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Review paper

TTHE ROLE OF GEOTHERMAL ENERGY PLANNING IN CREATING URBAN MORPHOLOGY OF CITIES AND TOWNS

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Abstract

Different manuscripts on the importance of energy planning at a community level explain why energy planning should go hand-in -hand with urban planning. They put emphasis on self-sufficient heat and electric power supply of communities, with locally available renewable energy such as geothermal energy (GTE). It also emphasized that this transition toward energy efficient communities does not have to be costly and that it could be done by means of system´s thinking. This article, however, puts more focus on general renewable energy integrative approach with refurbishments by analyzing literature. The presented case studies´ methods and conclusions are beneficial as they add to the knowledge on different geothermal energy utilization potentials within communities. The outcomes can help determine tools for similar approaches in future cities. Additionally, the presented research questions are beneficial as the results of the presented paper as they have been derived from different cities' experiences through the method of expert interviews. The paper gives foundation for a more comprehensive analysis' methodology in the field of geothermal energy use in architecture in the future.

Key words: *renewable energy, energy planning, case studies, review, geothermal energy*

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1. INTRODUCTION

The integration of Renewable Energy Sources (RES) into the energy infrastructure is a significant task, as future energy demands must align with low carbon emissions alongside sustainable and reliable energy sources. The highest demand for heating and cooling energy lies in the building sector, and it is expected to increase as urbanized areas grow over the coming years. Geothermal energy is recognized as a renewable resource that can provide stability in heating and cooling energy supply, utilizing known technology with cost benefits. Due to these facts, this paper addresses common practices in urban morphology and important topics that can enhance geothermal energy integration in urban planning.

In this paper, a short but detailed overview of the current state of research on geothermal utilization within cities is given. The elaborated studies focus on the geothermal resource as an opportunity for city development. In the context of urban refurbishments required across many cities in Europe and the U.S., particularly alongside the integration of geothermal energy, several innovative studies have expanded the knowledge base. The studies presented examine various types of geothermal energy, including low and high enthalpy systems, heat production and power production, individual and collective (district) systems, as well as Enhanced Geothermal Systems (EGS), and Ground Source Heat Pumps (GSHP). This diversity although challenging, is necessary in order to assess all possible aspects of GTE use in architecture and lead towards outcomes on the current state of research on their utilization in the conclusions. Currently, there are 395 geothermal district heating systems in operation in Europe (out of which 267 in EU27) and more than 500 systems at various stages of development [1], along with 6.46 million installed geothermal heat pump (GHP) units installed in the world, with China, United States, Sweden, Germany and Finland accounting for 77,4 % of the total number [2]. The paper presents an overview of selected studies that went ahead from the usual procedure of GTE integration in urban planning.

2. ON THE IMPORTANCE OF COMMUNITY-LEVEL ENERGY PLANNING

Notably, a 2014 study by Mastrucci et al. [3] developed a tool for calculating energy demand and supply in Rotterdam, covering 300,000 dwellings. A key achievement of this study was the creation of an energy analysis tool adaptable to other urban contexts. Additionally, the study's findings provided valuable insights for urban planning, particularly in shaping policies related to district heating networks and the decentralized use of renewable energy. As a result, local renewable sources gained stronger support at the policy level in efforts to reduce energy dependency. The study also proposed improved energy scenario modeling for future applications, offering a potential framework for refurbishment strategies in cities worldwide.

A study on the significance of community-level energy planning [4] underscores the necessity of aligning energy strategies with urban planning. It advocates for self-sufficient communities powered by locally available renewable resources, emphasizing that this transition need not be costly if approached through systems thinking. While the study takes a broad view of renewable energy integration in urban refurbishments, it provides limited focus on the potential of geothermal energy (GTE) as a catalyst for urban development. In contrast, detailed case studies contribute more concretely to understanding the diverse energy potentials across different communities. They help identify practical tools and strategies tailored to specific urban contexts. Although there is a strong push among researchers to develop universal "magical tools" for urban redevelopment, this approach often overlooks the unique characteristics of individual cities. This book therefore argues that in-depth case studies, rooted in local realities and expert insight, are more effective than one-size-fits-all solutions. The prevailing global emphasis on sustainability often imposes rigid frameworks, neglecting local energy data, the historical evolution of cities, and the nuanced roles of buildings and community voices in shaping energy policy [5][6].

