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Lidar vs Thermal Camera: monitoring building energy losses - bibliographic review

Lidar vs Camera termică: monitorizarea pierderilor de energie în clădiri - studiu bibliografic

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Abstract. *Today, energy efficiency plays a key role in achieving climate change targets. Globally, countries are trying to reduce emissions and provide renewable and sustainable energy resources. As most rely on non-renewable sources as their primary source of energy, it is important to adopt ways to be energy efficient with what is currently affordable [1]. In this article we present a bibliographical survey of the literature on this emerging topic, providing an in-depth study and analysis of works published over the last two decades. Within each research area, an overview of several recent applications of the use of two innovative technologies LIDAR and thermal camera is presented: regional classification of environmental data, providing relevant data needed for reporting the energy efficiency of a building, including the use of artificial intelligence algorithms.*

Key words: *LIDAR, thermal image, energy, losses, buildings*

1. Introduction

Energy efficiency plays a key role in achieving climate change targets. Globally, countries are trying to reduce emissions and provide renewable and sustainable energy resources. As most rely on non-renewable sources as their primary source of energy, it is important to adopt ways to be energy efficient with what is currently affordable [1]. In recent changes made by the European Union (EU) to the "Energy Performance of Buildings Directive" require buildings to be more energy efficient. on the new challenges of climate change and other global events [2].

These proposed goals can be achieved through innovative technologies that provide quick and simple energy inspection solutions [1]. Among these modern technologies that can help provide the relevant data needed to report the energy efficiency of a building are:

- LiDAR - Light Detection and Ranging is ideal for acquiring the accurate data needed for an energy efficiency report.

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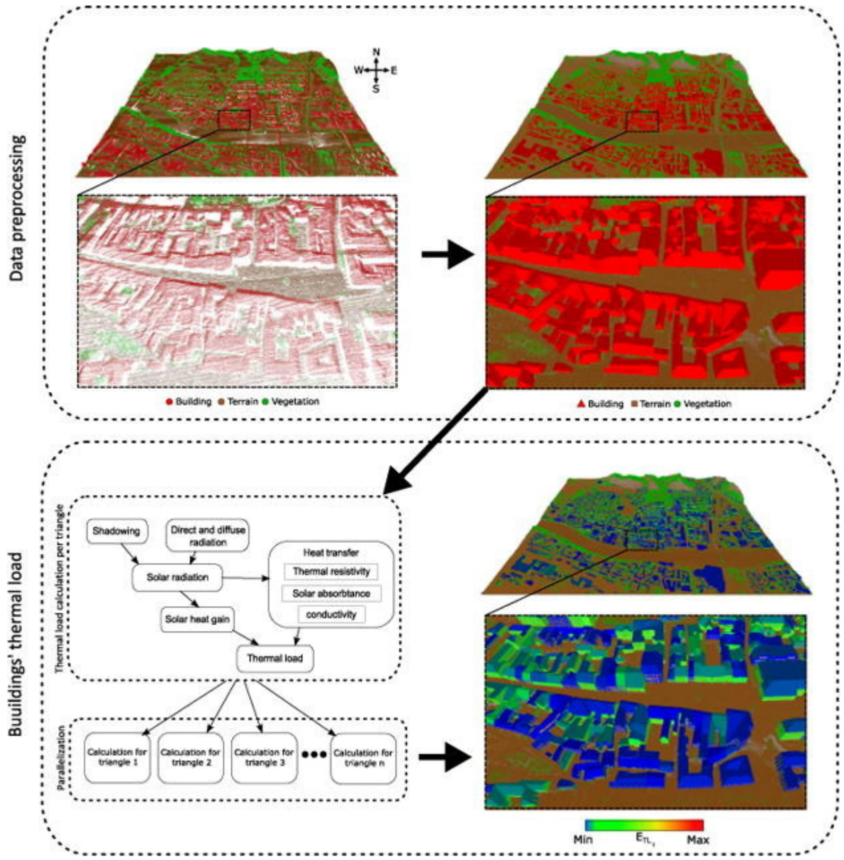

Fig. 1. Collection of thermal images using an infrared camera in the built environment [3]

• Thermal imaging - thermal imaging cameras detect thermal signals that highlight areas of heat loss, moisture penetration and insulation deficiencies.

