National University of Science and Technology POLITEHNICA Bucharest

Faculty of Industrial Engineering and Robotics

Doctoral School of Engineering and Management of Technological Systems.

PhD THESIS

Studies, research and contributions on technologies and management of organizations implementing decarbonization in the techno-economic system of construction

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CUPRINS:

ABBREVIATIONS

AI - Artificial Intelligence

BIM - Building Information Modeling

BREEAM - Building Research Establishment Environmental Assessment Method

C.Q. - Technical Quality Control

CDI - Research, Development, Innovation

CDP - Carbon Disclosure Project

CEO - Chief Executive Officer

CESE - European Economic and Social Committee

EAF - Electric Arc Furnace

EUI - Energy Use Intensity

EVA - Economic Value Added

FPC - Factory Production Control

GHG - Greenhouse Gas

HVAC - Heating, Ventilation, Air Conditioning

IMM - Small and Medium Enterprises

IMR - World Resources Institute

IoT - Internet of Things

IRO - Impacts, Risks, and Opportunities

ISCC - International Sustainability and Carbon Certification

ITT - Initial Type Testing of the Product

KPI - Key Performance Indicator

LCA - Life Cycle Assessment

LEED - Leadership in Energy and Environmental Design

MT - Technology Management

NREL - National Renewable Energy Laboratory

nZEB - Nearly Zero-Energy Building

NGO - Non-Governmental Organization

GDP - Gross Domestic Product

ROI - Return on Investment

RTL - Final Work Acceptance

IT - Information Technology

ICT - Information and Communication Technology

EU - European Union

GVA - Gross Value Added

INTRODUCTION

Relevance of the Research Topic

The research topic, "Studies, Research, and Contributions Regarding Technologies and Management in Organizations Implementing Construction Decarbonization in the Techno-Economic System," holds significant relevance in today's global context.

At a time when climate change and the reduction of greenhouse gas emissions are global priorities, the construction sector plays a crucial role in decarbonization efforts. Buildings and infrastructures account for a considerable portion of global CO_2 emissions, and the adoption of innovative technologies and sustainable practices can have a substantial environmental impact.

The construction industry is one of the largest producers of carbon dioxide, and emissions can be reduced through related actions, such as using limestone extracted with renewable energy (hydraulic, wind, etc.) or utilizing recycled concrete materials. Additionally, the burning process of limestone can employ fuels with lower CO_2 emissions. For example, at the cement plant in Medgidia, Romania, a waste incineration line has been introduced, which simultaneously achieves two goals: waste is reused, and less CO_2 is produced compared to using other fuels.

A technique for reducing waste used in concrete production was published in the article: "Ecological Technique for Producing High-Strength Geopolymer Concrete Reinforced with Animal Fibers from the Food Industry Waste," by Lucian Păunescu, Adrian Ioana, Bogdan Valentin Păunescu, in the Romanian Journal of Civil Engineering, Volume 15 (2024), Issue 1, pp. 88-97.

Using reinforced concrete produced from recycled steel and electric arc furnaces is another technology to reduce polluting emissions (Liberty Galați, Romania's largest steel producer, applies this technology).

All companies that have already implemented carbon reduction strategies have received certifications and attestations.

Motivation for Choosing the Research Topic

Energy production and consumption involve multiple aspects of unsustainability, starting with energy sources. Fossil fuel energy production causes air pollution, global warming, and resource depletion. This profoundly affects the legacy for future generations, who will be exposed to polluted air and climate change, potentially reducing access to valuable mineral resources.

My personal interest in ecological and environmental issues was a central element in choosing this topic, reflecting current concerns in this field. This factor motivated me to explore potential solutions for reducing the carbon footprint, bringing added value by integrating them into techno-economic organizations.

This subject is highly topical, so I chose to focus on well-known themes, such as products and processes in the construction industry, where I could make contributions. The knowledge gained during the research and the desire to discover new information motivated me to study the current state of companies in this sector.

The balance between human activity and the environment remains a priority for humanity.

When I started my doctoral studies in the Doctoral School of Engineering and Management of Technological Systems in 2019, no doctoral thesis in Romania addressed the subject of construction decarbonization. During the 2019-2024 study period, only two theses on similar topics were published, both from the University of Cluj-Napoca, according to the Ministry of Education's platform - List of Doctoral Theses (June 2016 - present), with the keywords: carbon emissions.

My personal motivation also stems from a professional interest in contributing to the development of an efficient model for integrating decarbonization technologies in the construction sector, bringing benefits to both the environment and the economy. Investigating and proposing technological and managerial solutions can generate significant added value for companies in this field, increasing their competitiveness in the international market and strengthening their ability to adapt to future challenges.

Thus, my research aims to offer a significant contribution both scientifically and practically, exploring and developing sustainable solutions that can accelerate the decarbonization process in the construction sector.

The doctoral program included preparation, presentation, and defense of exams and scientific reports, in-depth study, and the development of research skills.

Thus, **the purpose of this thesis** was to explore the relationship between polluting emissions and the circular economy in techno-economic organizations, using statistical methods to characterize data, identify correlations between the studied fields, perform principal component analysis, and predict trends.

The circular economy is an approach used to organically promote and enhance sustainability within organizations, companies, and society.

The doctoral thesis is structured into two parts:

The first part (Chapters 1-5) analyzes General Management, Technological Management in developing companies, as well as studies and contributions related to specific technologies and management.

The second part (Chapters 6-11) synthesizes the current knowledge on carbon emission reduction actions, as well as my personal contributions regarding the level of readiness required by companies to reduce their carbon footprint generated by any technological process. This section contains the research results and personal contributions to the specialized literature in the field, as well as the collaboration on a comparative evaluation of the efficiency of construction decarbonization using GeoBlock as an innovative solution for developing low-emission infrastructure for the first Austrotherm Geoblock project in Romania.

The experimental part focuses on two research directions: a preliminary market study to investigate construction decarbonization and research on the development and application of **nZEB** technology, as well as the improvement of the techno-economic organization by implementing a system to reduce carbon emissions using innovative technologies (Chapter 10).

Thus, the chapters are structured as follows:

Chapter 1: Provides a synthetic analysis of the current specialized literature on general management, the importance of knowledge and information management, and their role in strategic technologies, with special emphasis on small and medium-sized enterprises. The main motivation is related to managing the use of new technologies in the most critical areas.

Chapter 2: Highlights the importance of technology in the techno-economic system, which has caused profound economic and social changes. Issues related to sustainability, energy security, and climate change have gained particular significance, prompting a global reassessment of the concepts and responsibilities associated with systematization, development, and economic innovation. New functions have been needed to ensure efficiency in technological innovation systems, offering services and generating new business ideas that allow companies to grow.

Chapter 3: Describes the expansion of knowledge that builds the new economy or technology-based economy, leading to the emergence of a new type of management—knowledge-based management—while traditional management has been substantially revised, relying increasingly on technology.

Chapter 4: Describes the identification and resolution of key social issues for local, regional, and national development. These aim to increase competitiveness and creativity, develop organizational culture in the systems of the economy, public administration, education, and research. All these are objectives for a partnership focused on development, innovation, and improving the quality of industrial infrastructure structures in techno-economic organizations.

It presents action directions for economic-financial analysis. The economic study of a phenomenon or process involves researching it from the perspective of material, human, and financial resource consumption, as well as highlighting efforts and resulting effects in the form of efficient social values.

Current management practices show that large companies have an internal control and analysis department responsible for conducting economic surveys. In small companies, economic analysis is carried out by each functional department based on specific responsibilities. The economic-financial control and analysis department plays a role in preparing diagnostic reports, identifying problems when company dysfunctions occur, and analyzing balance sheets for presentation at board meetings.

Chapter 5: Presents challenges in asset management, which involve essential methods and technological processes for the long-term efficient operation of a company. Currently, two main approaches to infrastructure management stand out, opposite to each other: process management and functional management.

The process-oriented approach is a management method that considers the company not as a sum of departments but as a set of business processes. To implement process-oriented management in a company, it is essential to understand what types of business processes exist and how their efficiency is evaluated. Thus, the company must formalize decisions, establish efficiency indicators, and define process management procedures.

Chapter 6: This section addresses contributions related to the level of readiness required by companies to reduce the carbon footprint associated with technological processes, as well as a comparative analysis of the efficiency of traditional materials versus new construction materials, such as GeoBlock, used as filler material. These aspects are detailed in the second part of the thesis, along with proposed research directions and the final objective I aim to achieve.

Chapters 7-11: Provide information on the objectives, proposed targets, and research methodology of the doctoral thesis. Additionally, the materials, methods, and equipment necessary for both development and characterization are detailed. Information is presented on the methods and processes used for developing these technologies, highlighting the most relevant results obtained in the field. Maintaining industrial infrastructure sustainability by reducing carbon intensity, achieved by lowering greenhouse gas emissions produced by burning fossil fuels, is called "decarbonization."

With technological advances, there is an opportunity to reduce these emissions by using renewable energy sources, which involves reducing CO2 production per unit of electricity generated, as well as by implementing various strategies. Sustainability certifications are presented, which can be a major asset for construction companies.