Addressing cultural influences on GTE adoption, Shortall and Kharrazi [7] explored geothermal utilization in Japan and Iceland, revealing that cultural factors significantly shape the application and acceptance of geothermal technologies. Although overlapping elements exist, cultural specificity remains a key driver. The study emphasizes the importance of incorporating cultural analysis prior to techno-economic assessments and calls for greater public engagement. A lack of awareness among local stakeholders—such as Onsen owners in Japan—hinders broader adoption of GTE. A positive example of cultural influences and public engagement that go hand-in-hand with techno-economic is shown in the example of Altheim, shown on Figure 1.

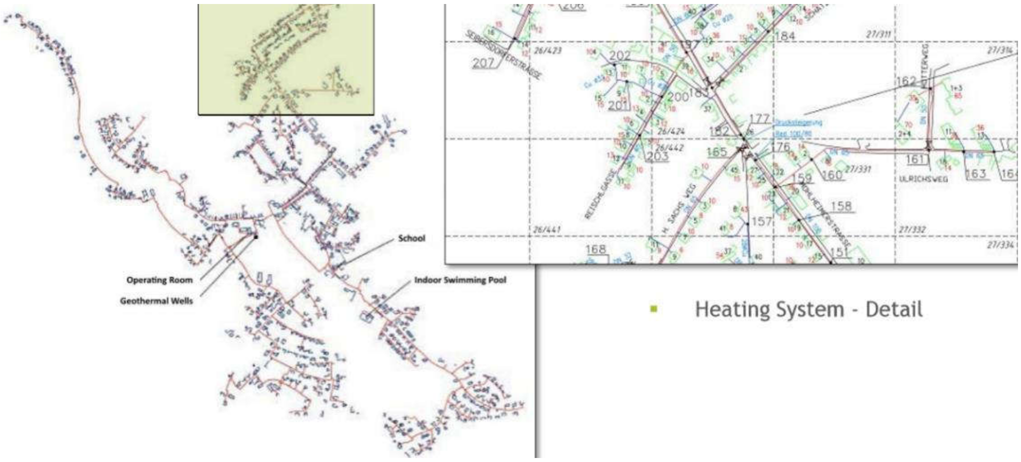

Figure 1, GDHS of Altheim, Upper Austria, with a detail (upper right), built around the beginning of the 1990s. As GTE came only after most of the urban tissue had been created, it was developed around the existing urban matrix of Altheim, the town can expand in many directions, possibly access to GTE stations and proximity of it, may have an influence on the position or length of the streets and neighborhoods.

Even though the first Historical utilization in the modern history of GDHS occurred at the end of the 19th century in the U.S, although 140 years later, no inference of this plan to other U.S cities schemes, is commonly made (see Figure 2 for details).

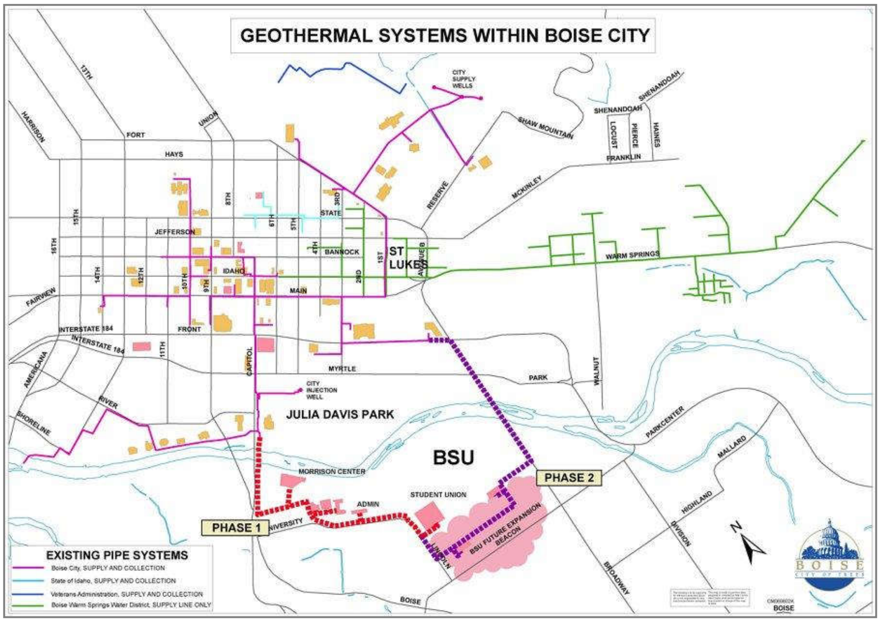

Figure 2, Boise, Idaho, USA, first contemporary geothermal district heating system in the world, operational since 1890. The urban morphology analysis implies the urban matrix of American cities and towns from the end of the 19th century, with GTE not reflected on the level of urban planning.

