BULETINUL ŞTIINŢIFIC

al

Universităţii Politehnica Timişoara, România

Seria INGINERIE ȘI MANAGEMENT

Vol. 11, Nr. 1, 2025

SCIENTIFIC BULLETIN

of

Politehnica University of Timisoara, Romania

Transactions on ENGINEERING AND MANAGEMENT

Vol. 11, Issues 1, 2025

ISSN 2392 – 7364

ISSN-L 2392 – 7364

BULETINUL ŞTIINŢIFIC

al

Universităţii Politehnica Timişoara, România

Seria INGINERIE ȘI MANAGEMENT

Vol. 11, Nr. 1, 2025

SCIENTIFIC BULLETIN

of

Politehnica University of Timisoara, Romania

Transactions on ENGINEERING AND MANAGEMENT

Vol. 11, Issues 1, 2025

ISSN 2392 – 7364

ISSN-L 2392 – 7364

This new journal series is the new face of two former journals:

- The *Scientific Bulletin of Politehnica University of Timisoara, Transaction on Economics and Social Sciences (ranked according to CNCSIS classification in Romania: D class);*
- *The Scientific Bulletin of Politehnica University of Timisoara, Transaction on Management. Economics Engineering. Transportation Engineering (ranked according to CNCSIS classification in Romania: C class).*

This new journal

CONTACT:

Politehnica University of Timisoara, Romania

Faculty of Management in Production and Transportation

14 Remus str., 300191 Timisoara, Romania

E-mail: scientific.bulletin@yahoo.com

Web address: https://mpt.upt.ro/buletin-stiintific/

CONTENT

	Editorial ……...	5
1	**Application of MHR and ABC Methods in the Calculation of the Costs of Scientific Publication** Andrei OSAN and Stelian Nicolae UNGUREANU	7
2	**Enforced Environmental Management in Local Public Administration,** Emanuel-Costel BĂLAN, Valentin-Luk IACOBESCU and Mihaela BORAN	13
3	**Integrating Project Management and Nature-Based Solutions in Urban Ecosystem Planning,** Valentin-Mihai VATAV, Lenuța-Zamfira HRIHOR, Ionel LUNGU, Izabela MACARIE	20
4	**Integrating New Emerging Technologies to Enhance User Experiences in Hospitality Industry. Developing Digital Tourism**, Marius MIHUT, Hazem ABU-AWWAD and Viorica BAESU	25
5	**Investigating Tourist Perceptions of Digital Tourism Experiences: A Comparison Between Romania and Spain**, Marius MIHUT and Anca DRAGHICI	35
6	**Absorption of European Funds in the 2014–2020 Financial Framework and Solutions for Efficient Implementation in the 2021–2027 Financial Framework,** Sebastian-Norbert HOJDA and Marian MOCAN	44
7	**Transition to Industry 5.0 and beyond,** Andrada-Denisa BECA and Ilie Mihai TAUCEAN	48
8	**Study on Optimizing Energy Consumption of an Energy. Independent House Project,** Diana BALUTI, Lavinia BOGDANOVICI and Matei TAMASILA	54
9	**Applying Total Productive Maintenance to Body Control Modules (BCM) in the Automotive Industry: Optimizing Reliability and Preventing Failures,** Lavinia BOGDANOVICI Diana BALUTI, and Matei TAMASILA	61
10	**Continuous Improvement of Support Services in Romanian Universities – A Methodological Approach,** Mihai Ioan COSTA, Matei TAMASILA and Maria Elena BOATCA	67

Scientific Bulletin
of Politehnica University of Timisoara, Romania

Transactions on ENGINEERING AND MANAGEMENT

Vol. 11 Issue 1, 2025

Editorial

Anca DRAGHICI[1]

The volume 1, from 2025 of the "***Scientific Bulletin of Politehnica University of Timisoara – Transaction on Engineering and Management***" (ISSN 2392-7364) continue to surprise having an increase visibility due to the journal index in CrossRef (https://www.crossref.org/), CEEOL (https://www.ceeol.com/) and index Copernicus (https://journals.indexcopernicus.com/) databases. In addition, the Editorial Board announced the compliance of the articles published with the Open Science movement and this only thanks to the excellent collaboration and constant support offer by the UPT Library and the Politehnica Publishing House.

All articles of the ***Scientific Bulletin*** of this number have been reviewed by the members of the *Associated Editors and of the Scientific Committee;* their professional and volunteer review work impact the quality content of the papers included in this volume. Furthermore, the ***Scientific Bulletin*** benefits from the constant support of the R&D staff of the ***Research Center in Engineering and Management (RCEM)***[2] (of the Faculty of Management in Production and Transportation, Politehnica University of Timisoara, FMPT/UPT, Romania); RCEM provide a productive and positive network, and a scientific community through which we support knowledge sharing, buddy schema and trainings (formal or informal).

In 2025, the "***Scientific Bulletin of Politehnica University of Timisoara – Transaction on Engineering and Management***" (ISSN 2392-7364) celebrate 10 years of regular and continuous appearance of our journal. That is why the Editorial Board has decided to have 2 separate numbers of volume 11 and to promote young generations of researchers together with their recent achievements, but also to demonstrate the power of our community by considering valuable contributions of the senior researchers.

The main research topics discussed in the current issue of the Scientific Bulletin of Politehnica University of Timisoara are:

- Activity-Based Costing and Machine Hour Rate methods for calculating the costs of publishing a scientific article, in a case study involving a CNC machine and open access publishing;
- Environmental Management;
- Nature-Based Solutions;
- Tourist perceptions on digital technologies;
- A comparison study of the tourism industry in Romania and Spain.