Buildings are a significant source of greenhouse gas emissions due to energy consumption, construction materials, and other factors. The goal of decarbonization is to make buildings more durable and environmentally friendly, and the nZEB concept (nearly Zero Energy Building) has become mandatory in construction, meaning buildings with very high energy performance.

Cutting-edge technologies could offer significant opportunities for progress. Various studies have shown that these technologies are essential for the fundamental changes needed to achieve global climate goals. Among them are digital twins, **Internet of Things** (IoT) sensors, and **artificial intelligence** (AI)-assisted diagnostics for monitoring operations.

The thesis aims to analyze **the techno-economic system**, optimize decisions, and the strategic policies adopted by the company with the help of economic tools. The company must develop its own stimulator, which represents the riskiest method, with a low success rate due to the persistence that is often lost along the way but with great potential for long-term evolution.

In practice, the most appropriate management strategy for improving techno-economic organizations is **risk management** implementation. By analyzing risks, the number and severity of failures can be estimated. The **cost-benefit** method is used to assess the economic feasibility of decarbonization measures.

Decarbonization strategies are periodically evaluated based on quantitative and qualitative criteria, which provide essential information on the effectiveness and necessary adjustments for reducing carbon emissions in construction. These data can guide and inform decisions regarding technological innovation.

Thus, the novelty and originality of the doctoral thesis lie in synthesizing applicable information in the engineering and management of technological systems. Many issues detected in recent decades still pose challenges to be solved.

The thesis concludes with a list of works published in the field of the thesis and acquired certificates, as well as bibliographical references.

PART I. CURRENT STATE OF GENERAL MANAGEMENT, TECHNOLOGICAL MANAGEMENT IN DEVELOPING COMPANIES, AS WELL AS STUDIES AND CONTRIBUTIONS RELATED TO SPECIFIC TECHNOLOGIES AND MANAGEMENT

CHAPTER 1. GENERAL MANAGEMENT. TECHNOLOGY MANAGEMENT IN DEVELOPING COMPANIES

Management involves the ability to leverage the organization's core competencies, and outsourcing technological services can be an effective solution for developing countries, allowing access to new technologies and resource optimization by focusing on core activities.

Outsourcing, through the transfer of operations to external providers, offers companies the opportunity to access missing expertise and make strategic decisions that impact human resources and competitive advantage. Entrepreneurial management of SMEs, essential for economic development and job creation, is based on creativity, flexibility, and the use of knowledge as the primary resource, becoming the main driver of the modern economy and innovation in cutting-edge fields.

Entrepreneurial management focuses on the relationship between the entrepreneur and management, aiming to improve the efficiency and effectiveness of decisions and actions, especially in small companies, where the entrepreneur's role is crucial for identifying and exploiting business opportunities. It combines the fundamentals of management with the specifics and dynamics of entrepreneurship.

Entrepreneurial-managerial relationships are characterized by increased involvement of the entrepreneur in management processes, emphasizing risk, innovation, and change. The success of information technology depends not only on massive investments but also on its efficient use and proper management. Many companies have been disappointed with the results of their IT investments, not because of the technologies themselves, but due to a lack of proper management in their use, especially in their efficient integration at the employee and workplace level, representing a key internal challenge.

The process of adapting to the information society involves several stages, including the acquisition, implementation, development, and use of information technology, with the final stage representing an internal challenge for the company—perhaps the most crucial in this process. Figure 1.1 presents **the stages of the IT integration process**.

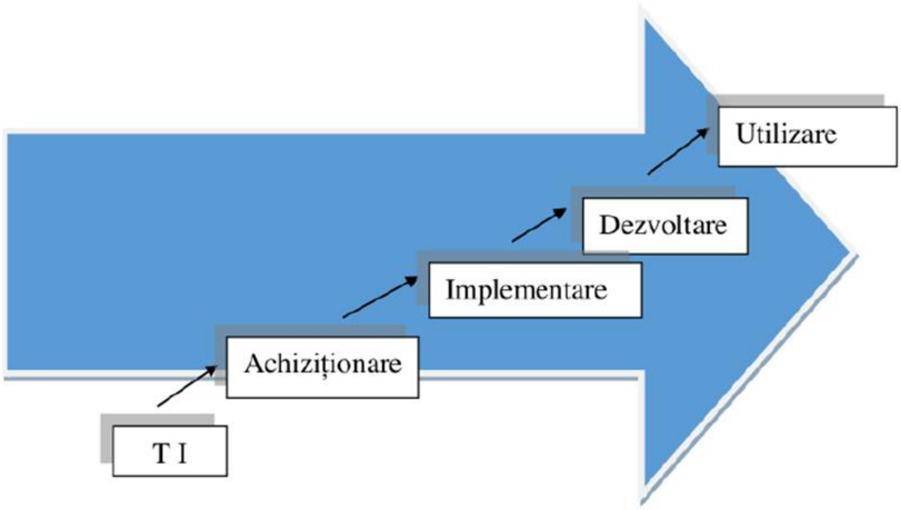

Figure 1.1 The stages of the IT integration process

The success of implementing information technology depends not only on technical characteristics but also on how employees interact with it. Managers must pay attention to employee training and their adaptation to change in order to achieve optimal organizational performance.

Technological management aims to develop and leverage technological capabilities to obtain a sustainable competitive advantage, involving rigorous processes of planning, selection, and implementation of technologies based on the organizational strategy. It is a key element in coordinating resources, impacting all dimensions of management, and being essential for the success of companies in the modern industrial environment.

CHAPTER 2. THE IMPORTANCE OF TECHNOLOGY IN THE TECHNICAL-ECONOMIC SYSTEM

Technology is recognized as a key factor in stimulating economic growth and competitiveness, and industrial and technological innovation parks play an essential role in this process. Technology parks, such as the one developed by the Polytechnic University of Bucharest, integrate academic, economic, and social institutions to encourage innovation, while the European Union and the international community support them as catalysts for innovative and competitive economies.

Current economic development places a greater emphasis on technology, making collaborations between the public and private sectors essential. Implementing structured management and collaboration among academia, businesses, and NGOs is necessary to stimulate innovation. It is important to align incentives for research with the private sector, and technology parks must offer updated services to support collaboration and technology transfer. At the same time, critical infrastructures, while vital for society, can have negative environmental effects, such as mercury emissions from coal-based energy.

Chapter 2 highlights the importance of adopting advanced technology in infrastructure, emphasizing the role of managers and decision-makers in motivating employees to maintain service quality and minimize the negative impact of technology. Research- and innovation-oriented companies must encourage employees to explore new technological applications. Managing critical infrastructure is also essential, as it can affect nearby communities. For instance, the expansion of a power plant, which initially generated economic benefits, may start causing dissatisfaction due to pollution.

Collaboration with the community and its involvement in decision-making are crucial for maintaining positive relationships. Communication tools and questionnaires are useful for understanding public concerns. Technology management strategies must be adapted based on the lifecycle stage of technologies, and ultimately, older technologies will be replaced by more advanced ones.

Technology can be classified into three main aspects: process technology, product technology, and information and communication technology. Each of these areas involves specific operations that contribute to the creation and delivery of goods or services. Information and communication technology facilitates data storage and transmission through the integration of computing and telecommunications systems.

Expanding infrastructure addresses community needs by generating more employees and customers and encourages the use of alternative transportation through policies such as bike facilities and parking for hybrid vehicles. Maintaining sustainability in this process is crucial, and equity in sustainability decisions must be prioritized to benefit all neighboring communities.

CHAPTER 3. SPECIFIC CHARACTERISTICS OF MANAGEMENT. MAIN ELEMENTS AND FACTORS AFFECTING MANAGEMENT

Technological advancements and the upskilling of human resources improve management efficiency, enabling companies to adopt innovative strategies and utilize advanced technologies, while government interventions support economic development. However, financial instability, hyper-competition, and challenges in raw material supply present significant risks to effective management within companies.

The global economic crisis of 2008-2010 generated financial and social instability, affecting organizations worldwide and highlighting the need to establish ethical norms in management, such as honesty and accountability. In this context, the Ringi management method from Japan promotes achieving consensus through collaboration and effective communication, facilitating decision-making within companies and enhancing flexibility in the face of major changes.

Diversity within organizations brings both benefits and drawbacks, such as the costs of multiculturalism and difficulties in achieving consensus, which can amplify internal complexity. Although 84% of employees report being satisfied with their jobs, their disengagement stems from a lack of development opportunities, the company's reputation, and the leaders' attitudes, underscoring the need for more efficient management based on scientific principles to improve organizational performance.

CHAPTER 4. STUDIES AND RESEARCH ON QUALITY IMPROVEMENT. CONTRIBUTIONS REGARDING TECHNOLOGIES AND THE SPECIFIC MANAGEMENT OF INDUSTRIAL INFRASTRUCTURAL STRUCTURES

4.1. Construction – the Main Field of Activity

Improving quality in construction can be achieved through the application of advanced technologies, the protection of historic buildings, minimizing environmental impact, industrializing the construction process, and designing energy-efficient buildings, while also fostering innovation and developing technical solutions for the resilience of structures against disasters and extreme climate changes. These measures contribute to cost reduction, enhance the lifespan of buildings, and increase the competitiveness of the national economy.