In another significant study, Carrera and Mack [8] employed the Delphi expert interview method across four European countries, using social indicators to evaluate renewable energy issues. Their methodology yielded insights that could complement public opinion surveys on renewable energy projects, while also introducing innovative methods like phone interviews to the field of social energy research. Inspired by this, the research presented in the book [9] also applies similar approaches to both European and American case studies. In particular, a study on Reykjavik, Iceland by Thorleikkur Johanesson on urban morphology of Reykjavik, shows the marginal status of GTE in terms of urban planning of the sprawled areas around the urban core (see Figure 3).

Ali et al. [10] examined the use of GTE in desalination, comparing it to other renewables like wind and solar. GTE's continuous thermal energy output was identified as a major advantage, though its potential application in urban contexts remains underexplored. However, progress has been made in studying shallow geothermal systems. Miglani et al. [11] investigated heat pump applications in urban neighborhoods, highlighting the gradual decline in geothermal potential due to prolonged heat extraction using borehole heat exchangers (BHE). They propose maintaining ground thermal balance—particularly during summer—through supplementary technologies like solar thermal energy. This study is among the few that explicitly address spatial constraints in applying geothermal systems to urban environments and emphasizes the need for integrated planning of energy systems and building typologies.

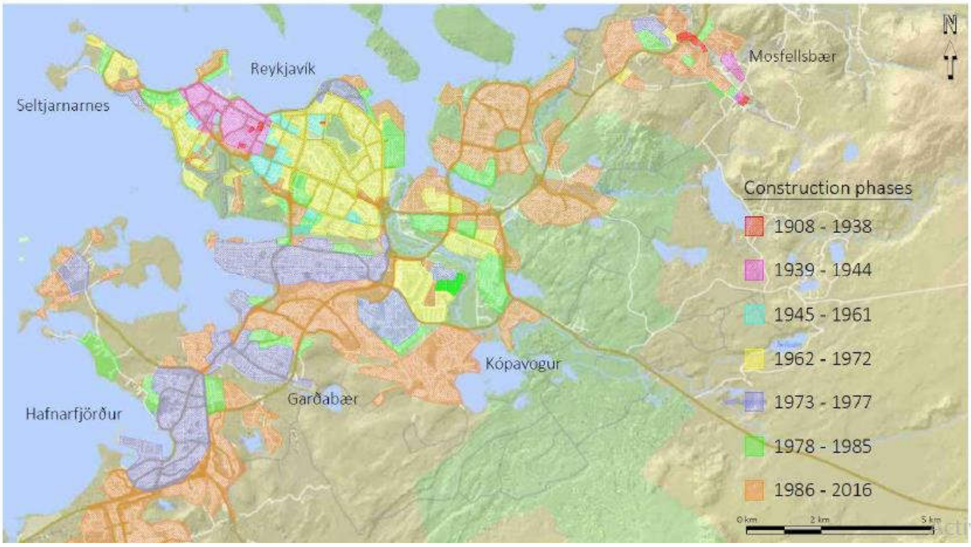

Figure 3, Reykjavik GDHS, evolution phases between 1908-2016, GTE and its vast technological use in Iceland, in particular in Reykjavik, made no reference to urban planning, as the city sprawled nonetheless due to its development, led by sole construction and infrastructure aspects [9]

On the other hand, deep geothermal systems—particularly Enhanced Geothermal Systems (EGS)—are the focus of several studies. Reber et al. [12] conducted a cost analysis of EGS in New York State, demonstrating its feasibility even in regions with low geothermal gradients. Although drilling and reservoir completion remain cost-intensive, the existence of district heating infrastructure makes transitioning to geothermal district heating systems (GDHS) economically viable. The study stresses the importance of clean energy in aging U.S. communities, particularly in the Northeast, and positions GDHS as a potentially transformative solution, despite its current underutilization.

However, although EGS primarily serve as a source of power, these systems are not commonly developed in towns and cities. To establish an EGS, it is necessary to "create" a geothermal reservoir, typically at depths of over 3-4 kilometers. This process entails drilling multiple deep wells and employing hydraulic fracturing and other reservoir stimulation techniques, which can be challenging to develop in populated areas.