The first paper, "***Application of MHR and ABC Methods in the Calculation of the Costs of Scientific Publication***" (the author is from Technical University of Cluj-Napoca, Romania). The paper compares the ABC (Activity-Based Costing) and MHR (Machine Hour Rate) methods for calculating the costs of publishing a scientific article, in a case study involving a CNC machine and open access publishing. ABC provides a detailed allocation of costs per activity, which is accurate but costly. MHR, simpler and more applicable in industrial environments, is less accurate in complex processes. Each method has specific advantages, and the choice depends on the complexity of the activities and the desired level of precision, influencing economic decisions and the efficient use of resources.

The second paper "***Enforced Environmental Management in Local Public Administration"*** by a group of authors from master and PhD studies at Politehnica University of Timisoara, Romania debates

[1] *Editor in Chief, Politehnica University of Timisoara, Romania, anca.draghici@upt.ro*
[2] *Information available at: http://www.mpt.upt.ro/eng/research/research-center.html*

the change of paradigm in environmental management in Romania. By analyzing legal frameworks, local projects, and implementation barriers, the paper demonstrates both successes - such as projects in infrastructure, sewage, water, and separate waste collection - and constraints like administrative capacity and budget limitations. The findings highlight the need for combining enforcement with targeted support to ensure a sustainable local environmental governance.

The third paper presents "***Integrating Project Management and Nature-Based Solutions in Urban Ecosystem Planning***" by a group of master students from Politehnica University of Timisoara, Romania. The analysis emphasizes the importance of adaptive planning, stake-holder engagement, and hybrid evaluation tools in ensuring ecological and social co-benefits. By integrating project management principles with nature-based approaches, cities can deliver scalable, measurable, and resilient ecosystem services. The findings offer a framework for aligning ecological innovation with institutional capacity, advancing the transition toward sustainable and livable urban futures.

The fourth paper entitled ***"Integrating New Emerging Technologies to Enhance User Experiences in Hospitality Industry. Developing Digital Tourism"*** by PhD students from Politehnica University of Timisoara, Romania presents an analysis of theoretical and practical aspects regarding the new changes in tourism industry. The present research explores the impact and potential of digital technologies in transforming the hospitality industry, focusing particularly on the emergence and development of digital tourism, by analyzing its evolution, from the integration of virtual and augmented reality (VR/VA) technologies to the implementation of artificial intelligence (AI) and digital tokens, highlighting how these innovations are redefining tourists' experiences with destinations and service providers.

Fifth paper, ***"Investigating Tourist Perceptions of Digital Tourism Experiences: A Comparison Between Romania and Spain"*** presented an exhaustive study of a PhD Student from Politehnica University of Timisoara, Romania. This research investigates and compares tourist perceptions of digital tourism experiences between Romania and Spain. Through comprehensive analysis of academic studies, industry reports, and market data, the research identifies significant similarities and differences in how tourists from these two European countries perceive and interact with digital tourism tools and experiences.

Th sixth paper explained the ***"Absorption of European Funds in the 2014–2020 Financial Framework and Solutions for Efficient Implementation in the 2021–2027 Financial Framework"*** and was prepared by Sebastian-Norbert HOJDA and Marian MOCAN, both Politehnica University of Timisoara, Romania.

Further, the paper "**Transition to Industry 5.0 and beyond"** as been provided as a large-scale debate developed by Andrada-Denisa BECA and Ilie Mihai TAUCEAN both Politehnica University of Timisoara, Romania.

The last three papers have been prepared by colleagues from the research group of prof. Matei TAMASILA and present:

- **A "Study on Optimizing Energy Consumption of an Energy. Independent House Project" developed by** Diana BALUTI, Lavinia BOGDANOVICI and Matei TAMASILA, all from olitehnica University of Timisoara, Romania;
- **"Applying Total Productive Maintenance to Body Control Modules (BCM) in the Automotive Industry: Optimizing Reliability and Preventing Failures"** by Lavinia BOGDANOVICI Diana BALUTI, and Matei TAMASILA, all authors being from both Politehnica University of Timisoara, Romania;
- **"Continuous Improvement of Support Services in Romanian Universities – A Methodological Approach"** by Mihai Ioan COSTA, Matei TAMASILA and Maria Elena BOATCA all from both Politehnica University of Timisoara, Romania.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Application of MHR and ABC Methods in the Calculation of the Costs of Scientific Publication

Andrei OSAN[1]

Abstract – The paper compares the ABC (Activity-Based Costing) and MHR (Machine Hour Rate) methods for calculating the costs of publishing a scientific article, in a case study involving a CNC machine and open access publishing. ABC provides a detailed allocation of costs per activity, which is accurate but costly. MHR, simpler and more applicable in industrial environments, is less accurate in complex processes. Each method has specific advantages, and the choice depends on the complexity of the activities and the desired level of precision, influencing economic decisions and the efficient use of resources.

Keywords: Costing; MHR Method; ABC Method

I. INTRODUCTION

This paper addresses the issue of identifying the most appropriate technique for calculating costs in a dynamic economic context. It is essential to understand that due to the rapid advancement of data processing and storage technologies and the advent of artificial intelligence, computing resources are now more accessible, powerful, and cheaper, being available to anyone, anywhere, and anytime.