4.2. Improving the Quality of Industrial Infrastructure Structures

Enhancing quality relies on collaboration in developing technologies and innovative solutions for complex issues, promoting technological competence and knowledge transfer. The objectives of a development partnership include supporting scientific research, conserving biodiversity, and optimizing public health, all in accordance with the principles of sustainable development. These initiatives are essential for increasing both economic and social competitiveness, as outlined in the smart specialization strategies promoted by the European Union.

The regional economic structure is diversified to maximize competitive potential by identifying areas of specialization for investment, integrating scientific research outcomes into the business environment. Management initiatives are based on various tools tailored to national particularities, redefining comparative advantages and improving the international competitiveness of firms, especially in the export sector.

4.3. Directions for Action in Quality Improvement

The directions emphasize essential initiatives for improving the research, development, and innovation system in Romania, including the creation of products and technologies, the development of innovation infrastructure, the accreditation of testing laboratories, and the importance of smart specialization, all aimed at supporting economic competitiveness and integrating research results into the business environment.

4.4. Types of Strategies to Encourage Progress in the Construction Sector

To stimulate change in the construction field, various international mechanisms are employed, including financial incentives, government regulations, research and development initiatives, and public-private partnerships, all aimed at promoting sustainable technologies and enhancing efficiency. Additionally, there is an emphasis on increasing research and development capacity by attracting researchers, evaluating their performance, and strengthening collaboration with the international scientific community.

4.5. Economic and Financial Aspects Specific to Industrial Infrastructure Structures

The activity of companies in the transition to a market economy occurs within a dynamic environment where decision-making efficiency depends on both understanding market demands and optimally utilizing internal resources. Economic and financial analysis plays a crucial role in underpinning strategic decisions, evaluating financial performance, and identifying risks and opportunities, thus contributing to the development and prosperity of the company.

4.6. Methods of Economic and Financial Analysis

Economic and financial analysis is divided into two types: qualitative analysis, which focuses on understanding phenomena and causal relationships, and quantitative analysis, which centers on quantifying influences through numerical data. The analysis process involves identifying and evaluating relevant factors, establishing cause-and-effect relationships, formulating conclusions, and implementing necessary measures for resource optimization, encompassing both an internal dimension carried out by company analysts and an external dimension performed by professionals such as independent auditors.

CAP. 5. RESEARCH ON ENTREPRENEURIAL MANAGEMENT IN CONSTRUCTION

Entrepreneurial management (EM) focuses on the managerial processes and relationships within small firms, emphasizing the importance of interpreting legislation and developing innovative methods for decision-making efficiency. In the context of globalization and smart technologies, a process-based approach becomes essential for assessing and managing effectiveness, especially in the face of emerging risks affecting critical infrastructure.

The protection of infrastructure varies between companies, but there are common elements in addressing challenges related to reliability and functionality, particularly concerning critical infrastructure. The assessment of the deterioration of these assets is based on various criteria, including region, size, and type of threats, and the study of the reliability of technological systems relies on statistical analyses and technical measures, considering the interconnection and management of human and intangible resources.

Although the concept of resource management is widely used concerning financial resources and tools, these resources also include human, informational, and intangible resources, as illustrated in Figure 5.1 below:

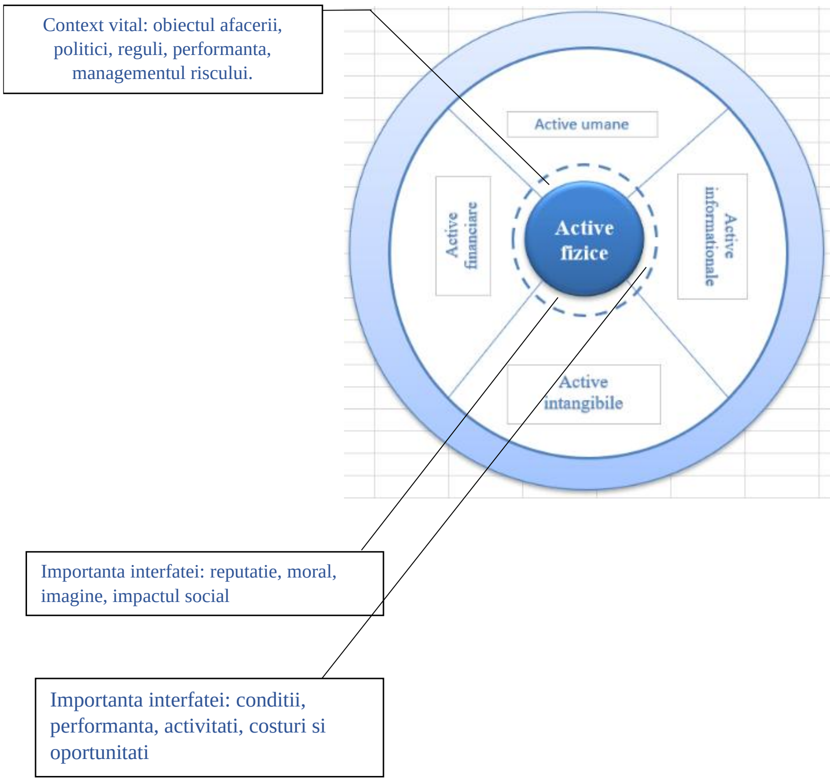

Figure 5.1. Distribution of assets with financial instruments

Engineering is essential for asset management, ensuring the alignment of activities with the organizational strategic plan, according to the ISO 55 002:2014 standard, which provides principles to support resource management and achieve organizational objectives. Companies must establish effective planning and control processes, assess the impact of changes on assets, and manage risks while promoting an organizational culture that supports continuous performance improvement.

Infrastructure asset management involves significant challenges, such as aging infrastructure, funding constraints, technological obsolescence, and cybersecurity risks, which require proactive approaches and integrated strategies to ensure performance, sustainability, and optimal value. Companies need to collect and analyze information about assets to effectively define their mission and objectives while managing external challenges such as climate change and evolving regulations.

CONCLUSIONS PART I. CURRENT STATUS OF GENERAL MANAGEMENT, TECHNOLOGICAL MANAGEMENT IN DEVELOPING COMPANIES, AND STUDIES AND CONTRIBUTIONS RELATED TO TECHNOLOGIES AND SPECIFIC MANAGEMENT

My contributions emphasize the essential role of general and technological management in developing companies, demonstrating how the implementation of innovative strategies, advanced technologies, and sustainable practices can enhance the competitiveness and efficiency of organizations. My research also highlights the importance of decarbonizing construction through an integrated approach that combines technological progress, responsible management, and a commitment to environmental protection, contributing to the creation of a green and resilient economy.

PART II. CONTRIBUTIONS REGARDING THE LEVEL OF PREPARATION REQUIRED BY COMPANIES TO REDUCE THE CARBON FOOTPRINT GENERATED BY ANY TECHNOLOGICAL PROCESS

CHAPTER 6. RESEARCH DIRECTIONS, GENERAL OBJECTIVES OF THE THESIS, AND RESEARCH METHODOLOGY REGARDING THE TECHNOLOGIES AND MANAGEMENT OF ORGANIZATIONS IMPLEMENTING DECARBONIZATION IN THE TECHNICO-ECONOMIC SYSTEM OF CONSTRUCTION

6.1. Synthesis of Factors That Disadvantage the Current Development Stage of Organizations

Studies on Management and Sustainability in Business Development highlight disadvantages such as the lack of expertise in decarbonization, high implementation costs, limited access to financing, insufficiently developed infrastructure, and inadequate regulations, which complicate the adoption of green technologies. In response to these challenges, I propose research on the preparation of companies for reducing their carbon footprint and a comparative analysis of traditional building materials versus innovations, including a cost-benefit assessment.

6.2. Research Directions in the Second Part of the Thesis

The adoption of sustainable solutions in construction, such as implementing energy efficiency technologies, using eco-friendly materials, integrating renewable energy sources, advanced recycling, and developing smart buildings, is essential for improving the technological management of companies and advancing towards a low-carbon economy, thus contributing to the decarbonization of the construction sector. Collaboration with a company has been important in supporting these initiatives and facilitating research in the field.

6.3. Objectives of the Study

The study focused on assessing the carbon footprint and CO_2 emissions in construction processes by analyzing emission sources, eco-friendly materials, innovative technological efficiency, and environmental impact, aiming to develop a detailed plan for implementing decarbonization within a company, which will lead to improved energy efficiency and reduced operational costs, thus aligning with global sustainability objectives.

6.4. Research Methodology

The research proposes a detailed analysis of the implementation of decarbonization in construction through qualitative and quantitative methods, including case studies, surveys, and data analyses, aiming to identify effective and sustainable methods that can be replicated in various organizations within the field, highlighting the importance of collaboration between research and industry.