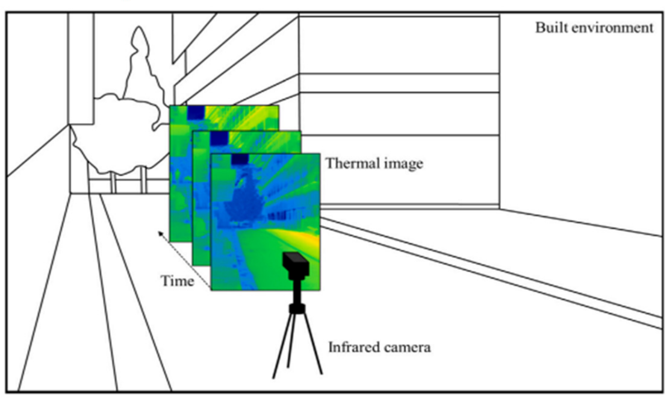

Fig. 2. Collection of thermal images using an infrared camera in the built environment [4]

In this literature review, we aim to conduct an analysis of energy loss monitoring in buildings using two innovative techniques, LIDAR, and thermal imaging. To know the extent of this research field, we searched the term "thermal comfort" in the electronic databases: Springer, Elsevier, Scopus, Scopus, reasarchgate.net, Web of Science, Crossref.

Thus, this literature search on this emerging topic will review some of the recent best practices in building energy efficiency using innovative technologies, considering the learning process and properties of these data for a complete understanding:

- How much progress has been made in monitoring building energy losses?
- What are some of the best practices in this regard?
- How can we process, access, manipulate and display the data?
- What are the opportunities for future research around spatially explicit energy loss efficiency?

2. Methodology and results

The literature selection in this research report started in a first step from the questions listed in the previous section, thus identifying that innovative LIDAR and Thermal Images technologies are future areas in the analysis, visualisation, and monitoring of buildings in terms of energy losses.

The bibliographical review conducted in this research report aimed to inform us about the problems that have been solved so far in terms of making buildings more energy efficient. This led to a bibliographic selection by keywords: lidar, thermal image, energy, losses, buildings, and published in databases such as: Springer, Elsevier, Scopus, reasarchgate.net, Web of Science, Crossref.

Also, for the selection of the bibliographical articles, it was considered that they must be published in peer-reviewed journals, be part of research projects in our proposed research area and present best practices in the literature.

Also, for the selection of bibliographical articles, it was taken into account that they should be published in peer-reviewed journals and present best practices from the literature.

Articles were selected that met the following criteria: published between 2017-2023, published in major journals or conferences on this emerging topic. Based on these criteria, 10 scientific articles were identified, detailed in Table 1. These literature studies were classified in Table 1 and according to the application problems solved in the field using the two technologies: lidar and thermal camera.

Table 1

Bibliographic review classification table

Item	Item from references	Article	Publications /Year	Information extracted in the research report
1.	3.	Directiva privind performanța energetică a clădirilor	2021	• With the strive to reduce energy emissions, the EU has ambitions to be climate-neutral by 2050. One of the steps they have taken is to revise its Energy Performance of Buildings Directive (EPBD) for 2022/23. • The EPBD is legislation aimed at promoting improvement in the energy performance of buildings within the European Union.

Item	Item from references	Article	Publications /Year	Information extracted in the research report
				Previously, the target for renewable energy used by the EU was 32% by 2030. Efforts to cut emissions even further have led to a revision of that target to an ambitious 45%.
2.	4.	Large-scale estimation of buildings' thermal load using LiDAR data	Energy and Buildings Volume 231, 15 January 2021, 110626, https://doi.org/10.1016/j.enbuild.2020.110626	• The proposed method is performed in two stages. First, the LiDAR data and buildings' metadata are preprocessed to generate high-resolution 3D building models that are represented by a triangle mesh. Thermal load of buildings throughout the year is then calculated per-triangle in a parallelised manner, while considering local micro-climate and shadowing from surroundings. Parallel design of the estimation enables significant speed-up of large-scale workloads, while maintaining accurate shadowing estimation. • In experiments, the method was applied over a part of the city of Maribor, where heating and cooling loads were inspected in addition to other factors of thermal load estimation. Yearly thermal load calculation with an hourly time-step for 4,817 buildings with over 9.17 million triangles took about 8 min on a modern GPU.
3.	5.	Infrared thermography in the built environment: A multi-scale review	Renewable and Sustainable Energy Reviews Volume 165, September 2022, 112540, https://doi.org/10.1016/j.rser.2022.112540	• presents a review on major contributions in infrared thermography to study the built environment at multiple scales
4.	6.	An innovative approach to check buildings insulation efficiency using thermal cameras	Ain Shams Engineering Journal 13 (2022) 101740, https://doi.org/10.1016/j.asej.2022.101740	• introduces on-going research that develops a hybrid thermal LIDAR system for rapid thermal data measurement and 3D modeling of buildings, which will allow "virtual" representations for the energy and environmental performance of existing buildings. • This research aims to stimulate the decision makers to improve their buildings by providing reliable and visualized information of their building's energy performance using the developed hybrid thermal LIDAR system
5.	7.	Innovations in Building	Review of Infrared	• discusses the fundamental principles of infrared thermography, the different types of

