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TESTING STRATEGIES OF CLIMATE CHANGE ADAPTATION OF BUILDINGS: A CONCEPTUAL FRAMEWORK

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Abstract

In light of the pressing need to adapt buildings to future climate change and the scale of the expenditure involved (estimated approximately at PLN 4 trillion), fundamental research and theoretical studies in this domain are crucial. Without the input provided by such research, it is impossible to assist building owners and managers in making informed decisions. Consequently, there is a risk that funds for modernization will not be used to the greatest benefit. The establishment of a theoretical foundation for the efficient and expeditious allocation of resources toward building retrofits is imperative not only for the construction sector but also for society and the economy as a whole.

This paper puts forward a research idea that aims to analyze the impact of climate change-related hazards and constraints (including financial, legal, and organizational factors) on property management activities, with the objective of enhancing the effectiveness of climate change adaptation strategies for buildings. In the subsequent phase of research, an analytical tool is to be developed. This tool will be a comprehensive multi-factor optimization model to simulate the effect of inputs, including opinions of multiple experts, on the selection and sequence of building retrofitting/modernization measures considered for a long/life cycle planning horizon. This paper identifies the objectives and limitations of the model and the tools proposed to achieve the set objectives. It also discusses the benefits that the execution of the planned research can bring to science and society.

Keywords: buildings, climate adaptation, climate change, facility management, maintenance.

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1. Introduction

Virtually all available prediction models point that global climate change will have a profound impact on civilization. The economic and social challenges that result from the accelerated transformation of the environment have already been reflected in international and local policies, and they are becoming apparent to the general public. One of the challenges is the inadequate performance of the existing building stock. Retrofitting of buildings is necessary if the buildings are to become resilient to the effects of the climate change observable today and expected in the future.

In Poland, the estimated value of the building stock is about PLN 7.5 trillion [1]. A considerable proportion of these durable assets, though structurally sound, operational and occupied, have been created according to the standards of the past. They become uneconomical and hardly viable (from the perspective of both the users and society at large) to be maintained without modernization. Therefore, the building owners, occupiers, and managers face urgent questions: what technical measures would best respond to future climatic conditions? Is it possible to think of building modernization and maintenance planning without consideration of future climate change? How to make the optimal use of inevitably scarce funds to make and keep the buildings future-proof?

This paper presets the research idea attempts to answer these questions. A preliminary review of the literature yielded the following thesis: The efficacy of adapting a building to climate change through technical interventions can be quantified. Accordingly, the program of such interventions can be optimized with regard to the actual constraints posed by financial, legal, technological and organizational considerations, as well as the preferences of decision-makers.

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Therefore, the aim of this research concept is to analyze the effect of climate change-related hazards and constraints (such as financial, legal, organizational) specific to property management activities on the effectiveness of climate change adaptation strategy for buildings. This requires constructing an analytical tool - a comprehensive multi-factor optimization model to simulate the effect of inputs, including opinions of multiple experts, on the selection and sequence of building retrofitting/modernization measures considered for a long/life cycle planning horizon. The concept of the model is presented in Figure 1.

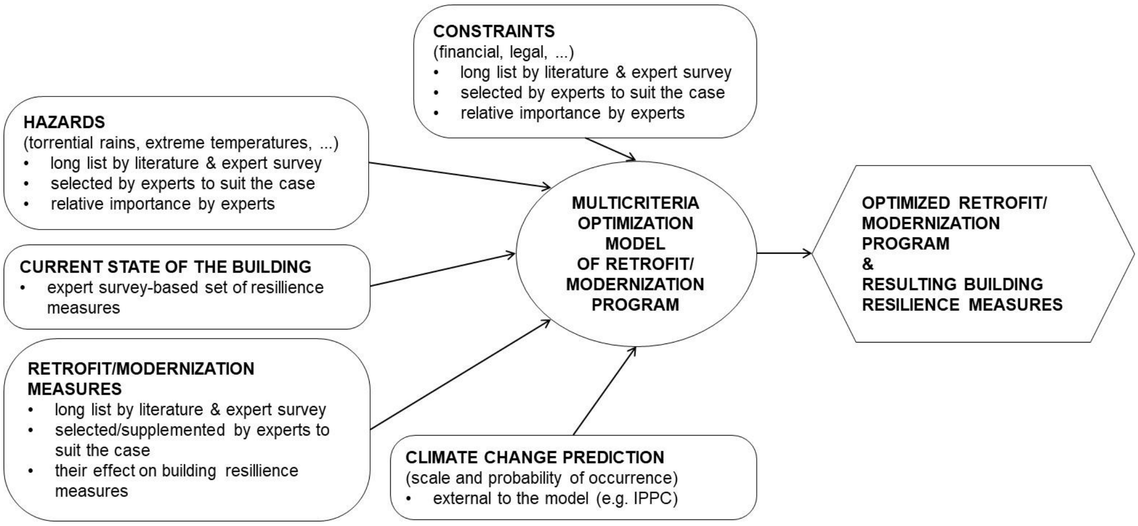

Fig. 1. Concept of the mathematical model

The concept objectives are thus as follows:

- To classify climate-change related hazards and property management constraints and review technical building retrofit measures: the established, the emerging and the prospective ones;
- To select or create the building's climate resilience metrics that can be related to effects of retrofit/modernization activities;
- To develop mathematical methods of group decision-making and metaheuristic reasoning to be applied in the model for testing the efficacy of retrofit measures;
- To develop a mathematical model to help understand the relationship between the climate-change related hazards, facility management constraints, climate change prediction and the effects of retrofit measures; in the future research, findings from these model-based analyzes have a potential to be used to construct a decision-support tool for programming retrofit measures.

2. The state of the art

Considering the recent research on technical intervention to the existing buildings and proposals for new build structures, the authors frequently analyze case studies – apply alternative design solutions to a particular building, group of buildings or a class of buildings in particular locations [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13]. Interestingly, all these works focused on the buildings' energy demand under climate change scenarios. Other aspects, such as increased risk of extreme weather phenomena, e.g. hurricanes [14], seem underrepresented. The scope of analyses of the impact of climate change of buildings ranges from urban [15] to building component levels [16]). There are a few proposals for building design optimization systems (e.g. [17] with three criteria: energy demand for lighting, cooling and occupants' indoor comfort, evaluated over the short, medium and long planning horizon). However, their narrow focus of optimization raises some concern. In general, the authors agreed that the adaptation of the existing assets is the most logical approach [18], [19], [20], [21], but little attention was given to practical constraints of the retrofit decision-making process. Some works were descriptive rather than analytical [19], or presented literature reviews [18], [22].

To sum up, the research on building stock adaptation to climate change is fragmented. Sources that present adaptation strategies tend to have narrowly defined objectives (e.g. reducing energy demand and greenhouse gas emissions) [18], and the most common single-criterion optimization models ignore the fact that improvement of one performance aspect may deteriorate the building's resilience to other factors. Obvious constraints of the decision-making process, such as cost and affordability of the retrofit measures, were often ignored. No work were found to consider the opinions of decision-makers (investors, managers) or building users, and these affect any retrofit strategy to be considered [23]. There was also no clarity on what factors, hazards and constraints should affect the decisions on adapting buildings to climate change. As the existing literature does not propose methodologies to address the problem in a comprehensive manner, so incorporating relevant risk factors associated with climate change and the actual constraints that exist in the decision-making environment, the proposed research is intended to fill this gap.

In general, research gaps were found for which the following remedies were provided:

Gap 1: The most numerous classes of the building stock, the residential buildings, have an estimated service life of 90-120 years [24]. Their design is specific to the period of origin. The performance expectations (among others, on energy performance [25]), are growing in the face of possible energy crises, climatic pressure, and technological progress, but there exist no guidelines how to design future-proof buildings. **Response 1:** The proposed concept focuses on the proactive adaptation of the buildings to future environmental conditions. The idea employs a long-term /life-cycle approach, anticipating potential changes rather than reacting to them.

Gap 2: The cost of adapting the Polish building stock may reach PLN 4 trillion ([1], [26]). The scope and scale of adaptation pose a challenge for the construction industry, research and development organizations, the policymakers and the society who will ultimately bear its costs. There exists no methodology on how to rationally invest in inevitably stepwise modernization in pursuit of targets that are both uncertain and in flux. **Response 2:** This idea addresses the topic that is important for the construction sector, the society, and the state. The concept is to integrate cost considerations and other constraints pertinent in the real estate management process. The research will identify the key factors influencing the adaptation of buildings to future conditions, thereby enabling an effective allocation of financial resources.

Gap 3: There is a wide knowledge gap in terms of factors and constraints affecting the outcomes of building adaptation to climate change. **Response 3:** The proposed research will contribute to the body of knowledge on factors and constraints determining efficacy of climate change adaptation strategies. Given the pioneering nature of the research, its comprehensive character and ambitious scope, it is likely to become a foundation for subsequent researchers working on this topic.