CHAPTER 7. MAINTAINING THE SUSTAINABILITY OF INDUSTRIAL INFRASTRUCTURE THROUGH THE APPLICATION OF INNOVATIVE THERMAL INSULATION TECHNOLOGIES

Decarbonization is the process of reducing greenhouse gas emissions from fossil fuel combustion, aiming to diminish CO_2 emissions generated by transportation and energy production through methods that utilize sustainable materials, renewable energy sources, and smart technologies in construction to support the global sustainability objectives established by the Paris Agreement.

Decarbonization standards for buildings, as defined by the World Resources Institute, involve prioritizing energy efficiency, utilizing renewable energy sources, and assessing operational carbon emissions, which are essential for the development of sustainable cities by setting clear sustainability objectives and integrating them into organizational strategy.

In new constructions, the simultaneous assessment of operational and embodied carbon emissions is crucial to avoid inaccurate estimates of environmental impact, and the choice of suitable materials and technologies, such as foamed polymers and efficient hardware, can significantly contribute to reducing the carbon footprint throughout the building's entire life cycle.

In 2024, global sustainability trends highlight an increasing necessity for decarbonization, surpassing current building certification standards through the application of rigorous accreditation tests for materials, in line with the Green Deal and Fit for 55 regulations, to significantly reduce greenhouse gas emissions by 2030.

Decarbonization is becoming a global priority in 2024, with an emphasis on energy efficiency in construction, promoting the use of optimized thermal insulation and advanced HVAC systems. Sustainability certification is gaining popularity due to the growing demand for green buildings, thus contributing to the reduction of carbon emissions and improving environmental conditions.

National and international building certifications, such as ISCC, BREEAM, LEED, WELL, VERDE, and DGNB, promote sustainability by evaluating and recognizing compliance with ecological, social, and economic standards, significantly impacting the reduction of carbon emissions in the construction sector, which is responsible for a considerable share of global CO2 emissions.

CHAPTER 8. PRELIMINARY STUDY TO RESEARCH DECARBONIZATION OF BUILDINGS IN THE PROCESS OF CONSTRUCTING NEARLY ZERO ENERGY BUILDINGS (nZEB)

The preliminary study for researching decarbonization in construction involved collecting essential information, including an analysis of existing literature, assessing current carbon emissions, and utilizing production and electrification technologies, particularly in the concrete and steel industries, to reduce environmental impact and transform buildings into more sustainable structures.

The concept of Nearly Zero-Energy Buildings (nZEB) imposes strict regulations in construction, aimed at ensuring very high energy performance, where the energy required for operation is minimized and largely covered by local renewable sources, thus promoting sustainability and reducing carbon dioxide emissions.

nZEB = Nearly Zero-Energy Building

nZEB (nearly Zero Energy Building) is a mandatory concept in construction, referring to buildings with very high energy performance.

The operations required throughout all life stages of an nZEB, from design and construction to use, must be carried out in accordance with the energy performance requirements set by standards, aimed at optimizing energy efficiency, reducing environmental impact, and enhancing user comfort.

Digital planning through BIM methodology allows for an integrated approach to information management and efficient collaboration between architects and engineers in the authorization process for nZEB construction, facilitating quick access to essential details and reducing risks associated with the implementation of new technologies.

Specific actions in the nZEB construction process influence costs, highlighting significant savings compared to traditional options, and underline the importance of integrating suppliers in the initial stages of design to ensure thermal comfort and maximize the economic viability of the building.

The operationalization phase of equipment and systems for net-zero emissions buildings is crucial to ensure optimal functionality and reduced operating costs, involving rigorous checks, quality control, and technical documentation, culminating in the final acceptance of the works by the beneficiary.

The nZEB compliance report contains a detailed description of the objective, verification of energy performance requirement fulfillment, documentation for calculating energy consumption and CO2 emissions, as well as general data regarding location, climate region, usage regime, and the importance of the building.

Carbon emission reduction technology plays a crucial role for modern, lightweight materials with low carbon emissions. Transitioning to cleaner fuels represents the most impactful emission reduction strategy in the industry.

Reducing carbon emissions requires adopting modern technologies, such as Direct Reduced Iron (DRI) and the use of green hydrogen as an alternative to fossil fuels, while advancements in energy efficiency and smart material design are essential to tackle challenges in the steel and cement sectors to achieve climate goals.

The development of interconnected and "smart" technologies in steel and cement production, including digital twins and IoT sensors, promises to improve energy efficiency and material usage but requires significant investments and slow progress, while innovations such as green hydrogen and carbon capture are essential for achieving global climate objectives, highlighted by an increasing number of patents in this field.

The effectiveness of decarbonization in construction is assessed through life cycle analysis and the mitigation of hard-to-eliminate emissions, depending on the accuracy of assessments and the results of offset projects, influenced by factors such as project scale, subsidies, technology maturity, and holistic approaches that combine multiple innovative strategies.

Comparisons of two buildings to evaluate construction performance show that, although two 100 sqm buildings with 4 tenants and a height of one story appear similar, the one constructed according to nZEB regulations after 2020, equipped with photovoltaic panels and heat pumps, emits significantly less carbon compared to the one equipped with a gas boiler, thus highlighting the efficiency of the former.

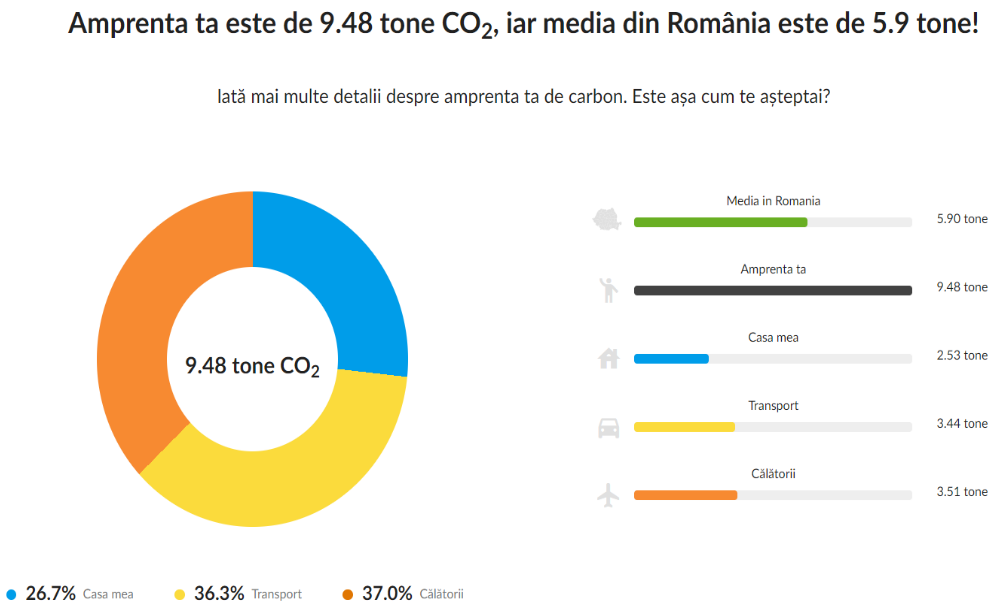

Figure 8.1. Carbon footprint measurements for an old building, constructed before 2020, with an area of 100 sqm, without insulation, in Bucharest

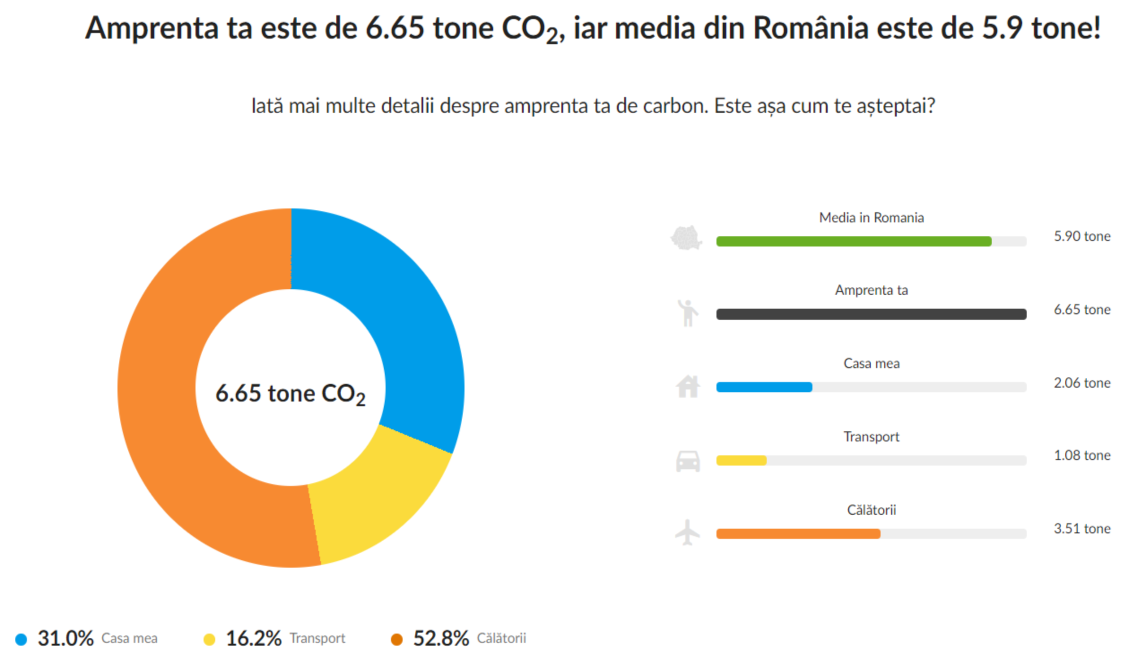

Figure 8.2. Carbon footprint measurements for a new building, constructed after 2020, with an area of 100 sqm, featuring insulation and heat pumps, in Bucharest.

