Thesis Evaluation Report

Title: Constructing Semi-Automated Buildings' Energy Loads Model to Retrofit Built Heritage by Using a Data-Driven Model and Computer Vision

Author: **Mgr inż. arch. Hassan Bazazzadeh**

Supervisor: Dr hab. inż. arch. Adam Nadolny, Prof PP

Submitted for: Doctor of Philosophy in Architecture and Urban Planning

Institution: Poznań University of Technology

Year: 2023

Reviewer: Prof. Emanuele Naboni, University of Parma, Royal Danish Academy, UNSW Sydney, Norman Foster Institute, SOS School of Sutainability in Milan

REPORT

This evaluation report focus on the thesis by Mgr inż. arch. Hassan Bazazzadeh, submitted for the Doctor of Philosophy in Architecture and Urban Planning at the Poznań University of Technology. As the reviewer, Prof. Emanuele Naboni, I have undertaken a thorough assessment. The evaluation is structured into distinct sections, each focusing on critical aspects of the thesis.

FOUNDATIONS OF THE THESIS

The title of the thesis, "Constructing semi-automated buildings' energy loads model to retrofit built heritage by using a Data-driven model and computer vision," is highly reflective of its focus and underlying argument, succinctly capturing the essence of the research.

The introduction situates the work in the global challenges of climate change and energy efficiency within Poland's unique context. However, it falls short in offering a overview of the thesis. A more detailed introduction, providing a clear roadmap of the thesis's main arguments, methodologies, and expected findings, would significantly enhance its effectiveness and guide the reader is needed. In scholarly terms, an introduction typically provides an overview of the entire thesis, outlining its main arguments, methodologies, and anticipated findings. This road map is missing.

The problem statement of the thesis robustly identifies the critical challenges in global warming, emphasising the pivotal role of building energy efficiency in addressing this issue. It provides a understanding of the complexities involved in retrofitting existing buildings, especially in Poland's energy landscape and financial constraints. This foundation sets the ground for the thesis goals by highlighting the urgent need for innovative solutions in energy auditing and building retrofitting. It may be advice that to yo align more closely with the thesis goals, the statement could further emphasise the potential for new methodologies and data-driven approaches, creating a smooth transition to the goals of streamlining energy audits, assessing data-driven methods, and proposing surrogate approaches.

Examining the alignment between the goals, research questions, and hypotheses of the thesis reveals both effective and areas for improvement. The first goal of streamlining the energy audit process aligns well with the first cluster of questions about challenges in conducting energy audits. The second goal of evaluating data-driven methods is mirrored in the third research question, which explores how these methods can refine audit processes. But what looks weak in alignment (not in scopes) to me is the third goal of proposing a surrogate data-driven method, that has a less direct connection with the second cluster of questions, which mainly focuses on streamlining existing processes rather than developing entirely new methods.

Consider rewrite the third goal for better alignment, indeed, while there is a strong alignment in some areas, particularly between the first goal and its corresponding questions and hypotheses, there is room for improvement in ensuring that the research questions and hypotheses equally and adequately address all the goals. This could involve modifying the goals to meet exactly what done in the thesis. Also check later if the conclusion meet all of the goals, more comments will follow on that.

METHODOLOGY

The methodology is characterised by its multi-disciplinary approach, combining technological innovation, data analytics, and environmental considerations to address the challenges in energy auditing and building retrofitting. The research introduces a novel approach to estimating energy performance in heritage buildings. This user-friendly approach relies on accessible technologies like smartphones and data-driven algorithms. , the methodology's focus on innovative data collection and analysis techniques, considering climate change impacts and using advanced computational methods, is well-aligned with the research questions.

It provides a robust framework for exploring new avenues in energy auditing, assessing current practices, and proposing effective solutions for existing buildings.

