materials.
- Quantify the **improvements** in the thermal performance of a real energy geostructure by its **coupling** with **solar energy** (like solar thermal collectors or solar ponds) to make the housing self-sustaining.
- Assessment of the **changes** in the **subsoil thermal inertia** with the introduction of PCMs, in the view of limiting mutual interferences and interactions among shallow geothermal energy systems.
- Provide hints to select the **most convenient and efficient solution** for heat storage, among the case studies, taking into account a cost-benefit analysis.

Geothermskin prototype and experimental site

The GeothermSkin system is a very shallow energy wall located within Politecnico di Torino Campus, in the Energy Center building (Fig. 2), that has the purpose of investigating application such as **seasonal thermal energy exchange** and **storage**. The results from experimental campaign carried out (Baralis & Barla, 2021) suggest that an average thermal power of about 17 W/m^2 can be exchanged with the ground in heating mode, while an average of 68 W/m^2 is exchanged in cooling operations. The GeothermSkin prototype is above the unconfined aquifer present in Turin and, with the help of the watering system (Fig. 3.) or when rainfall events occur, different infiltration levels can be reproduced.

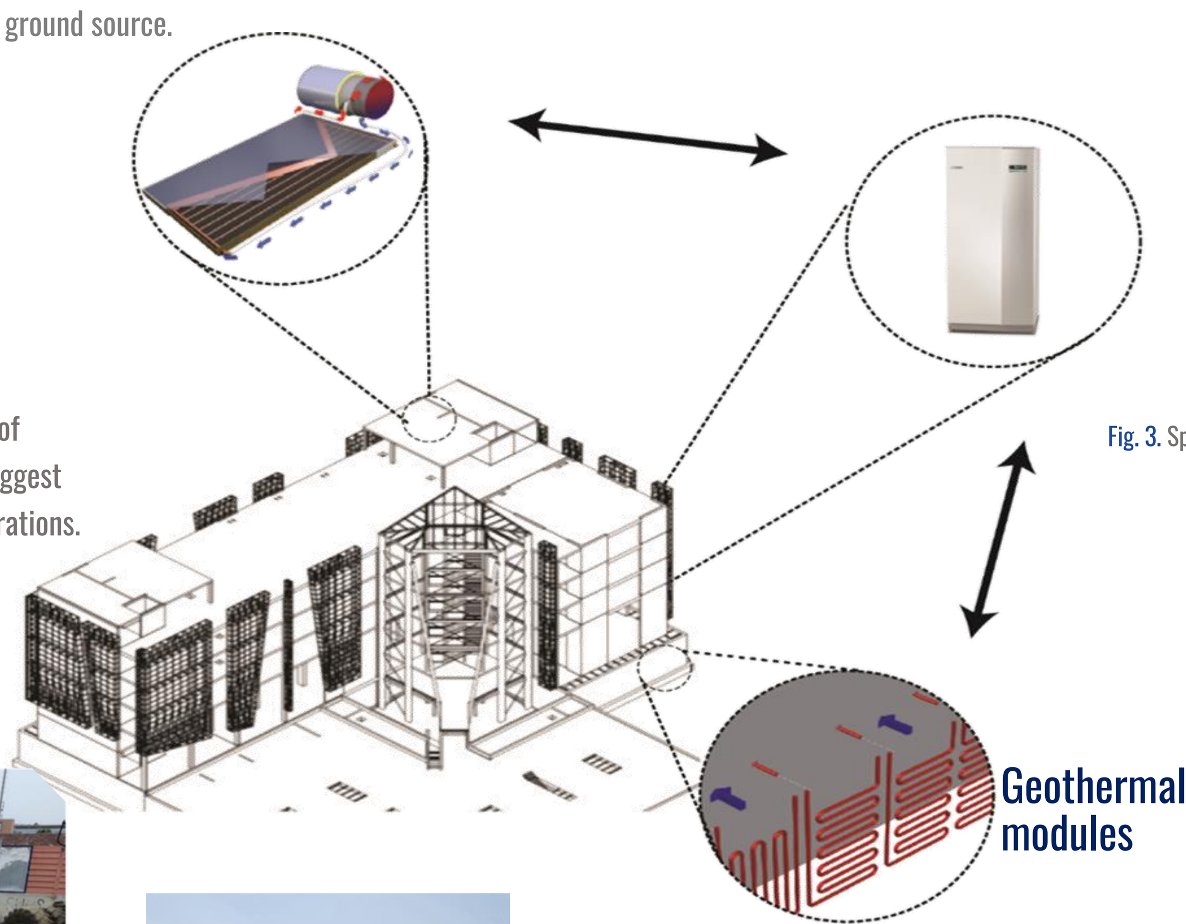

Fig. 2. The Energy Center building with the location of the experimental site of the GeothermSkin system.