*Measurements were taken using the “Your Carbon Footprint Reduction Calculator, provided by ENGIE.”

Evaluations of embodied carbon, life cycle analysis, energy performance matrix, integration of renewable energy, improvements in operational efficiency, and cost-benefit analysis are essential methods for quantifying carbon emissions and the effectiveness of decarbonization measures in construction. They help identify the most effective approaches for reducing emissions and optimizing long-term costs.

We examined case studies and best practices from similar construction projects to identify successful decarbonization strategies, comparing industry leaders to set ambitious goals, analyzing the impact of each phase on emissions, and using a techno-economic model that considers social, economic, and environmental variables. This highlights the advantages and disadvantages of district heating through decarbonization, which can provide affordable heating and jobs but also presents challenges related to costs and implementation, all underscoring the need for efficient regional planning in the transition to low-carbon buildings.

It is desired that accelerated and systematic decarbonization strategies become essential for the world’s ambitious cities, and an objective assessment of sustainability will be necessary, providing relevant information about environmental, social, and governance impacts, risks, and opportunities.

CHAPTER 9. IMPROVING THE TECHNICAL-ECONOMIC ORGANIZATION THROUGH THE IMPLEMENTATION OF A CARBON EMISSION REDUCTION SYSTEM SIMULATING A CARBON MANAGEMENT PLATFORM

Within organizations, decision-making is a crucial managerial issue, where all decisions are economic. This thesis analyzes the optimization of these decisions through economic tools, suggesting that developing a "stimulator" for the company, although risky can lead to significant long-term results by sequentially addressing methods and adapting to the specific micro and macro environments.

In cost-benefit analysis, managers need to be aware of planned revenues and costs, evaluating at least three scenarios (optimistic, realistic, pessimistic). The optimistic perspective focuses on energy performance that minimizes expenses over the building's entire operational life, considering investments in energy efficiency and their impact on costs and carbon emissions—all of which are crucial in managing budget constraints that may arise during the project.

Maintenance management in the modern industrial environment is essential for extending equipment lifespan, preventing unplanned downtime, and increasing overall safety. This involves analyzing historical data and real-time monitoring of assets, using strategies such as proactive maintenance and reliability-centered maintenance. Risk management helps identify and address issues to optimize organizational efficiency.

An economy with a reduced carbon footprint relies on low greenhouse gas-emission energy sources, and carbon pricing is an effective strategy for encouraging pollution reduction. At the same time, the flexibility of techno-economic systems, establishing clear sustainability objectives, and integrating sustainability into strategic planning contribute to the long-term success of companies by engaging employees and promoting innovation in sustainable technologies.

Cost-benefit analysis is essential for assessing the feasibility of decarbonization measures, learning from previous case studies helps identify best practices and possible obstacles, while collaboration with research institutions and risk assessment contribute to developing effective strategies. Given that buildings generate 41% of global CO_2 emissions, construction companies must adopt a sustainable approach that includes the circular economy, financial incentives for sustainability, and educating customers—all with the potential to improve the technical-economic organization and provide long-term economic benefits.

Reducing emissions within a company requires a detailed analysis of various aspects of the business, including defining key performance indicators (KPIs) aligned with the company's objectives, assessing the baseline of current performance, setting realistic improvement goals, calculating energy efficiency and return on investment (ROI), as well as analyzing economic value added (EVA). All these contribute not only to sustainability and operational efficiency but also to enhancing the company's reputation, while calculating the carbon footprint helps protect the climate by avoiding emissions at the source.

Carbon management platforms are essential for companies wishing to monitor, report, and reduce carbon emissions, combining advanced technologies for data collection, analysis, and reporting.

They allow real-time monitoring of emissions using IoT sensors, assessing the environmental impact of products, generating reports compliant with international standards, and developing action plans for reducing emissions, such as energy efficiency improvements and the use of renewable energies.

Examples of platforms include Enablon, Carbon Trust, Simble, and Measurabl, each demonstrating significant results in emission reductions, such as the Edge Amsterdam project, which achieved a 70% reduction in CO2 emissions, and the Bullitt Center in Seattle, which reached net zero energy consumption, demonstrating the positive impact of these tools on organizational sustainability and the transition to a low-emission economy.

To assess the carbon emissions of a building, it is essential to collect accurate data on energy consumption, such as electricity and gas bills, vehicle mileage, fuel consumption, and water use.

This process may include methods such as energy and carbon audits, monitoring energy consumption through specific equipment, assessing building materials, and conducting life cycle analysis, which provides a detailed picture of environmental impact throughout the entire life cycle. It is also useful to rely on available public data to understand emission trends in the construction sector.

After collecting this data, it must be converted into CO2e emissions using standardized conversion factors that reflect the impact of each type of emission on climate change.

To obtain the total carbon footprint, all emissions converted to CO2 are summed, and it is essential to report and monitor these results over time to assess progress and identify opportunities for emission reductions.

However, since calculating the carbon footprint can be complex and depends on the specific context and methods used, it is often helpful to consult experts or use specialized tools to ensure these calculations are accurate and comprehensive.

To combat climate change, the maximum amount of CO2 that a person can generate in a year is 0.600 tons, and improving the technical-economic organization through energy efficiency management and monitoring energy consumption at the building level can bring long-term benefits, such as reducing energy consumption and costs by 10-20% in the short term, savings of up to 35% with minimal investments, and by implementing modern technologies, savings of 45-65% with a payback period of 5-6 years.

CHAPTER 10. COMPARATIVE EVALUATION OF THE DECARBONIZATION EFFICIENCY OF CONSTRUCTION. GEOBLOCKS AS AN INNOVATIVE SOLUTION FOR DEVELOPING LOW-EMISSION INFRASTRUCTURE FOR THE FIRST AUSTROTHERM GEOBLOCK® PROJECT IN ROMANIA

Decarbonization is essential for combating climate change and involves advanced technologies, appropriate policies, and behavioral changes.

An example of progress in Romania is the introduction by Austrotherm of GeoBlock expanded polystyrene blocks, an innovative material used in geotechnical engineering that offers significant advantages in infrastructure projects, especially in improving soft and compressible soils.

GeoBlock, or expanded polystyrene (EPS geofoam), is a very lightweight geosynthetic material with a closed-cell structure, used in geotechnical engineering due to its high strength relative to its low density. It is produced by expanding polystyrene using a blowing agent, such as pentane, resulting in a material with excellent thermal insulation and buoyancy properties. GeoBlock is sustainable and can contain additives to enhance its mechanical, water, or fire resistance, as well as to reduce its carbon footprint.

This material is used in a variety of applications, such as lightweight fills for support structures, embankments over tunnels or underground networks, slope stabilization, and the construction and expansion of embankments for highways and bridge ramps. Due to its flexibility and strength, GeoBlock helps stabilize soils and extend the lifespan of infrastructures.

The first project in Romania to use Austrotherm GeoBlock was carried out in 2023, involving the construction of a roadway ramp over a municipal pipeline within the A0 Highway, segment Jilava. The project location is presented in Figure 10.1.

My role in this project was to calculate the carbon footprint in comparison between two construction methods and to conduct a cost-benefit analysis, highlighting the technical-economic advantages and disadvantages regarding sustainability through decarbonization.

Figure 10.1. Location of the roadway ramp in relation to the municipal pipeline and the positioning of the Pumping Station relative to the A0 Highway; the dotted white line indicates the pipeline located beneath the embankment, surfacing a few meters further on

Initially, the project proposed a traditional construction solution for the roadway ramp, without considering alternatives. However, during the works, water infiltrations were discovered, necessitating a reevaluation of the initial solution.

The National Company for Road Infrastructure Administration (CNAIR) and the National Agency for Land Improvement (ANIF) analyzed several options, including halting the work or using a lighter fill material.

Ultimately, the option of filling with GeoBlock, an innovative and lighter material than ballast, was chosen. This decision allowed for a reduction in pressure on the underground pipes. This solution was preferred due to its light weight, rapid implementation, and lower costs.

The Austrotherm GeoBlock project in Romania involved the delivery of 915 cubic meters of material, and implementation took only 4 days. The embankment measures 50 m in length, 12 m in width, and has a maximum height of 3 m.

In comparison, 1 cubic meter of soil or ballast weighs between 1,600 and 2,400 kg, while 1 cubic meter of GeoBlock weighs only 22 kg. Thus, for the 915 cubic meters, the soil would have weighed at least 1,464,000 kg, whereas the GeoBlock weighed only 20,130 kg.