As an examiner of the PhD thesis, my comments on the methodology's coherency and potential improvements would be as follows:

1) A more explicit framework outlining how each part of the process feeds into and influences the others. A clearer workflow roadmap at the beginning would aid in understanding how the various methods collectively address the research questions.
2) The methodology presents diverse techniques, from 3D modeling to big data analytics and machine learning. While , the integration of these methods could be more cohesive. For instance, how the data derived from 3D models and significant data generation specifically feed into and enhance the machine learning models could be made more evident.
3) A more detailed explanation of the interconnectivity between these methods would strengthen the coherency of the methodology. The methodology is technically robust, but it may benefit from a emphasis on the practical application of these methods in real-world scenarios. Addressing how these methods can be feasibly implemented in the field of energy auditing, considering factors like resource limitations and user accessibility, would enhance the practical relevance of the research.
4) The use of advanced data analytics and machine learning is nice, but the methodology could be improved by including a more detailed discussion on model selection, validation, and the handling of potential biases.
5) Including climate change considerations is an important aspect of the research. but more in-depth discussion on selecting climate models and scenarios, ensuring that the assumptions are aligned with current scientific consensus and accurately reflect the complexities of future climate impacts may be needed
6) The methodology involves automation to improve efficiency, perhaps is missing on the user interface and user experience could be beneficial. This is important for ensuring that the automated systems are accessible and usable by practitioners in the energy audit field.
7) discussing its limitations and how they are mitigated would be valuable. Acknowledging potential challenges and describing strategies to overcome them would demonstrate a deeper understanding and rigour in the research approach.

CORE CHAPTERS

In Chapter 3 of the thesis, it is evident that the chaptercontributes to the overarching theme of energy efficiency in residential buildings in Poland. The chapter highlights Poland's deviation from EU energy consumption norms and its significant reliance on coal, underscoring the urgency for policy interventions and energy-efficient upgrades, especially in rural areas. articulating the practical implications of these findings more pronouncedly would provide more straightforward guidance for policy and practice.

Based on the study's findings, this would involve specifying steps for energy efficiency improvements.

Chapter 4 on "Climate Change Consideration" presents a analysis of the effects of climate change on building energy consumption in Poznan, Poland, mainly focusing on the changing demands for heating and cooling. The chapter effectively utilises statistical downscaling methods to project future weather conditions and their impact on energy demands in various building prototypes. It reveals a significant increase in cooling loads and a decrease in heating loads by 2080, highlighting the need for adaptive strategies in building design and energy management. The chapter's strength lies in its detailed methodology and the relevance of its findings to urban planners and policymakers. It underscores the critical need for preemptive strategies to manage increasing cooling demands, aligning with broader environmental sustainability goals. Some may argue that the study's reliance on a single climate model under one emission scenario could be a limitation, suggesting the need for future research using diverse models to ensure a more understanding of the potential impacts of climate change on urban infrastructure.

In reviewing Chapter 5, "Data-driven Methods Application," as part of a methodological section leading to results in a subsequent chapter, the chapter stands out for its technically detailed examination of various machine learning algorithms applied to building energy consumption prediction. The methodological approach is nice for its breadth, covering a spectrum from MLR to advanced techniques like ANNs, SVMs, RF, and XGB. This provides a solid foundation for the methods that will likely be applied and analyzed in the results chapter. The chapter's technical depth in explaining the mechanics of each algorithm is good, offering clear insights into how these methods function and their applicability to different predictive scenarios. The chapter could be enhanced by directly linking the discussed methods to the specific applications and anticipated results in the next chapter. A clearer roadmap on how these algorithms will be operationalized in the study and the criteria for their selection based on the dataset characteristics provide a more direct bridge to the results. Also, a brief discussion on the expected challenges in applying these algorithms and potential strategies for addressing them would be a valuable addition. The chapter is technically robust and provides a overview of applicable machine-learning methods. some crits and forward-looking statements could make the transition to the results even more seamless.

RESULTS

Chapter 6, titled "Results", presents a detailed and examination of the process involved in deploying and fine-tuning machine learning models, focusing on Artificial Neural Networks (ANNs). The chapter successfully integrates various elements of the research, including exploratory data analysis, model deployment, and fine-tuning, and culminates in a practical application through a real-life case study. This approach solidifies the chapter's position as a crucial research segment, effectively linking the theoretical and methodological foundations laid in previous chapters with tangible outcomes. Exploratory Data Analysis (EDA): The EDA is thoroughly conducted, encompassing statistical inferences, inter-variable relationships, and distribution normality.