In the U.K., McMahon et al. [13] explored the application of ground source heat pump (GSHP) systems in older Victorian buildings. Their study found that conventional thermal modeling tools, like the Standard Assessment Procedure (SAP), often underestimated the capabilities of GSHP systems. Despite SAP limitations, GSHP installations showed a payback period of five to seven years. Key success factors included installer expertise, user behavior, and long-term system monitoring. The findings challenge the prevailing focus on new, well-insulated buildings and suggest that older structures—especially those off the gas grid—stand to benefit significantly from GSHP adoption. This is especially relevant for Europe and the U.S., where many architecturally and historically significant buildings require energy-efficient retrofits. GSHP systems may play a critical role in revitalizing cities facing economic decline, urban shrinkage, or social fragmentation.

Fourth-generation district heating systems (4GDH) also present promising opportunities. Lund et al. [14] and Girardin et al. [15] propose integrating 4GDH with smart thermal, gas, and electricity grids, supported by low-energy buildings on the demand side. A GIS-based model developed by Girardinet al. provides valuable guidance for optimizing urban energy efficiency, identifying appropriate conversion technologies, and improving the integration of renewable energy sources.

A recent study by Schiel et al. [16] focused specifically on the integration of shallow GTE in the urban context of Ludwigsburg, Germany. The study calculated heating demand and geothermal extraction potential at the parcel level and introduced the Smart City Energy Platform, which visualizes GE borehole placements and spatial constraints. The research concluded that shallow geothermal is best suited for low-density urban areas—such as single-family homes and low-rise buildings—where it can efficiently provide space heating and hot water. The study highlighted the importance of stakeholder collaboration and comprehensive data analysis as prerequisites for successful project implementation.

3. METHODOLOGY

These diverse studies collectively underscore the value of context-specific research and stakeholder engagement in advancing the role of geothermal energy in urban development. This paper uses these insights as a foundation for further inquiry and for shaping a more tailored, evidence-based approach to energy planning in cities.

Table 1. Research Question as methodological approach of the paper

R1: To what extent have architectural and urban planning practices acknowledged geothermal energy (GE)?
Methodology: Expert interviews focused on selected case studies.
R2: Has geothermal energy been integrated into urban morphology—the physical form and structure of cities?
Methodology: Historical analysis combined with expert interviews based on case studies.
R3: How has the integration of geothermal energy unfolded historically, and in what ways has it influenced urban development?
Methodology: Examination of historical documents and expert interviews centered on case studies.
R4: Is geothermal energy currently being incorporated into contemporary architectural and planning practices?
Methodology: Expert interviews focusing on recent and ongoing case studies.

There were four expert interviews, all done within Austria. Two interviews were done in Altheim Gemeinde, Upper Austria, the second was done in Kirchdorf an der Krems, Upper Austria, followed by an expert interview in Graz, Styria, and, these were then triangulated with expert interview done at Cornell University in Ithaka, NY and one in Reykjavik, Iceland. Please refer to [9] for more detailed explanation of the interview sample.

4. IN CONCLUSION

There is a potential for using GTE as a source for supplying cities and towns with heat and power. Probably the EGS will play a greater role in these processes as the need for energy independence of cities and countries is a necessity due to different political implications. The analysis of the use of GTE for district heating in towns and cities in Europe and in the U.S., indicated that towns used geothermal energy as an external element of technology that does not affect how cities are developed or planned. Enhanced Geothermal Systems (EGS) primarily contribute to cities and towns as sources of power, but these systems are not commonly developed in them, as due to the employed fracking and reservoir stimulation methods, it remains a challenge to develop these in populated areas. Therefore, GTE's future in cities and towns lies in the heating and cooling sector, utilizing organized systems such as district heating and cooling (DHC) or single-use systems.

The analyzed papers show that the number of installed units of GSHP as well as DHS that utilize GTE as well as EGS, will rise in the years to come. The technological aspects of GTE have been advancing significantly in the years before now. What fails to follow is the re-thinking of how GTE finds a place in urban morphology creation, and, how urban planning that addresses heat transfer rules, combined RES utilizations and passive design may affect the future towns and cities and their current urban morphology stereotypes.

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Abbreviations:

(RES) Renewable Energy Sources
(GTE) Geothermal Energy
(EGS) Enhanced Geothermal Systems, (GSHP) Ground Source Heat Pumps
(GDHS) Geothermal District Heating System