Gap 4: The majority of analyses presented in the literature on the climate change adaptation of buildings are narrowly focused. **Response 4:** The proposed research intends to build a comprehensive, multi-factor model to analyze and optimize the building climate change adaptation levels. The model will be used to conduct research on the impact of factors and constraints on the selection of modernization steps.

Gap 5: There is a lack of knowledge about how decision-makers understand dealing with climate change and what are the constraints they face in planning and implementing building modernization measures (including, but not limited to, costs and funding). **Response 5:** The proposed research intends to survey a broad group of experts. Information they provide, combined with that gained from the literature, is going to be the source of input for the model.

Gap 6: The extant literature on building maintenance planning and building modernization programing neglected the impact of climate change. **Response 6:** The proposed model for assessing the efficacy of retrofit measures in search for optimal solutions is focused on climate change adaptation.

Gap 7: There is a lack of analytical tools to study the impact and relevance of factors and constraints on strategies for adapting buildings to climate change. The extant literature presents few attempts to use optimization tools for retrofit planning to respond to climate change (e.g. Yan et al. [17], but the model's scope was very limited). **Response 7:** The proposed model will capture the decision-making process for building retrofit to address future environmental conditions considering multiple factors and constraints. It is intended to rest upon a state-of-the-art hybrid algorithm (possibly, the Comprehensive Learning Particle Swarm Optimization Algorithm With Local Search) to find suboptimal solutions.

3. Research concept and work plan

In order to fill the research gaps identified, research proposals were made, a diagram of which is shown in Figure 2.

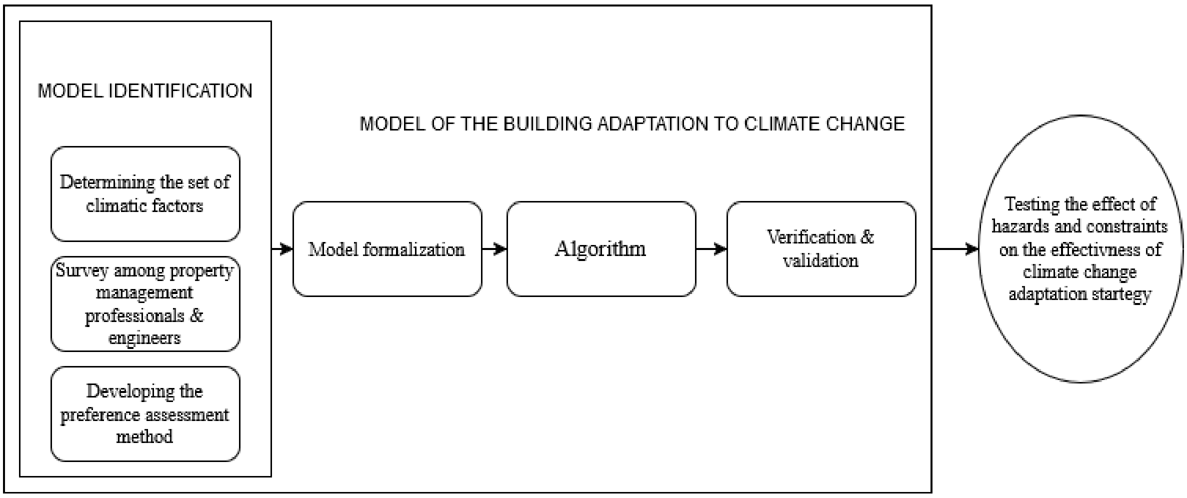

Fig. 2. The research plan flowchart

To achieve the objectives general work plan consists of the following steps:

Step 1 *Determining the set of climatic factors (hazards) under consideration, their impact on buildings, methods of addressing these hazards, and metrics that express resilience of buildings to climate change.* The task is to collate and organize a list of climate-change related hazards affecting buildings (current and predicted scale and frequency of occurrence), analyze the methods of addressing the hazards to reduce their impact on buildings, select/create building performance metrics that capture effects of retrofit measures. This is to identify theories and trends related to both environmental changes and technology development.

Step 2. *Survey among property management experts to specify model components*. A diversified group of practitioners (property managers, architects etc. involved in retrofit projects) will be approached to gain insight on: current practices and constraints in building modernization planning, opinions on the impact of climate change on buildings, perceived importance of particular hazards, measures to address such hazards, metrics for building performance and resilience, and expectations towards the model inputs and outputs to inform their planning practices. Respondents will be approached via professional organizations.