From an economic perspective, any production or service provision activity inevitably involves costs. In this context, the knowledge and understanding of these costs becomes an indispensable condition for substantiating correct and efficient decisions.

The complexity of the modern economy, characterized by fierce competition specific to the market economy, emphasizes the importance of quality information flow in the decision-making process. The quality of financial and cost information is essential, as it directly influences both immediate decisions and the long-term vision, implicitly determining the results obtained.

In the current economic environment, any decision error resulting from incomplete or deficient information on costs is severely penalized, underlining the need for precise and correct cost management.

Analyzing the specialized works in the field of cost calculation, [1-6], we discovered that each method has specific advantages depending on the complexity of the activities and the typology of the organizations, and the choice of the right technique depends on the desired precision in allocating costs and the necessary flexibility in managing them.

In another cost-focused study, [7] proposed an innovative and detailed process-based cost estimation model that considers various battery cell geometries, such as cylindrical, prismatic, and bag-like. This model uses user-specified performance data to enable flexible battery cell design and provide an accurate cost estimate a functionality absents in many of today's models.

Kádárová, [8] argues that companies frequently encounter problems related to waste in production processes. In a comparative analysis of the results obtained through various methods of production management and waste reduction on a pro-duction line, the focus was on reducing costs. For this, industrial engineering techniques were used, focused on technical and economic analysis, ergonomics and pro-duction management.

Cost calculation by classical method represents the present, the future being rep-resented by the calculation of costs with the help of artificial intelligence. Relich & Nielsen [9] states that the use of parametric modeling implies the need to collect a considerable amount of data on similar products, which may be a constraint to the pro-posed method. In addition, the definition of many parameters for the development and training of artificial neural networks, as well as the application of constrained programming techniques, can be seen as other limitations tag. In another study, Relich & Świć, [10] argues that the use of artificial neural networks increases the efficiency of the search process in the case of project prototyping, especially when several viable solutions are available. The research also highlights the application of artificial neural networks to determine cost estimation relationships throughout a product's life cycle. However, it is important to emphasize that although neural net-works process data, the calculations are still based on traditional methods.

[1] Technical University of Cluj-Napoca, North University Center of Baia Mare, Department of Engineering and Management of Technology, Str. Dr. Victor Babes 62A, Baia Mare, Maramures, 430083, Romania; andrei.osan@imtech.utcluj.ro

In this context, the present paper aims to analyze and compare two widely used cost calculation methods: the ABC (Activity-Based Costing) method and the MHR (Machine hour rate) method. Both techniques aim to allocate indirect costs, but they differ in their approach.

This comparison will highlight not only the efficiency of each method, but also their advantages and disadvantages, identifying the most appropriate technique according to the specifics of each economic entity and the complexity of its processes.

II. THEORETICAL ASPECTS

2.1 Activity-Based Costing (ABC)

The ABC method is a modern approach that emphasizes "activities" and "cost factors". This allows for detailed measurement of costs, task performance, re-sources used, and cost-generating objects. The concept of "activity" emphasizes the link between the resources consumed and the resulting products, while the "cost factor" helps to identify the elements that influence the price of a product [11].

Activity-Based Costing is a method of attributing indirect costs to activities, processes or products, starting from the activities that generate these costs, as opposed to the traditional approach, determining a real and well-founded cost. In the traditional system, indirect costs are first distributed to various departments and then allocated to individual products using criteria such as direct wages, direct working hours or ma-chine operating hours.

We imagine that in the factory all overheads are calculated according to the operating hours of the machines. This doesn't make much sense, because not all indirect costs are directly related to how long the cars run. As a result, the indirect and total costs attributed to the products become wrong and do not reflect reality, which can create serious problems for the business. In contrast, the Activity-Based Costing method distributes overhead expenses according to the activities that generate them. For example, for the costs related to the purchase of goods, they can be divided into several stages, such as placing orders, receiving the goods or checking and storing them. Thus, the cost for placing an order is divided according to the number of times an order was placed, and the cost for inspection is allocated according to the number of checks made [12-13].

The activity-based costing (ABC) method involves a structured multi-step process for accurately allocating costs and improving organizational efficiency. The first step is to identify the relevant costs, followed by the creation of groups of secondary costs (e.g. IT, administrative salaries) and primary costs (directly related to production, such as research, advertising). The activities are then measured using existing data, and the secondary costs are allocated to the primary ones based on these activities. Subsequently, the costs are distributed to the cost objects (products/services) according to the use of the activities, generating detailed reports. Finally, the information obtained is used to optimize resources and reduce costs, providing a clear picture of the company's performance and efficiency.

Advantages of the ABC method: The activity-based costing (ABC) method provides a clear understanding of overhead, being useful in decisions such as outsourcing production, setting the minimum price, comparing the efficiency of production units, optimizing distribution channels, evaluating customer profitability, calculating profit margins, and reducing the costs of activities. Through detailed analysis, ABC helps identify profitable segments and allocate resources efficiently, improving cost management and strategic decision-making.

Limitations of the ABC method: Although valuable, the ABC method has drawbacks: data collection can be expensive and requires automation, fixed costs are sometimes treated as variables, which can distort the results, certain expenses (e.g. the di-rector's salary) are difficult to allocate, and the implementation of an automated ABC system involves significant investments. These limitations must be carefully managed to ensure the accuracy and usefulness of the analysis.