Fig. 3. Sprinklers system installed in the shallow layers of the ground.

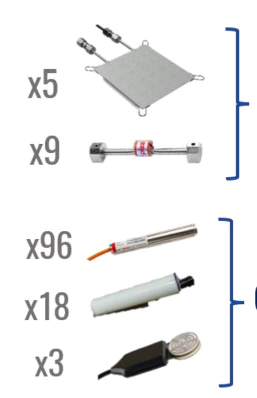

Fig. 4. Sensors available at the GeothermSkin experimental site.

Available facilities

- A rich and detailed monitoring system is installed on the wall itself and within the ground for the measurements not only of the **thermo-mechanical induced stress** and **strains** of GeothermSkin and temperature variations in the subsoil, but also the **soil moisture levels** and water content (Fig. 4).

  In particular, 8 hygrometers and 3 tensiometers at -0.75 m from the g.s. (Fig. 5) are currently installed, since the shallowest layers are characterized by significant gradients due to infiltration.

- Now, the prototype is also coupled with solar thermal collectors (10 kW potential) available on the roof (Fig. 6), allowing to combine the two renewable energy sources to **increase the heat production** and **efficiently manage** the **intermittent** nature of **solar energy**.

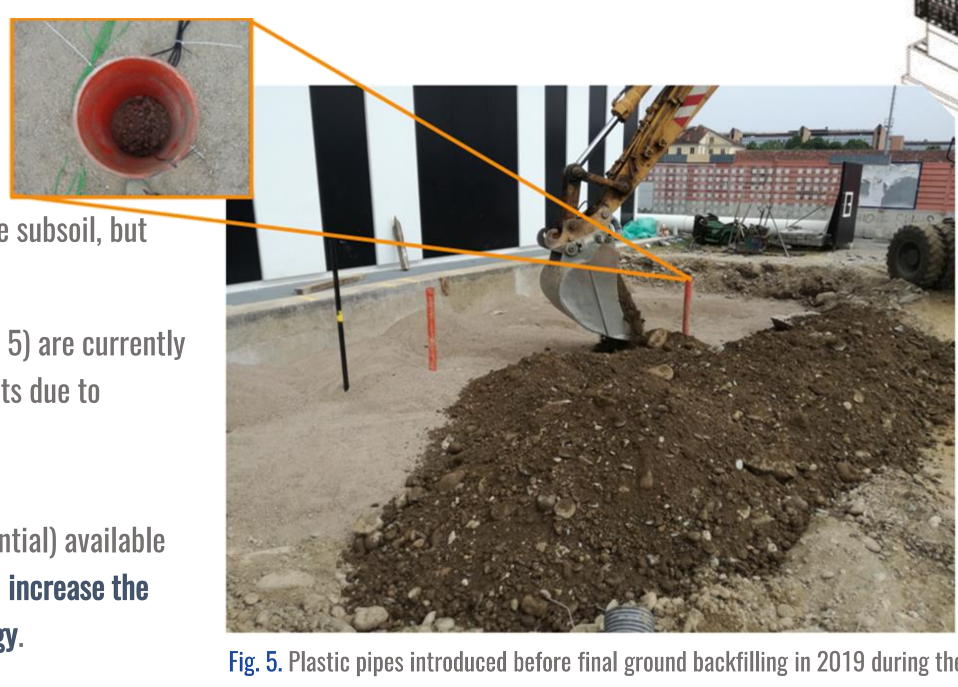

Fig. 5. Plastic pipes introduced before final ground backfilling in 2019 during the installation of very shallow sensors.

Fig. 6. Solar vacuum tubes on the building's roof.

Enhancement of the heat storage capacity and thermal properties of the ground..

...considering the introduction of novel materials

In view of the current works for the construction of the Digital Revolution House, the GeothermSkin prototype will be relocated. Since the underground building surface allocated for the installation of the heat exchange pipes can be increased (with respect to the prototype built in 2019), **shape stabilized phase change materials** (SSPCMs) could be **introduced within the soil** during the future excavation (Fig. 7) to test the heat storage capacity of the overall, also with the help of numerical modelling (Fig. 8).

Fig. 7. Excavation planned for the relocation of GeothermSkin.

Phase change materials (PCM) are **latent heat storage materials**, storing 5-14 times **more heat per unit volume** than sensible storage materials, like water or rock (Sharma et al., 2009). Only small-scale laboratory tests and numerical studies have considered their integration with energy geostructures, as the circulating fluid in heat pipes (Sani & Singh, 2023) or in the grouting/concrete or backfill for mixing in energy piles (Fei et al., 2023, Neto et al., 2023, Mousa et al., 2021).