Item	Item from references	Article	Publications /Year	Information extracted in the research report
		Diagnostics and Condition Monitoring: A Comprehensive	Thermography Applications. Buildings 2023, 13, 2829. https://doi.org/10.3390/buildings13112829	infrared approaches, and the condition monitoring of buildings using infrared imaging techniques. It also discusses research showing how infrared thermography has been applied to recognize and solve different building-related problems. • The article highlights the potential for infrared thermography to advance while also acknowledging its current limits. Infrared thermography is predicted to become an even more effective technique for building diagnostics with the development of more sensitive cameras and the incorporation of artificial intelligence.
6.	8.	Energy Efficiency Assessment for Buildings Based on the Generative Adversarial Network Structure	Eng 2023, 4, 2178–2190. https://doi.org/10.3390/eng4030125	• proposes a method for improving the accuracy of the measured outside temperature on buildings with different surrounding parameters, such as air humidity, external temperature, and distance to the object. • A model was proposed for improving thermal image quality based on KMeans and the modified generative adversarial network (GAN) structure. It uses a set of images collected for objects exposed to different outside conditions in terms of the required weather recommendations for the measurements.
7.	9.	Quantification of heat energy losses through the building envelope: A state-of-the-art analysis with critical and comprehensive review on infrared thermography	Building and Environment Volume 146, December 2018, Pages 190-205, https://doi.org/10.1016/j.buildenv.2018.09.050	• This study starts from the common approaches for the U-value evaluation (analogies with coeval buildings, the calculation method, the *in-situ* measurements and the laboratory tests), with the underlying standard procedures and the most important advantages, problems, and potential sources of errors defined by the literature
8.	10.	Visualising urban energy use: the use of LiDAR and remote	Visualization in Engineering (2017) 5:22 DOI 10.1186/s403	• Authors explores the potential for using remotely sensed data from a combination of commercial and open-sources, to improve the functionality, accuracy of energy-use calculations and visualization of carbon emissions.

Item	Item from references	Article	Publications /Year	Information extracted in the research report
		sensing data in urban energy planning	27-017-0060-3	• Paper presents a study demonstrating the use of LiDAR (Light Detection and Ranging) data and aerial imagery for a mixed-use inner urban area within the North - East of England and how this can improve the quality of input data for modelling standardized energy uses and carbon emissions.
9.	11.	Thermal image building inspection for heat loss diagnosis	IOP Conf. Series: Journal of Physics: Conf. Series 1297 (2019) 012004 IOP Publishing doi:10.1088/1742-6596/1297/1/012004	• Article presented thermal imaging inspection for building applications it is powerful and non-invasive method for monitoring and diagnosing the condition of buildings. With a thermal imaging camera, you can identify problems early.
10.	12.	Thermographic methodologies used in infrastructure inspection: A review—Post-processing procedures	Applied Energy Volume 266, 15 May 2020, 114857, https://doi.org/10.1016/j.apenergy.2020.114857	• In this work, an exhaustive review is performed regarding the most recent and important practical thermographic procedures for infrastructure applications, focusing on the post-acquisition stage, due to the lack of an in-depth analysis regarding the most recent and used algorithms.
11.	13.	LiDAR point-cloud mapping of building façades for building energy performance simulation	Automation in Construction, Volume 107, November 2019, 102905, https://doi.org/10.1016/j.autcon.2019.102905	• introduces a semi-automated BEPS input solution for existing building exteriors that can be integrated with other related technologies (such as BIM or CityGML) and deployed across an entire building stock.

In the following we will summarize from the most relevant articles presented in Table 1, the most relevant applied research in terms of the progress of infrared thermography and LIDAR systems in terms of technical analysis for building energy performance diagnosis and the incorporation of artificial intelligence algorithms. Within each research area that will be presented below, we will discuss the major features that are relevant to building energy loss monitoring, including, key challenges regarding the accessibility and reliability of the information recorded by the two techniques LIDAR and thermal camera.

A review of the main contributions of infrared thermography to the study of the built environment at several scales are presented by the authors in paper 4. From the classification, most of the studies reviewed have been carried out to assess the thermal performance of buildings or to detect building defects using images collected by an infrared camera [4].