2.2 Machine Hour Rate (MHR)

It was technological advances that led to the introduction of the MHR (Machine hour rate) method, an approach designed to overcome the limitations of the direct costing method. In contrast, MHR manages to meet several essential needs: it distributes indirect expenses efficiently towards the costs of products, work or services, monitors the optimal use of production capacities and directs the attention of technical, economic and managerial staff to the areas where machines, which have become central pieces of management accounting, generate expenses. At the same time, the method encourages a rational and well-thought-out use of labor.

Essentially, MHR places the machines or groups of machines, known as pro-duction centers, at the center of the costing process, these are the places where expenses occur. To put this method into practice, it is necessary to establish three main indicators: the hourly cost of the machine, called M.H.R., the operating time and the expenses with materials related to each product unit. Through this structure, the method provides a clear and well-organized perspective on cost management [11].

Calculating the hourly rate of a car involves several steps: the overhead of the factory is allocated to the production departments, then allocated to the machines, considered cost centers. Specific expenses (depreciation, energy) are attributed directly to the machine, and the actual working hours are estimated, deducting non-productive times (cleaning, heating). The total overhead is divided by the actual hours to obtain the hourly rate. For a full tariff, direct salaries and spare equipment costs are included. General

expenses are divided into fixed (rents, taxes, lighting) and variable (depreciation, repairs, energy, water), the latter depending on the use of the car.

Depreciation is calculated based on the initial cost of the machine (including transportation and installation), and repairs and energy are considered variable expenses, adjusted for working hours. The final tariff results from the sum of fixed and variable hourly expenses [14-15].

Advantages of the MHR method: The Machine Hour Rate method based on the hourly rate of the machines has multiple benefits. This proves to be an accurate, practical and scientifically grounded approach, ideal for industries where machines play a central role in the production process. By considering the time factor, the method ensures accurate results and provides valuable information for estimating the costs of a project, setting production standards and determining sales prices. It also supports management in assessing the advantages of using machines over manual labor and allows differentiation between the contribution of skilled and unskilled labor to indirect costs.

In addition, it facilitates analysis of the efficiency and running costs of different machines, highlighting possible downtime through distinct hourly rates for fixed and variable expenses. Indirect cost ratios through this method are reliable, providing management with a solid basis for strategic decisions, especially in mechanized pro-duction contexts.

Disadvantages of MHR methods: The Machine Hour Rate method based on the hourly rate of cars has certain limitations. Its application involves an additional effort to monitor the operating time of the machines, which makes it an expensive solution. It also does not consider costs that do not directly depend on the operating time of the machines, which can lead to imprecise results, especially in situations where manual work plays a significant role.

Estimating machine working hours becomes challenging, especially without a pro-duction schedule set in advance. Therefore, this method proves to be inappropriate in contexts dominated by manual activity.

III.CASE STUDY- THE COST OF PUBLISHING AN ARTICLE

Any research initiative initiated to publish a scientific article inevitably involves the assumption of costs, an aspect well known by any researcher. Research and publication activities generate both visible and less obvious costs, the quantification of which may vary depending on the method used. Thus, the question arises: how can the total cost of a published research paper be accurately assessed?

The literature offers a variety of cost calculation methods, but the present paper aims to analyze two of them comparatively: the activity-based method (ABC) and the Machine Hour Rate (MHR) method. Both methods will be applied to estimate both the direct and indirect costs associated with the process of writing, reviewing and publishing a scientific article. The main objective of this comparative analysis is to high-light the differences in the allocation of financial and hu-man resources between the two methods, thus contributing to a clearer and more substantiated understanding of the effectiveness of each approach.

The paper involves applied experiments with a CNC machine, as part of research intended for publication in an open access scientific journal. This option involves significant costs: publication fee, experimental materials (e.g. steel block), indirect resources and the time of the staff involved in the whole process.

For a fair allocation of indirect costs, an average volume of five articles published annually is considered, allowing for proportional distribution of expenses. The research process, from the theoretical and experimental stages to writing and publication, requires a rigorous allocation of resources, essential for realistically estimating the total cost of a scientific publication.

3.1 Costs of publishing an article.

The costs associated with the production and publication of a scientific article can be classified into two main categories, depending on their nature and how they are allocated:

Direct costs - represent expenses that can be identified and directly attributed to specific scientific work. This category includes, for example, the publication fee imposed by the scientific journal, the consumable materials used in the experiments, as well as the costs associated with the operation of specialized equipment (e.g. CNC machines) involved in the research process.

Indirect costs - reflects the set of general expenses necessary to support the re-search activity, which cannot be directly associated with individual work. These include the working time of the staff involved (researchers, technicians, administrative staff), the depreciation of support equipment (e.g. office equipment, IT infrastructure), as well as the costs related to access to scientific databases or documentation platforms. In Table 1 are the annual indirect costs that support the research activity and are distributed among 5 articles.

Table 1. Types and amount of indirect costs.

No	Cost Type	Description	Value
1	Author's own time	Estimated value of personal time (€1/hour for 800 hours/year)	800 €
2	Equipment (Laptop, Printer)	Annual depreciation of office equipment.	300 €
3	Scientific database subscriptions	Annual cost of access to journals and databases	250 €
4	Utilities (Electricity, Internet)	Annual office bills	230 €
		TOTAL	**1580 €**

Table 2. Types and amount of indirect costs.