The depth of analysis in assessing the dataset's characteristics and identifying potential redundancies in features demonstrates a sophisticated approach to handling data, which is essential for the accurate application of machine learning models. Model Deployment and Fine-Tuning: The deployment of various machine learning models, including LightGBM Regressor, Random Forest, and SVM, before focusing on ANN, reflect a systematic approach to model selection. The subsequent fine-tuning of these models, especially ANNs, highlights the attention paid to enhancing model performance, particularly in mitigating overfitting. This process not only demonstrates technical proficiency but also ensures that the models are reliable and generalisable. Real-Life Application and Validation: The chapter's practical application through a case study involving 3D reconstruction and EUI simulation is commendable.

This application serves as a robust validation of the models developed, providing a tangible measure of their efficacy. The comparative analysis showing the performance improvement of the final model over the base model substantiates the practical utility of the research. Integration with Research Goals and Hypotheses: This chapter effectively relates to the research questions and hypotheses outlined in earlier chapters. It addresses the challenges in energy audit processes, explores improvements within traditional methodologies, and leverages data-driven methods and technological advancements.

The results and analyses presented in the chapter contribute significantly to the overarching goals of enhancing energy efficiency and streamlining audit procedures in building retrofitting. Suggestions for Future Research: While the chapter is , there is always scope for further exploration. Future research could delve deeper into the scalability of these models across different building types and locations or explore the integration of additional emerging technologies in the energy auditing process. , Chapter 6 is a well-executed, crucial part of the research that effectively demonstrates the application of advanced machine-learning techniques in energy audits for existing buildings. The chapter’s thorough analysis and practical application significantly contribute to the field and set a strong foundation for future advancements.

CONCLUSIONS

The conclusion is the area that may be improved the most: while the conclusion addresses various aspects related to the research questions, it could benefit from more explicit connections to each question, especially in directly addressing the challenges, domains for improvement, and the development of surrogate methods as posed in the research questions. Here I tried to align research question to the candidate answers:

Research Question 1: *What are the significant challenges and hurdles encountered in conducting energy audits for existing buildings, considering factors such as limited data availability, invasive inspections, financial constraints, complex building systems, and the absence of standardised procedures?* the conclusion does acknowledge some of the challenges in traditional energy audits, such as being time-consuming and costly, it doesn't explicitly mention the factors listed in this research question, such as limited data availability, invasive inspections, financial constraints, and the absence of standardised procedures. To address this research question more explicitly, the conclusion could be

enhanced by discussing how the proposed methodology directly mitigates or overcomes these challenges.

Research Question 2: *In energy audits for existing buildings, what specific domains within the traditional audit process hold potential for improvement and optimization, encompassing aspects such as data collection methodologies, analysis techniques, reporting standards, and the incorporation of real-time monitoring systems?* The conclusion highlights improvements and optimisations achieved through machine learning, LiDAR technology, and smartphone data collection. it could be more explicit in directly connecting these innovations to the domains within the traditional audit process mentioned in the research question, such as data collection methodologies, analysis techniques, reporting standards, and real-time monitoring systems.

Research Question 3: *To enhance the efficacy and efficiency of energy audits for existing buildings, how can data-driven methodologies, leveraging advanced analytics, machine learning algorithms, and modelling techniques, contribute to the refinement and streamlining of the audit process, enabling accurate predictions of energy consumption patterns, identification of energy-saving opportunities, and the customisation of recommendations based on diverse building characteristics?* The conclusion addresses this research question by emphasizing how data-driven methodologies, specifically machine learning (Artificial Neural Networks), contribute to refining and streamlining the audit process. It mentions accurate predictions of energy consumption patterns, which align with the research question. further discussion on the identification of energy-saving opportunities and the customisation of recommendations based on diverse building characteristics would provide more connection

Research Question 4: *By synergistically integrating data-driven techniques with cutting-edge technological advancements, such as remote sensing, Internet of Things (IoT) devices, smart metering, and building energy modelling, how can a surrogate method for energy audits in existing buildings be developed, circumventing the need for invasive inspections and extensive data collection, while still ensuring robust energy performance?* The conclusion effectively highlights the integration of data-driven techniques with technological advancements like LiDAR and smartphone technology. discuss how this integration develops a surrogate method for energy audits and addresses the need to circumvent invasive inspections and extensive data collection while ensuring robust energy performance. Providing a direct link to your question also here please.