No on-site experiments considered the improvement of the heat exchange through energy geostructures and a subsoil-PCM mix (Fig. 9).

Thus, introducing SSPCMs within the soil that surround the prototype represents an alluring option to test the already patented GeothermSkin technology, paving the way towards **real size energy geostructures**.

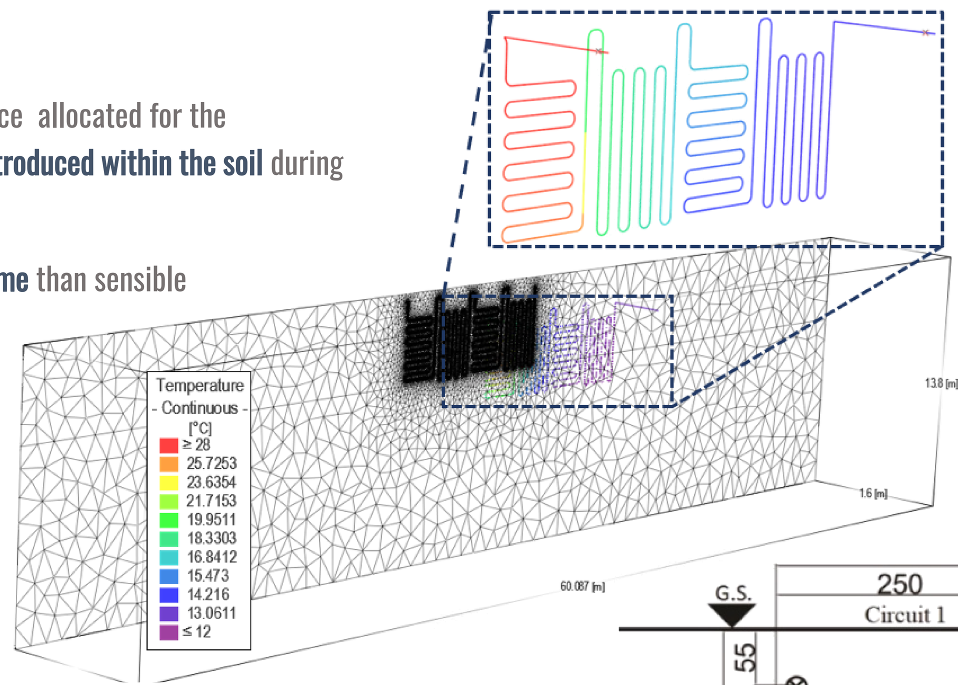

Fig. 8. 3D numerical modelling adopted to assess the feasibility of different technologies.

Fig. 9. Sand mixed with granules with paraffin and cylindrical high-density polyethylene containers filled in with hydrated salts (Bottarelli et al., 2022).

...combining shallow geothermal energy with solar energy

Since **solar energy availability varies**, effective storage solutions become essential for managing energy supply and demand and avoiding wastage. For example, this could be explored **storing the heat within the ground** or **in a pond/lake** in a closed loop system (through a circuit of pipes coupled with a heat pump). In the first case, the use of energy geostructures could be envisaged.

Even considering their primarily structural support to buildings and/or soil, their integration with solar thermal systems for underground thermal energy storage may introduce **detrimental thermo-mechanical couplings**, since larger temperature changes are involved, compared to standard seasonal geothermal operation. With reference to **GeothermSkin**, the **monitoring sensors** installed on the energy wall (i.e. pressure cells and strain gauges, as in Fig. 10), the possible insurgence of detrimental thermo-mechanical stresses and strains can be observed.