A major advantage is that if GeoBlock is used from the design phase, no support walls are needed, as the material reduces pressure on the structures. This leads to faster implementation and lower costs compared to conventional solutions that can take months to complete. The efficiency of the materials is compared in the table below (Table 10.1):

Table 10.1. Comparison of the efficiency of traditional fill materials with the GeoBlock system

Umplere cu materiale tradiționale		**Eps GeoBlock**
Punerea în opera este mai lentă		Procesul de construcție este rapid
Costurile de mobilizare/ de punere în operă sunt ridicate		Costurile mobilizare/de punere în operă sunt scăzute
Sunt necesare utilaje grele pentru aducerea materialului, depozitarea lui în șantier și compactare		Nu sunt necesare utilaje grele, amplasarea se face cu ușurință
Dificultăți în utilizarea utilajelor grele în anumite zone limită		Instalare ușoară în zone limită
Presiunea greutății materialului în laterale		Nu sunt necesare laterale de sprijin
Emisii CO2 ridicate		Emisii CO2 scazute, material 100%reciclabil

When implementing GeoBlock expanded polystyrene blocks in a project, total costs are primarily influenced by the duration of implementation. Since GeoBlock is prefabricated, loading and transportation costs are reduced, especially as the material can be quickly delivered from nearby warehouses. Another significant advantage is the reduction of indirect costs, as less personnel is needed for installation.

In the case of the roadway ramp project over the municipal pipeline, GeoBlock simplified the process, reducing the labor and logistics required. The use of this material brought significant economic benefits compared to traditional fill methods.

The cost analysis for implementing GeoBlock expanded polystyrene blocks compared to traditional solutions highlights several significant advantages. In terms of transportation and handling, the lightweight nature of GeoBlock allows for more efficient transport, resulting in lower fuel consumption and reduced CO2 emissions.

Additionally, handling the material requires smaller equipment, significantly reducing logistical and labor-related costs. In contrast, traditional solutions such as ballast or compacted soil involve higher transportation costs and larger equipment for installation, thereby increasing overall costs.

From the perspective of implementation time, GeoBlock blocks offer a considerable advantage due to their quick and simple installation, leading to significant savings by reducing the indirect costs associated with site supervision and resource management. Traditional methods require more time for site preparation and compaction, extending project duration and consequently operational costs.

Regarding material costs, although the initial cost of GeoBlock blocks may be higher than that of traditional materials, the material's efficiency and reduced execution time lead to a faster return on investment. Traditional materials, while initially cheaper, require additional long-term investments for maintenance and repairs. One of the most significant economic advantages of using GeoBlock is the substantial reduction in indirect costs due to the short implementation time. Costs have been compared in Table 10.2.

Table 10.2. Implementation costs of the GeoBlock-based solution vs. implementation costs of traditional solutions

Umplere cu materiale tradiționale					EPS GeoBlock				
Descriere activitate	**U.M.**	**Cant**	**P.U.**	**Total (Ron)**	**Descriere activitate**	**U.M.**	**Cant**	**P.U.**	**Total (Ron)**
Îndepărtare resturi/ curățare zona	mp	600	18	10,800	Îndepărtare resturi/ curățare zona	mp	600	18	10,800
Strat de nisip (5-10 cm)	mc	30	135	4,050	Strat de nisip (5-10 cm)	mc	30	135	4,050
Transport pământ/ balast	mc	915	45	41,477	Transport GeoBlock	mc	915	0.60	549
Pământ/ balast de umplutura	mc	915	200	183,000	GeoBlock	mc	915	225	205,875
Compactare material de umplere	mc	915	15	13,725	Manipulare blocuri de polistiren	zi	3	1,520	4,560
Strat de beton/ BSC (10cm)	mc	60	450	27,000	Strat de beton/ BSC (5cm)	mc	30	450	13,500
Mixtura asfaltică	mc	60	325	19,500	Mixtura asfaltică	mc	60	325	19,500
				299,552					**258,834**

A detailed analysis of the use of GeoBlock highlights the excellent maintenance of structural and physical properties over the long term, demonstrating the viability of the material in geotechnical and infrastructure projects.

It provides economic and ecological advantages by reducing waste, carbon footprint, and transportation, handling, and implementation costs, along with high stability under load and in challenging environments.

Calculating the Carbon Footprint of a Road Ramp Crossing a Municipal Pipeline

Evaluating the carbon footprint associated with constructing a roadway ramp involves analyzing the impact of construction materials (concrete, asphalt, steel, aggregates), emissions generated by the equipment used (excavators, bulldozers, trucks, mixers), working time, and the transportation of materials and personnel. All these factors are integrated to provide a comprehensive estimate of CO_2 emissions, aiming to identify opportunities for emission reduction and enhance project sustainability.

Assessing the materials, machinery, and equipment required during the design stage is essential to ensure efficient and sustainable resource use, considering the project's time and budget constraints. This involves identifying the types and quantities of construction materials, the technical specifications of equipment, and the operational requirements of machinery. The analysis includes calculating CO_2 emissions, highlighting the impact of individual factors on the total carbon footprint, emphasizing the correlation between execution time and increased emissions.

Construction materials, particularly concrete, represent a significant source of carbon footprint, making it necessary to identify and quantify the impact of each project element on total emissions to assess sustainability.

Machinery and equipment, especially the trucks involved in transportation, contribute significantly to these emissions. Implementing sustainable strategies, such as using eco-friendly concrete, recycling steel, adopting green asphalt technologies, and utilizing high-energy-efficient machinery, can reduce the carbon footprint.

In calculating carbon emissions for using GeoBlock in constructing a roadway ramp crossing a municipal pipeline, factors such as material production, transportation, and machinery use are considered, resulting in estimates that demonstrate the efficiency of the GeoBlock solution in reducing carbon emissions.

To calculate the carbon footprint associated with using GeoBlock in constructing a roadway ramp crossing a municipal pipeline, factors such as material production, transportation, machinery use, and the construction process are analyzed. The materials used include GeoBlock expanded polystyrene blocks, reinforcement, concrete, and asphalt mix. The project will take place over a duration of 4 days, with 8 hours of work per day.

The carbon emissions for producing expanded polystyrene (EPS) are estimated at 3.9 kg CO_2/kg, while transportation is calculated at 0.2 kg CO_2 per ton-km, with a loader emitting 13 kg CO_2/hour for 8 hours.

The comparative evaluation between the traditional solution and the innovative GeoBlock solution illustrates the efficiency of decarbonizing construction, as shown in Table

10.3 and Graph 10.8, where the traditional solution is represented by an orange line and the innovative one by a green line.

Table 10.3. Calculation of CO2 Emissions and Total for Implementing GeoBlocks for the Road Ramp Crossing the Municipal Pipeline

Soluție implementare GeoBlock pentru rampa rutieră care traversează conducta municipală	**Valoare emisii**	**U.M**
GeoBlock: 915 mc x 22 kg x 3.9 kg/CO2	78,507	Kg CO2
Transport: 50 km x 20.13 Tone x 0.2 kg/CO2	201	Kg CO2
Încărcător: 8 ore x 13 kg/CO2	104	Kg CO2
Oțel beton: 1.3 tone x 1850 kg CO2/tonă	2,405	Kg CO2
Beton: 66 tone x 2400 kg CO2/tonă	158,400	Kg CO2
Mixtură asfaltică: 90 tone x 28 kg CO2/tonă	2,520	Kg CO2
Compactor asfalt: 24 ore x 6.2 kg CO2/oră	149	Kg CO2
Total Amprenta de Carbon	**242,286**	**Kg CO2**

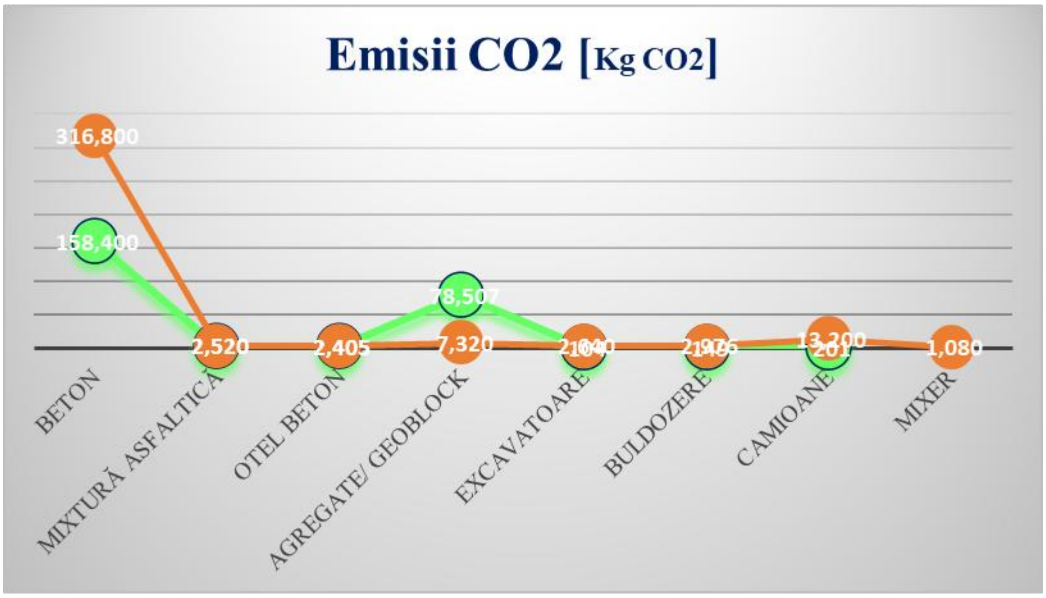

Figure 10.2. Comparative assessment of decarbonization efficiency in construction (the orange line represents the traditional solution, while the green line represents the innovative solution)

In the current context of sustainability requirements in the construction sector, a comparative analysis of traditional approaches and innovative solutions, such as GeoBlock, becomes essential for reducing carbon footprints and optimizing the ecological performance of infrastructure.