No	Cost Type	Description	Value
1	Publication Fee	Payment to the open access journal for the publication of the article	500 €
2	Specialized Software	The annual cost of a CAD/CAM software license (€250/year) is divided into 5 items per year.	50 €
3	Consumable Material (Office)	Paper and ink for printing article sketches	15 €
4	Tools CNC	Roughing and finishing cutters used in experiments, which wear out completely for this article	160 €
5	Semi-finished (Steel Block)	The raw material processed on CNC.	25 €
6	Usage: CNC Machine (Including Power)	Cost of Using CNC Machine for 20 Hours	40 € /h
7	Transport to the Workshop CNC	Trips to the workshop where the CNC machine is located	30 €

3.2 Cost Calculation by MHR Method

The MHR method allocates indirect costs based on the time of use of a main re-source involved in the research activity – in this case, the laptop, considered an essential tool both for conducting research activities and for writing scientific material.

In this approach, the laptop is treated as a machine tool, being evaluated according to the total number of hours of annual operation, estimated at 600 hours. They represent 75% of the actual working time allocated by the author to scientific activities. Assuming that five articles are written and published over the course of a year, it follows that a single article corresponds to a volume of 120 hours of laptop operation.

Under the MHR method, direct costs are specifically attributed to the use of the numerically controlled machine tool (CNC), which is considered the main operational resource involved in carrying out experimental activities. The other categories of costs, which do not vary according to the direct use of re-sources through the hourly rate, are treated as fixed costs and are subsequently added to the calculation of the direct expenses associated with the preparation and publication of the scientific paper.

Direct cost calculation:

$$\text{MHR cost direct} = (\text{MHR} \cdot t) + \text{Chm} \quad (1)$$

$$\text{MHR cost direct} = (40 \cdot 20) + 25 = 825\ €/\text{article} \quad (2)$$

$$\text{MHR cost direct total} = \text{MHR cost direct} + \text{Fixed direct costs} \quad (3)$$

$$\text{MHR cost direct total} = 825+770 = 1595\ €/\text{article} \quad (4)$$

Indirect cost calculation:

$$\text{MHR cost indirect} = (\text{Cost indirect total})/(\text{Total hours laptop}) \quad (5)$$

$$\text{MHR cost indirect} = 1580/600 = 2{,}63\ €/\text{h} \quad (6)$$

$$\text{MHR cost indirect/article} = 120\ \text{h} \cdot 2{,}63\ €/\text{h} = 316\ € \quad (6)$$

$$\text{MHR total} = \text{MHR cost direct} + \text{Cost indirect} \quad 7)$$

$$\textbf{MHR total= 1595+316 = 1911 € / article} \quad 8)$$

3.3 Calculation of the Cost by the Activity-Based Costing Method

The Activity-Based Costing (ABC) method involves allocating indirect expenses according to the specific activities that generate these costs, providing a more precise approach compared to traditional methods. Direct expenditure is directly attributed to each product, while indirect expenditure is distributed among five items, based on a clearly defined set of activities. These indirect expenditures are organized into four main categories of activities, each category being allocated with a specific proportion of the total indirect expenditure, depending on its contribution to the production process. This methodology facilitates a better understanding of costs and supports informed managerial decision-making.

To allocate indirect expenses to items, we choose cost factors for each activity. Since no detailed data is provided on the specific consumption of each item (e.g. different working hours per item), we assume that all 5 items consume indirect resources equally.

Table 3. Identifying activities and allocating expenses.

Activity	Description	Value
Research and writing	The author's own time for writing the article	800 €
Technical Support	Use and depreciation of equipment (laptop, printer)	300 €
Access to resources	Subscriptions to scientific databases for documenta	250 €
Office Operation	Utilities (electricity, internet) for office operation	230 €
	TOTAL	**1580 €**

Table 4. Indirect expense calculation per item.

Activity	Value
Research and writing	160 €
Technical Support	60 €
Access to resources	50 €
Office Operation	46 €
Total	**316 €**

The total cost per item is determined by summing the direct cost with the indirect cost.

$$\text{ABC total} = \text{ABC cost direct} + \text{ABC cost indirect} \quad (9)$$

$$\textbf{ABC total = 1595+316 = 1911 € /article} \quad (10)$$

3.4 Comparative Assessment of the Approach

With regard to the MHR method, the approach in which the laptop is treated as the main resource and the indirect costs are allocated in proportion to its estimated time of use of 600 hours per year, i.e. 120 hours for each item, seems to be an atypical approach, given that the MHR is usually applied to production

equipment, such as CNC machines, in this case the justification is plausible: the laptop is an essential tool in research and writing. However, the method has an important limitation: it does not consider differences in the intensity of various activities, such as the fact that drafting can take more time than researching. Uniform cost allocation, based on laptop usage time, simplifies reality more than would be advisable.

On the other hand, the ABC method provides a more detailed and appropriate approach to the allocation of indirect costs. It identifies specific activities, such as re-search and drafting, technical support, access to resources or administrative activities, and associates' costs to them according to the actual consumption of resources. However, the assumption that indirect resources are consumed equally for the five items is an oversimplification. In practice, the ABC method should be based on more specific cost factors, such as the hours of work dedicated to each individual activity for each item. A clear advantage of this method is the high degree of detail, which allows for a deeper understanding of how each activity contributes to the total cost.

The key differences between MHR and ABC are reflected in the way indirect costs are allocated. The MHR method uses a simplified calculation, based on the hours of use of the laptop (€2.63/h), without distinguishing between the types of activities. In contrast, the ABC method distributes these costs according to concrete activities, such as €160 allocated to research and writing, which provides a clearer picture of the contribution of each stage of the process.