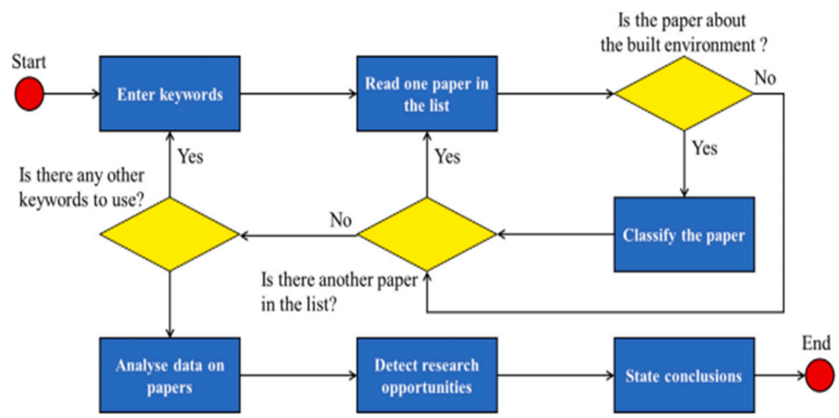

Fig. 3. Workflow used to review papers on infrared thermography for the built environment. [4]

Finally, the authors propose to monitor a city's energy consumption and improve its sustainability that thermal images be integrated into Internet-of-Things and digital twin platforms [4].

Future directions for the use of thermography in buildings are presented in Articles 5 and 6. The authors present the innovation side of thermography in terms of energy efficiency by identifying thermal leaks and insulation deficiencies, contributing to specific retrofit efforts, and thus reducing energy consumption and greenhouse gas emissions [5], [6]. In contrast to the other literature studies, the authors of paper 7 propose a method to improve the accuracy of outdoor temperature measured on buildings with different environmental parameters, such as air humidity, outdoor temperature, and distance to the object. A thermal image quality improvement model based on KMeans and modified generative adversarial network (GAN) structure has been proposed. This method improves the diagnosis of thermal deficiencies in buildings [7].

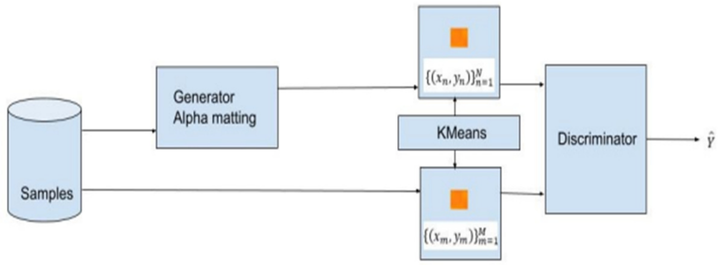

Fig. 4. Schematic representation of an adapted GAN. [7]

The SEMANCO project presented by the authors in Article 9, was developed to convert LIDAR datasets into accurate and consistent urban data to be used in COBie-compliant BIM tools, as well as specific energy-related information fields, to achieve an energy-related ontology (Corrado et al., 2015). This is achieved by creating a formal vocabulary according to the Ontology Web Language specification to assess the energy performance of an urban area [9].

Fig. 5. Developed SEMANTIC tool for Urban Energy Model [9]

3. Discussion

In this research, thermal imaging and LIDAR inspection for building applications are powerful and non-invasive methods for building condition monitoring and diagnosis. Through these methods, heat loss through the building surface is exemplified, in conjunction with heat loss calculation, provides a technical and economical solution to the problem of thermal discomfort in buildings. The different thermal behaviour between defects and undamaged areas allows the detection and thermal characterisation of surface and subsurface defects, which must be considered when maintaining a structure in optimal conditions. Infrared thermography and LIDAR technology are among the most suitable non-destructive techniques to measure these thermal behaviours, represented on temperature maps of the infrastructure analysed by thermal imaging, regardless of the size of the structure. In addition, they are also used for thermal characterization of structures for such important purposes as the energy study of buildings [10].

In the bibliographical studies, an exhaustive analysis is carried out on the most recent and important practical thermographic procedures for infrastructure applications, focusing on the post-procurement stage, due to the lack of an in-depth analysis on the most recent and widely used algorithms. Specifically, the theoretical side of these thermal image processing techniques are described, classifying them according to the corresponding theoretical post-acquisition approach used: qualitative and/or quantitative analysis [11].

4. Conclusions

So, we can conclude that thermography and LIDAR technology are useful methods for monitoring building energy losses because they are non-contact, two-dimensional and three-dimensional and real-time information is obtained to monitor the energy performance of buildings.

In contrast to existing approaches, the open research possibilities presented in this paper enhance the use and manipulation of neighbourhood energy analysis and integration with other visualization tools allows unfamiliar users to access customized and versatile information [9].

In addition, the trend of performance improvement in thermal image processing algorithms and LIDAR technology seems to continue a positive trend for the coming years by including artificial intelligence algorithms.

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