Step 3. *Developing customized tools for multicriteria analysis: a) a method of aggregating opinions of multiple experts, b) constructing an integrated metrics of building resilience to climate change.* A considerable part of the model's input is to be based on judgement and opinions of multiple experts. Part a) is to provide a method for capturing, aggregating and quantifying hesitant evaluations. The author intends to combine the Analytic Network Process (ANP) with the Best Worst Method (BWM) [27] to allow for interactions between the criteria and control the consistency of judgments by reducing the pairwise comparison times. Part b) is to define metrics for how well buildings adapt to climate; they are needed for the model to operate and select retrofit measures that meet expectations. To assess solutions, some existing metrics of distance (Euclidean, Chebyshev, et.), or similarity (Gower measure, cosine) are intended to be used.

Step 4. *Constructing the mathematical model of the building adaptation to climate change.* Using input from Tasks 1-3, a mathematical programming model will be constructed to schedule retrofit measures for a preset planning horizon in a way that improves the building's climate change adaptation metrics. The model's intended principal of operation is as follows: to consider adaptation of a particular building to climate change, a group of experts (e.g. members of the board of a housing cooperative, maintenance coordinator, chief technician) assemble. Supported by the long list of hazards, they brainstorm on the selection of hazards relevant for their case. The experts evaluate the condition of the building and its current performance in respect to these hazards and current conditions. Next, the experts identify a set of possible retrofit solutions, determine their impact on the metrics of the building's climate adaptation to the hazards, and define the time horizon for introducing the measures. They input funding constraints (e.g. renovation fund, retrofit loans). Using this information and the embedded model of climate change (external component, e.g. by the Intergovernmental Panel on Climate Change [28]), the model's optimization algorithm will search for the (sub)optimal schedule (sequence and timing) of retrofit measures that meet constraints of the availability of funds and the logic of the works.

Step 5. *Constructing the optimization system to be embedded in the model*. There is no explicit procedure for selecting the most suitable metaheuristic algorithm [29], [30]. Therefore, the features of the problem under consideration must provide some guidelines. Planning construction activities is restricted by a multitude of constraints, and therefore the hyperspace of potential solutions is large, yet expected to contain a small number of genuinely useful solutions. Therefore, the objective is to identify an algorithm that would efficiently explore a large solution hyperspace and, at the same time, capable of intensive searching the neighborhood of a useful solution once identified. Among algorithms developed in recent years, the Comprehensive Learning Particle Swarm Optimization Algorithm with Local Search [31] seems the most promising candidate. It integrates the exploration capabilities of the CLPSO algorithm with the intensive exploration of selected locations in the solution hyperspace facilitated by Local Search heuristics. The algorithm will be custom built and thus flexible in terms of the selection of constraints and hazards. Apart from the development of the algorithm itself, this step includes verification and validation tests to be conducted using case studies and feedback from ten experts involved in the project.

Step 6. *Testing the impact of hazard selection and constraints on the results.* This analysis will involve multiple case studies based on the characteristics of existing buildings. Its purpose is to provide understanding how the building modernization and maintenance priorities (and allocation of naturally limited resources) should be driven by adaptation to climate change scenarios. The potential scope of this task includes testing: the impact of particular retrofit measures on the building's performance, the impact of funding availability on the strategies, the impact of technologies that are still in the R&D phase, the impact of technology X (not yet known), the limitations imposed by the original design of the building, the impact of the scale of the planning horizon, the way in which decision makers express their preferences (pairwise comparisons, distance from ideal solutions, or simply linguistic assessment), or the way in which building adaptation is defined (the form of the objective function). This analysis is likely to point to further research gaps and identify limitations of the proposed approach, setting out directions of further research, though it may also generate direct recommendations for the practitioners and the retrofit policy makers.

4. Conclusions

The idea aims to assess the impact of climate-related hazards and technological, organizational and financial factors and constraints on the efficacy of building adaptation to climate change. It will yield new insights into the most effective procedures for adapting buildings to maximize their resilience in the long term. The extant literature was found to be fragmentary. This gives the principal investigator grounds to claim that, thus far, no such bold and in-depth research has been attempted. Adoption of a comprehensive multifactorial approach to the topic of adapting the existing built assets to climate change while keeping the analysis on the technical plane of buildings, and not general urban policies or simple multicriteria building certification schemes, would be a total novelty in the discipline of construction. Therefore, this research may become a trend-setter and a reference for future research.

In light of the pressing need to adapt buildings to future climate change and the scale of expenditure on these measures (roughly estimated at PLN 4 trillion), fundamental research and theoretical studies in this domain are essential. In their absence, it is impossible to assist building owners and managers in making informed decisions. Establishing a theoretical foundation for the efficient allocation of resources towards building retrofits is crucial not only for the construction sector, but for the society and economy at large.

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