At the level of detail, MHR is less granular, making it easier to apply in da-ta-limited situations. ABC, however, offers a more complex and accurate approach, requiring a detailed analysis of each activity and the resources consumed. Interestingly, in this case, both methods arrive at the same total cost of €1911 per item, a result made possible by the simplifying assumption that resources are distributed equally among the five items.

In terms of aspects that can be improved, in the case of the MHR method, the use of the laptop as the main resource for allocating indirect costs is less conventional. A more representative alternative could be the use of the researcher's total working time or a combination of several resources.

For the ABC method, the lack of detailed data on specific consumption per item limits accuracy. If, for example, an article involves several hours of documentation, then the cost of database access should be adjusted accordingly. In addition, both methods would benefit from an analysis of seasonal variations or differences between items, some works may be more complex and consume more resources than others.

Speaking of advantages and disadvantages, the MHR method has the advantage of being easy to apply, especially in contexts where there is a dominant resource. It also does not require the collection of large volumes of data. On the other hand, it ignores the differences between activities and can lead to a less precise allocation of costs in complex processes, such as scientific research.

The ABC method, on the other hand, allows for a detailed and realistic allocation of costs per task, which makes it easier to identify areas that can be optimized. It is more suitable in contexts where processes are diversified, and re-source consumption varies significantly. However, it requires detailed data and can be costly and time-consuming to implement.

IV. DISCUSSION

Convergence of results between MHR and ABC methods.

Both the Machine Hour Rate (MHR) method and the Activity-Based Costing (ABC) method led to the same total cost of €1,911 per item in the analyzed scenario. This uniformity of results is explained by a simplifying assumption, according to which indirect costs are divided equally between the five items, without reflecting the real differences in resource consumption.

Differences in approach in cost allocation.

The MHR method involves a proportional allocation of indirect costs according to the time of use of a single resource – the laptop. Thus, the 600 hours of annual operation translates into 120 hours per item, at a cost of €2.63/hour. This approach is reductive, as it places the laptop as a central resource, which is less realistic in the context of scientific research, where human resources, specialized equipment or access to databases usually have a more significant impact on costs.

In contrast, the ABC method provides a more nuanced picture, by assigning costs according to specific activities carried out in the drafting and publishing process (e.g., research, writing, technical support, access to resources, administrative activities). The costs are distributed based on the actual consumption of resources, which allows a more accurate estimate of reality – for example, €160 is allocated only for research and writing activities.

Recommendations for optimizing methods.

For the MHR method, it is recommended to reconsider the reference resource: re-placing the laptop with the researcher's total working time or with a composite model that includes more resources would allow for a more representative allocation of costs.

In the case of the ABC method, an improvement would be to introduce more precise cost factors, such as the number of hours worked for each activity associated with an item, and to adjust costs according to the complexity of each material (e.g. extensive documentation or frequent access to databases).

For both methods, it is recommended to consider sectional variations or differences between articles, as

some works may require significantly more resources than others.

Considerations on the relevance and applicability of the methods.

The ABC method is more suitable for the field of scientific research due to its high level of detail and the ability to allocate costs according to specific activities, thus facilitating better management of resources. Although the MHR method is simpler and faster to apply, it provides a less accurate picture, being limited by the fact that it is based on a single resource and does not capture variations between process steps. For a more realistic cost estimate, both methods should be supported by detailed data on the actual consumption of resources per item. However, in complex contexts such as the publication of scientific articles, the ABC method remains the preferable option.

V. CONCLUSIONS

Based on the case study, both costing methods, MHR and ABC, are correctly applied and arrive at the same total cost of €1911/item, due to the equal distribution of indirect costs between the five items. However, the ABC method is more suitable for scientific research, as it allocates indirect costs to specific activities, providing a detailed picture and allowing for the optimization of resources. The MHR method, although simpler, is less accurate, relying on a single resource (the laptop) and ignoring variations between activities. For more realistic results, both methods would benefit from detailed data on the specific consumption of each article, but ABC remains preferable for complex processes such as publishing a scientific article.

REFERENCES

[1] Mahadik, A., Masel, D. (2018). Implementation of Additive Manufacturing Cost Estimation Tool (AMCET) Using Break-down Approach. *Procedia Manuf*., 17, 70–77.

[2] Dogear, R., Yan, X.T., Millar, R.(2023). An extended cost analysis method for complex lightweight aircraft components manufactured with selective laser melting. Sn *Appl. Sci*., 5, 182.

[3] Enparantza, R., Revilla, O., Azkarate, A., Zendoia, J. (2006). A life cycle cost calculation and management system for machine tools. *In 13th CIRP international conference on life cycle engineering*, pp. 717-722.

[4] Niazi, A., Dai, J. S., Balabani, S., Seneviratne, L. (2006). Product cost estimation: Technique classification and methodology. *Review J Manuf Sci Eng Trans ASME*, 128 563-575).

[5] Ebbeken, K., Possler, L., Ristea, M. (2000). Calculaţia şi managementul costurilor. *Editura Teora,* Bucureşti, România,

[6] Dragomirescu, S., Solomon, D. (2007). Classical calculation methods of costs and their limits in actual frame of romanian economy. Present tendencies in cost accountancy. *Studies and Scientific Researches. Economics Edition*, "Vasile Alecsandri" University of Bacau, Faculty of Economic Sciences, issue 13.

[7] Soldan Cattani, N., Noronha, E., Schmied, J., Frieges, M., Heimes, H., Kampker, A. (2024). Comparative modeling of the costs of formats and chemicals of large-scale battery cells. *Batteries*, 10, 252. https://doi.org/10.3390/batteries10070252.