Expanded polystyrene GeoBlock blocks not only reduce structural loads but also contribute to diminishing environmental impact, as they have a low carbon footprint. These blocks have undergone extensive testing that confirms their efficiency and durability in geotechnical engineering applications, highlighting the advantages in reducing carbon emissions and maintaining structural performance over the long term.

The GeoBlock Project in Romania illustrates their use as a promising alternative to traditional filling materials, thus providing structurally, economically, and ecologically efficient solutions for low-emission infrastructure development.

CAP. 11. ORIGINAL CONTRIBUTIONS. RESEARCH DIRECTIONS AND UTILIZATION OF RESULTS

11.1. Original Contributions

Through my research, I aimed to explore the decarbonization of construction through innovative technologies and managerial practices within the construction field. The thesis provides a detailed techno-economic analysis, highlighting the interconnection between efficient management and sustainable technological solutions. The contributions of this work include:

1. **Calculation of the Carbon Footprint:** Development of a methodology for assessing the environmental impact of construction activities.
2. **Determination of CO2 Emissions:** Analysis of carbon dioxide emissions, providing an understanding of the environmental impact of materials and technologies.
3. **Investigation of Innovative Materials:** Exploration of materials that can reduce costs and carbon footprint, emphasizing their efficiency and sustainability.
4. **Case Studies:** Analysis of the adoption of decarbonization technologies by organizations, illustrating best practices.

5. **Evaluation of Insulation Solutions:** Comparison of insulation solutions, highlighting their advantages and disadvantages in the context of emission reduction.

The thesis not only contributes significantly to the existing literature but also offers practical recommendations for construction managers. By examining the connections between efficient management and the technical aspects of construction, the research demonstrates that an integrated approach is essential for achieving sustainability goals, highlighting that data-driven strategies can optimize resources and reduce the associated carbon footprint.

Following extensive research and updating information regarding the implementation of decarbonization in construction, I conducted a survey addressed to industry specialists active on LinkedIn. The purpose of this survey was to correlate the research results with the perspectives and interpretations of engineering and management professionals regarding the topic of decarbonization.

The results of the survey are presented in Figure 11.1, providing an overview of external perceptions related to this topic. This approach aids in understanding how theoretical and applied concepts of decarbonization are perceived by practitioners in the field.

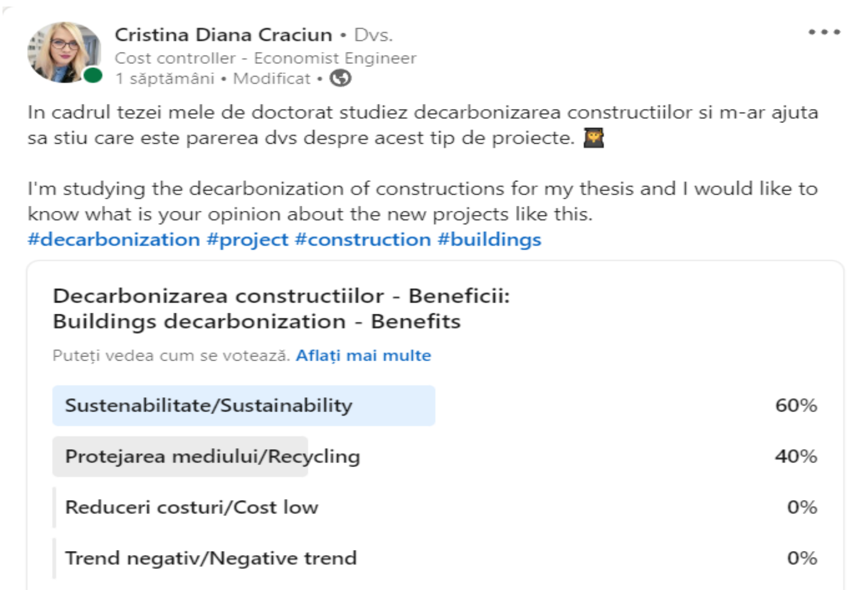

Figure 11.1. An opinion survey conducted among industry professionals, reflecting their perspectives on the implementation of projects aimed at reducing carbon emissions in the construction sector - https://www.linkedin.com/in/cristina-diana-craciun

The transition to decarbonization in construction projects is recognized as an essential measure in combating climate change. Based on this topic, I have highlighted the following key points:

- **Decarbonization Initiatives:** Aimed at reducing greenhouse gas emissions generated by buildings, aligning with global efforts for more sustainable practices.
- **Innovation and Technology:** Decarbonization is seen as a driver of innovation in construction, integrating new technologies and materials to create more energy-efficient buildings.
- **Regulatory Support:** Government policies promote decarbonization through incentives and certifications that encourage eco-friendly practices.
- **Sustainable Economic Benefits:** Although implementing decarbonization measures may involve initial costs, the long-term economic advantages, such as reduced operational expenses, are significant.
- **Public Awareness:** There is an increasing awareness among the population regarding environmental issues, which provides a competitive advantage for builders promoting sustainable buildings.
- **Global Collaboration:** Decarbonization is a global challenge that requires cooperation among nations and industries to share best practices.

The thesis also addresses the management of risks associated with implementing decarbonization, highlighting types of risks such as design, external, organizational, project management, and construction risks. It provides solutions for identifying, assessing, and monitoring these risks through specialized software applications.

The research included a detailed assessment of the carbon footprint associated with the construction of a road using GeoBlock technology, comparing it with traditional methods. The results suggest that GeoBlock significantly reduces the carbon footprint and installation time, which is crucial for project management.

The thesis proposes solutions for optimizing the implementation of technologies and their efficient management, emphasizing the importance of an integrated approach that includes continuous monitoring of performance and environmental impact. It also highlights the challenges related to costs and the necessity of a holistic perspective on energy efficiency and the life cycle of constructions.

The original contributions of the research extend from literature studies to techno-economic analyses and proposals for technological processes aimed at supporting sustainability and cost reduction.

11.2. Future Research Directions

Research and development in the field of decarbonization in construction focus on informed decision-making and the development of efficient solutions through the use of intelligent tools and machine learning algorithms. The main objective is to support decision-making processes in maintenance management. To achieve this goal, research will focus on several key areas:

- **Development of Advanced Materials:** Creating and improving eco-friendly materials, including the use of nanotechnology for insulation and durability, to reduce energy consumption and carbon emissions.
- **Streamlining Construction Processes:** Implementing automation and robotics to minimize resource waste and reduce construction time through prefabrication.
- **Integration of Renewable Energy Sources:** Studying ways to integrate solar panels, wind turbines, and geothermal heating systems, along with efficient energy storage solutions.
- **Advanced Monitoring Systems:** Developing platforms for continuous monitoring of carbon emissions and real-time resource optimization.
- **Education and Collaboration:** Creating educational programs for professionals and promoting collaboration between communities, policymakers, and industry to formulate policies favorable to reducing carbon footprints.
- **Case Studies:** Conducting pilot studies to assess the effectiveness of implemented solutions and comparing various technologies to identify the most efficient practices.

These research directions must consider unique resources and global challenges, as well as industrial competitiveness. In this context, financial analysts play a crucial role in supporting management in strategic decision-making. Energy efficiency remains a key aspect of sustainable development, with prospects for continuing this trend in the future.

11.3. Valorization of Research Results

This chapter of the thesis highlights the contributions and results of the conducted research, which have been materialized through scientific articles, posters presented at international conferences, and the publication of the book *Financial Management - Theory, Applications*, *Case Studies*. The results obtained have a direct impact on optimizing technological and managerial practices in engineering through:

- Implementation of Innovative Solutions: Reducing carbon emissions;
- Adoption of Sustainable Technologies: Utilizing eco-friendly materials;
- Development of Management Models: For the transition to sustainability;
- Creation of Collaboration Opportunities: Between industry and research;
- Contribution to Public Policies: And regulations in the engineering and ecological fields.

The research underscores that decarbonization is not only an ecological necessity but also an economic opportunity, offering advantages such as process efficiency and added value creation. The application of advanced technologies and responsible managerial practices ensures compliance with environmental regulations while contributing to economic competitiveness and improving quality of life.

CONCLUSIONS FROM PART II: CONTRIBUTIONS REGARDING THE PREPARATION LEVEL REQUIRED BY COMPANIES TO REDUCE THE CARBON FOOTPRINT GENERATED BY ANY TECHNOLOGICAL PROCESS

The study emphasizes the importance of preparing companies to reduce the carbon footprint associated with technological processes. The necessary preparation encompasses both technical and strategic aspects.