FINAL JUDGMENT OF THE REVIEWER

In rendering a final judgment on the thesis presented by Mgr inż. arch. Hassan Bazazzadeh, it is essential to acknowledge the exemplary quality and nature of the research undertaken. This thesis, representing a detailed study at the intersection of sustainable architecture, energy management, and building adaptation, stands as a testament to the academic diligence and technical proficiency of the candidate. Notably, the thesis has a good macro-level structure, effectively linking each section to build upon the last. The clarity in signposting and the seamless connection between paragraphs,

sections, and chapters exemplify the candidate's adeptness in maintaining a consistent narrative flow. The thesis continually reminds the reader of its core purpose and argument without redundancy, maintaining engagement and focus throughout.

While the thesis is comprehensive and well-structured, a slightly more detailed introduction could have provided an even clearer overview of the research. Additionally, enhancing the connection between the research questions and results could further refine the thesis. This, along with a bit more integration of the literature review in the conclusions, would seamlessly augment the depth and context of the study. These suggestions are minor enhancements to a thesis that already stands as a significant academic achievement, reflecting the candidate's expertise and dedication to his field.

The candidate indeed presents a compelling argument for the research methodology, balanced with up-to-date methodological literature. The research design is not only appropriate for the questions posed but also meticulously executed, employing a rich variety of evidence to develop a balanced argument, with some minor improvement made possible as suggested. The candidate demonstrates advanced analytical skills, laying down a clear chain of evidence and maintaining a disciplined discussion throughout.

The methodological approach of the thesis, integrating technological innovation, data analytics, and environmental considerations, is particularly strong. The novel approach to estimating energy performance in buildings, utilizing the computational power of smartphones and machine learning algorithms, showcases the candidate's ability to innovate and adapt to contemporary research needs. This cost-effective solution enhances the accessibility and practicality of energy performance assessments, particularly for buildings with limited geometric data.

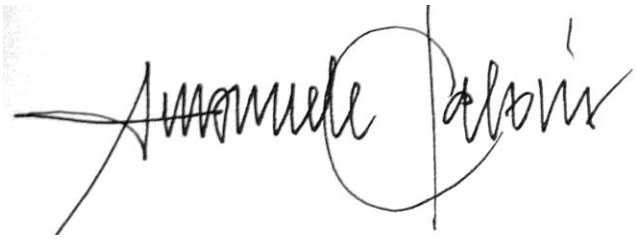
The innovative methodologies introduced in the thesis, balancing traditional architectural sensibilities with advanced technological applications, navigate the complexities of preserving historical heritage in tandem with pursuing sustainability. The interdisciplinary nature of the research, blending academic excellence with practical applicability, sets a high standard for future work in sustainable heritage conservation.

In terms of contribution to knowledge, the thesis is original in its approach and interpretation of findings, occasionally leading to the discovery of new facts. The ability of the candidate to effectively communicate these findings in the professional arena and in an international context further elevates the value of this research.

The societal impact of this research is significant, offering practical insights for a broad range of stakeholders. The work contributes to improving sustainable energy management practices and reducing the environmental impact of buildings, aligning with global efforts to combat climate change.

In conclusion, the thesis by Hassan Bazazzadeh is not just an academic achievement but a significant contribution to the fields of sustainable architecture, energy management, and buildings conservation. Thus, it is with great confidence and respect that I

recommend the thesis for the award of Doctor of Philosophy in Architecture and Urban Planning. The work demonstrates that the research 'apprenticeship' is complete, and the candidate is rightfully admitted to the community of scholars in the discipline. The thesis is a remarkable achievement, and I think it is deserving of high commendation and recognition.



Emanuele Naboni ,

Milan 1st of December 2023