[8] Kádárová, J., Kočišová, M., Teplická, K., Suhányiová, A., Lachvajderová, L. (2022). Optimizing the costs and production process of fire dampers. *Aplic. Sci*., 12, 75. https://doi.org/10.3390/app12010075.

[9] Relich, M., Nielsen, I., Gola, A. (2021). Reducing the total cost of the product at the product design stage. *Appl. Sci*. 12. https://doi.org/10.3390/app12041921

[10] Relich, M., Świć, A. (2020). Parametric estimation and programming-based planning and simulation with constraints of the production cost of a new product. *Appl. Sci*, 10, 6330. https://doi.org/10.3390/app10186330

[11] Birle, V., Osan, A. (2025). Pilotarea activităţilor economice prin costuri. *U.T. Press Cluj-Napoca*. ISBN 078-606-737-748-4.

[12] Nishith, P., Gurudutta, P. J. (2018). Activity based costing- a tool of accurate costing. *Gap Interdisciplinarities – a global journal of in-ter-disciplinary studies*, 1(2):57-60.

[13] Smith, J.A. (2007). Management Accounting. *Elsevier Publishing,* New York, pp. 425-427.

[14] Tenovici, C. (2014). Utility of the method T.H.M. (Machine - Hour - Rate) Production century process automation. *Management Strategies Journal*, Constantin Brancoveanu University, vol. 26(4), pages 262-270.

[15] Bohatkiewicz-Czaicka, J. (2023). Calculation methodology of the hourly rates on the example of a specialist engineering company. *Scientific Papers of Silesian University of Technology Organization and Management Series*.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Enforced Environmental Management in Local Public Administration

Emanuel-Costel BĂLAN [1], Valentin-Luk IACOBESCU[2] and Mihaela BORAN [3]

Abstract – Environmental and climatic challenges across the world have led to increasing enforcement of regulations at any level, mostly at the local level, and especially in the EU. This study investigates how commune local authorities respond to enforced environmental management measures. By analyzing legal frameworks, local projects, and implementation barriers, the paper demonstrates both successes - such as projects in infrastructure, sewage, water, and separate waste collection - and constraints like administrative capacity and budget limitations. The findings highlight the need for combining enforcement with targeted support to ensure a sustainable local environmental governance.

Keywords: Environmental management, local administration, enforcement, sustainability, water systems, separate waste collection.

I. INTRODUCTION

Environmental management at the local government level has become increasingly important as municipalities face growing environmental challenges and regulatory requirements. This overview examines the concept of "enforced environmental management" in local public administration, synthesizing key themes and findings from academic literature and practical guidance. The focus is on how local governments implement, enforce, and maintain environmental management systems and regulatory compliance.

In the context of growing environmental pressures, all the world is looking for means of waste disposal, but most EU member states emphasize local compliance with directives such as the Water Framework Directive and Waste Framework Directive of the European Council, local administrations in all member states, thus becoming frontline actors responsible for translating these policies into practice.

This article examines how enforced environmental mandates influence administrative and operational practices in the communes of Romania without any refers to big cities in Romania. Environmental management represents a method to maximize well-being and to prevent and minimize possible environmental damage by organizing human activities that affect the environment.

II. ASPECTS RELATED TO THE LITERATURE REVIEW

a. Conceptual Framework

Defining Enforced Environmental Management is a complex approach that must consider the theoretical perspective of the concept and the practical implications [1; 2]. Enforced environmental management in local public administration refers to the systematic approach through which local governments ensure compliance with environmental regulations, standards, and policies through formal enforcement mechanisms. This includes:

1. **Regulatory Enforcement -** The application of legal and administrative tools to ensure compliance with environmental laws and regulations [1];
2. **Environmental Management Systems (EMS)** - Structured frameworks that help local governments systematically address environmental impacts [1; 2];
3. **Compliance-Focused Approaches -** Strategies specifically designed to achieve and maintain regulatory compliance [2];
4. **Accountability Mechanisms -** Systems that hold both the administration and regulated entities responsible for environmental outcomes [2].

Key Components of Enforced Environmental Management are presented in the following [12; 13].

First, and the most important component is the **Regulatory Framework and Governance -** The

[1] Politehnica University of Timisoara, Romania; emanuel-costel.balan@student.upt.ro
[2] Politehnica University of Timisoara, Romania; valentin.iacobescu@student.upt.ro
[3] Institution of Prefect – Timiș County, Romania; mihaela.boran@prefecturatimis.ro

literature identifies effective governance as a critical foundation for environmental management enforcement [12; 13]:

- **Institutional Design -** Research suggests that the structure of local environmental agencies significantly impacts enforcement effectiveness;
- **Regulatory Authority** - Clear delineation of enforcement powers and responsibilities is essential for effective implementation;
- **Policy Integration -** Environmental considerations must be integrated across all policy domains, not isolated in environmental departments;
- **Vertical Coordination -** Alignment between national, regional, and local environmental regulations creates more coherent enforcement.

The second aspect to be considered as a key component is the **Compliance-Focused Environmental Management Systems (CFEMS).** A significant theme in the literature is the development of environmental management systems specifically focused on compliance [12; 13]:

- **Structured Approach -** CFEMS provides a systematic framework for identifying compliance requirements, assessing risks, and implementing controls;
- **Operational Controls -** These systems establish procedures to ensure operations conform with environmental requirements;
- **Documentation and Record-Keeping -** Formalized systems for maintaining evidence of compliance activities;
- **Performance Measurement -** Regular monitoring and reporting mechanisms to track compliance status.