On the technical side, organizations must adopt advanced technologies and innovative solutions to minimize carbon emissions, which involves investing in energy-efficient equipment, renewable energy sources, and emission monitoring systems.

On the strategic side, it is crucial for management to develop sustainable policies and practices and promote an organizational culture dedicated to sustainability, including training employees on eco-friendly practices and the benefits of reducing emissions. Studies suggest that a well-structured plan and the implementation of a carbon management system are essential for achieving carbon footprint reduction objectives. Periodic assessments of emissions and the establishment of clear and measurable targets are necessary.

Collaboration with other organizations, research institutions, and government authorities is fundamental for accessing resources and disseminating best practices, facilitating the transfer of knowledge and technologies for a quicker transition to sustainable practices. An integrated approach that combines technological innovation with effective organizational strategies is essential for reducing carbon footprints.

In conclusion, this work significantly contributes to the field of construction management, establishing a solid foundation for developing decarbonization strategies, thus promoting a more sustainable and responsible construction sector.

GENERAL CONCLUSIONS

By integrating environmental topics into engineering and economic science study programs in universities, and by providing information resources regarding CO2 emission reduction practices for the internal training of operational staff within companies, manufacturing companies can take significant steps in this direction in a shorter time frame.

The essential conclusions related to the research and development activities carried out within the doctoral thesis, aimed at achieving the main objective in accordance with the reference methodological aspects, are as follows:

Chapter 1. Technology is considered essential in business management, but it cannot fulfill this role alone. Therefore, the implementation of technological management within a company must include the diversity of activities mentioned, integrated into the organization's general management processes. The field of technological management has evolved to emphasize the management strategies that businesses should adopt to effectively integrate technologies into their commercial strategies and business operations.

Chapter 2. Critical infrastructures have a significantly negative impact on sustainability, and their neglect can compromise their purpose of serving the public. Although attention is paid to developing critical infrastructure with a minimal footprint, facilities often operate without properly assessing their interactions with the surrounding environment or the community.

I have observed that regular maintenance and operations provide a significant opportunity to mitigate the negative impact of infrastructure on sustainability. Unlike the design phase, during maintenance operations, most sustainability-related issues are identified and addressed. Recent economic growth increasingly emphasizes production, exploitation, and the importance of technology. It is essential to design and strengthen collaborations between public sector stakeholders and private companies to ensure a sustainable and efficient infrastructure.

Chapter 3. Studies in the field of management can vary considerably in terms of the explored themes, research methods, formulation of conclusions, and application of results. The classification of these studies is primarily based on methodological criteria, which include: the number of cultures analyzed, the types of issues discussed, hypotheses regarding the origins of similarities and differences observed in management practices, and the degree of generality of the conclusions drawn.

Although these studies are generally considered fundamental in general management, some specialists argue that they can be seen as a preliminary form of comparative management studies, as they attempt to extend the validity of conclusions and provide perspectives on management in other countries.

The goal of the research was to analyze cultural similarities by extending theoretical studies. Additionally, it is important to recognize that the professional skills development of managers can be optimized through training and development strategies conducted in workshops that align with the company's interests.

Chapters 4-5. The research plan is the main tool through which we can implement the strategy. By defining a solid strategy, we establish concrete objectives to transition to a high-value-added development model, oriented toward innovation and the pursuit of knowledge, and focused on the continuous improvement of quality of life and social relations in harmony with the natural environment. In designing this plan, I considered the role of the national research-development-innovation system, which aims to advance science and technology to improve quality of life and amplify knowledge, having the potential to leverage and expand the horizons of action, as well as stimulate economic competitiveness.

Through this plan, the proposal is to achieve the following strategic objectives:

- Creating knowledge and obtaining cutting-edge scientific and technological results, competitive at the global level, to enhance the international visibility of research and transfer results into the technical-economic sphere.
- Identifying technical and scientific solutions that contribute to improving the quality of social life.
- Stimulating economic competitiveness through innovation, with a direct impact on economic agents and economic practice.
- Obtaining scientific and technological results comparable to those at the European level to enhance the visibility and international recognition of Romanian research.

Therefore, the research plan aims to serve as a key instrument in achieving strategic objectives and promoting high-quality research with significant impact. The economic and financial analysis can be demonstrated as a fundamental element in the decision-making process of management, significantly contributing to planning and control activities, dynamically adjusting economic processes, and increasing the importance of quality factors in economic development. It highlights opportunities and action alternatives, while also providing solutions for achieving established objectives.

The absence of economic and financial analysis from a firm's financial activities may indicate mediocrity in that business and poor financial performance of its management. Currently, infrastructure is expanding and amplifying its functions, increasing its role in the process of managerial organization and the operation of various types of markets. The state of infrastructure largely contributes to the efficient reproduction of commercial relationships and to the stability and efficient functioning of existing markets.

The requirements for market infrastructure, economic-managerial tools, and its overall configuration, along with its constituent elements, are changing in this context. Infrastructure that adapts to new realities creates the necessary conditions for stable economic functioning and for realizing the potential of economic relationships. In this context, issues related to the analysis and formulation of prospective directions in the development of the economy's infrastructure become important both theoretically and practically.

I actively sought such collaboration, intended to support my research and to sustain the chosen theme, which I established with Austrotherm Romania. The adoption of these development directions will help developing companies improve their general and technological management, overcome current disadvantages, and advance toward a low-carbon economy.

For the integration of the decarbonization process in the construction sector within a company, a detailed research study is required, including multiple stages and dimensions. Each of these dimensions focuses on different aspects of the construction process, the use of materials, innovative technologies, and other relevant considerations, aspects that were emphasized in the second section of the paper.

Chapter 6 presents the methodology used in the research, the directions of investigation addressed within the conducted study, as well as a synthesis of the unfavorable factors hindering the development of companies in the technological sector. The objectives formulated in this chapter have been appropriately achieved in the subsequent chapters.

Chapters 7–11 present the necessary stages in the overall decarbonization process of constructions, which include reducing operational carbon and embodied carbon.

Construction beneficiaries should prioritize achieving an operational carbon value equal to zero or, at the very least, consider reducing it in the case of already existing constructions, where the impact of embodied carbon in the materials used is significant. The Climate Change Commission has emphasized that achieving carbon neutrality is not only feasible but also necessary and cost-effective.

Current legislation stipulates that, from the design and planning phase, even before the execution of a Net Zero Energy Building (nZEB), performance indicators must be established and monitored for achievement. nZEBs are buildings that utilize smart technologies and do not generate pollutant emissions. In addition to the long-term environmental benefits, beneficiaries of these constructions will also notice immediate benefits regarding maintenance costs.

The results of risk management can help decision-makers select the most suitable strategy in developing organizational stimulation methods.

A low-carbon or decarbonized economy is an economy based on energy sources that generate low levels of greenhouse gas emissions.

Benefiting from the experiences of other similar projects helps us identify best practices and anticipate potential obstacles by assessing community attitudes and their level of awareness. The greatest emission reductions come from projects that adopt a holistic approach, combining several tailored strategies and innovating through technology.

The comparative assessment of the efficiency of building decarbonization involves comparing their performance – Chapter 10.

Chapter 10 takes into account the current context of climate change and the urgent need to reduce carbon emissions; thus, the research and implementation of innovative solutions in the construction sector become essential imperatives.

The development of eco-friendly and recyclable materials, along with the integration of nanotechnology, represents crucial steps to enhance the ecological performance of construction materials and minimize environmental impact.

At the same time, streamlining construction processes through automation, robotics, and prefabricated methods can significantly reduce energy and resource consumption, thereby contributing to a lower carbon footprint.

Integrating renewable energy sources and developing efficient energy storage solutions are essential aspects to ensure the energy sustainability of modern buildings. Furthermore, the implementation of advanced monitoring systems and smart resource management allows for optimizing energy and material consumption, enhancing the operational efficiency of buildings, and reducing associated carbon emissions.

The role of education and stakeholder engagement cannot be underestimated, as promoting a culture of sustainability and cooperation among all involved actors – from politicians to communities and industry professionals – is fundamental to the success of these initiatives. Education and training programs, along with favorable policies and regulations, can facilitate the transition to greener and more sustainable construction practices.

Case studies and comparative analyses are necessary to evaluate the effectiveness of innovative solutions and identify best practices. These evaluations provide valuable insights that can guide future research and implementation efforts.

In conclusion, the future of research in carbon footprint reduction solutions must be collaborative and innovation-oriented, aiming to transform the construction industry into a pillar of global sustainability.

Only through an integrated approach that combines advanced technology, education, and stakeholder engagement can we achieve ambitious goals for reducing carbon emissions and protecting the environment for future generations.

Following research and updating current information on everything new in the market, including how decarbonization is **implemented in the technical-economic system of construction**, I conducted a survey targeting specialists in the field – Chapter 11.

By conducting a well-developed preliminary investigation, the necessary information is obtained to formulate a comprehensive strategy for the decarbonization of buildings. This stage lays the foundation for making informed decisions regarding the development of effective solutions tailored to the specific context.

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