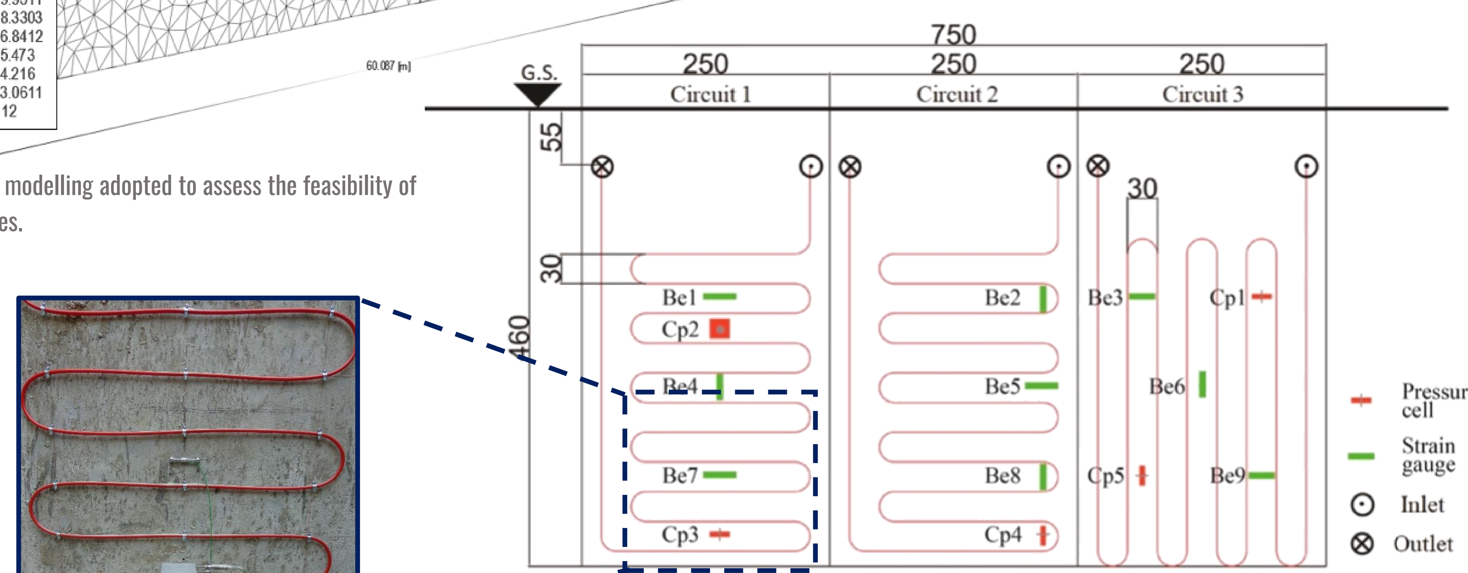

Fig. 10. Heat exchangers prototype layout and sensors for monitoring of stresses and strains on the wall surface.

Next steps

- Depending on the undisturbed temperature and compatibility with the ground itself, the **proper phase change material** (PCM) should be selected.
- **Introduction** of PCM in a chosen portion of the soil in contact with the geothermal modules for the evaluation of the heat exchanged and stored with the help of GeothermSkin. Then, **comparison** of the thermal performance with the traditional operation of the prototype.
- **Injection of heat from solar thermal collectors** to transform the underground in a thermal 'battery' before the winter season and study the improvement of the system.
- Considering the use of the coupled system in a sequential manner during winter season, **storing the excess heat from solar thermal collectors** for the **ground thermal recharge** and to avoid wastage.

Expected outcomes

1. Efficiently manage the heat production **combining** a stable energy source like the **shallow geothermal** with a **high production** energy source (but **intermittent**) like **solar energy**.
2. **Develop feasible thermal energy storage solutions** to supply the heating and cooling demands of buildings, with the help of energy geostructures. This will also facilitate their **integration** into **district heating networks**.
3. **Increase the thermal inertia** of the subsoil and limit the thermal affected zones due to the thermal activation of shallow geothermal systems, **avoiding possible interferences** with other energy systems installed nearby (Fig. 11).

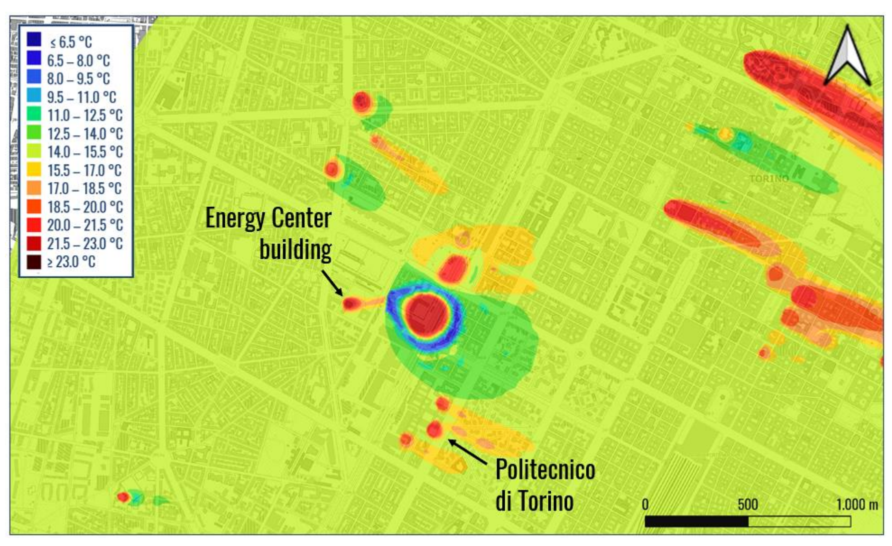

Fig. 11. Case study of thermal interferences in Turin central districts (with the focus on the area surrounding the Politecnico di Turin Campus) evaluated with numerical modelling.

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