For example, the United States Environmental Protection Agency has developed guidance on CFEMS models that have been used as the basis for EMS requirements in many enforcement settlements.

The third component is the **Enforcement Mechanisms and Tools.** The literature identifies several key enforcement mechanisms employed by local administrations [12; 13]:

- **Inspections and Monitoring** - Regular site visits and environmental monitoring to detect violations;
- **Administrative Orders -** Formal directives requiring specific actions to achieve compliance;
- **Penalties and Sanctions -** Financial and legal consequences for non-compliance;
- **Injunctive Relief** - Court-ordered actions to address environmental violations;
- **Supplemental Environmental Projects -** Environmentally beneficial projects undertaken as part of enforcement settlements.

Research indicates that a balanced approach combining these mechanisms is most effective, with penalties serving as deterrents while compliance assistance promotes positive change.

The fourth component is **Public Participation and Accountability.** A growing body of literature emphasizes the role of public participation in strengthening environmental enforcement [12; 13]:

- **Citizen Complaints -** Research demonstrates that public demands measured by environmental complaints significantly influence environmental governance;
- **Transparency Mechanisms -** Public access to environmental performance data increases accountability;
- **Stakeholder Engagement -** Involving community members in environmental decision-making improves compliance outcomes;
- **Public-Private Partnerships** - Collaborative approaches between government, industry, and civil society enhance enforcement capacity.

b. Challenges in Enforced Environmental Management

The literature identifies several persistent challenges facing local governments in environmental enforcement. In the following we shall describe them briefly, by pointing out key aspects to be considered from the practical implications.

First, the **Institutional and Structural Challenges** are discussed by key aspects as described in the following [12; 13]:

- **Overlapping Authorities** - Jurisdictional confusion between different levels of government and agencies hampers effective enforcement;
- **Resource Constraints** - Limited budgets, staffing, and technical capacity restrict enforcement activities;
- **Political Interference** - Local political pressures may undermine consistent enforcement efforts;
- **Regulatory Fragmentation** - Disconnected environmental regulations create compliance difficulties.

Second aspects to be described are related to the **Implementation Challenges** [12; 13]**:**

- **Lack of Effective Enforcement Tools -** Many local governments lack appropriate mechanisms to ensure compliance;
- **Technical Complexity** - Environmental issues often require specialized expertise that may be unavailable locally;
- **Data Management** - Difficulties in collecting, analyzing, and utilizing environmental compliance data;
- **Balancing Approaches -** Finding the right mix between punitive enforcement and compliance assistance.

The third aspect to be considered and characterized is related to **Best Practices and Effective**

Approaches. The literature identifies several best practices for enforced environmental management in local public administration [12; 13]:

1. Systematic Management Approaches:

- **Integrated EMS Implementation**: Adopting comprehensive environmental management systems that align with local government operations and needs;
- **Risk-Based Prioritization**: Focusing enforcement resources on highest-risk activities and facilities;
- **Performance Measurement**: Establishing clear metrics to evaluate enforcement effectiveness;
- **Continuous Improvement**: Building feedback mechanisms to refine enforcement strategies based on outcomes;

2. Capacity Building and Resources:

- **Staff Training**: Investing in technical and legal training for enforcement personnel;
- **Technology Utilization**: Leveraging digital tools for monitoring, reporting, and data analysis;
- **Resource Sharing**: Pooling resources across jurisdictions to enhance enforcement capacity;
- **External Partnerships**: Collaborating with academic institutions and NGOs to access specialized expertise.

c. Emerging Trends and Future Directions

Recent literature points to several emerging trends in enforced environmental management [12; 13]:

- **Digital Transformation -** Increasing use of technology for remote monitoring, data analytics, and compliance reporting;
- **Climate Change Integration -** Growing focus on incorporating climate adaptation and mitigation into environmental enforcement frameworks;
- **Collaborative Governance -** Shift toward more participatory approaches involving multiple stakeholders;
- **Outcome-Based Enforcement -** Moving from process-focused to results-oriented enforcement strategies.

d. Preliminary Conclusions Related to the Literature Review

The literature on enforced environmental management in local public administration reveals a complex landscape requiring systematic approaches, clear authority, adequate resources, and public engagement. While challenges persist, evidence suggests that well-designed enforcement systems with appropriate tools and strategies can significantly improve environmental outcomes at the local level.

Effective enforced environmental management requires balancing regulatory enforcement with compliance assistance, leveraging public participation, and adopting systematic management approaches. As environmental challenges grow more complex, local governments will need to continue evolving their enforcement strategies to ensure environmental protection while addressing resource constraints and jurisdictional complexities.

III. LEGAL AND POLICY FRAMEWORK

a. Foundational Legal Frameworks

Effective environmental management at the local level is crucial for sustainable development and public well-being. This requires a robust legal and policy framework that defines responsibilities, sets standards, and provides mechanisms for enforcement. Local public administrations play a pivotal role in translating national and regional environmental objectives into actionable policies and ensuring their compliance within their jurisdictions. This document explores the key components of such a framework, drawing insights into various examples and general principles of environmental law and governance.

The legal and policy framework for environmental management at the local level typically originates from national legislation, which then delegates powers and responsibilities to subnational entities, including local public administrations. These frameworks are designed to provide a comprehensive approach to environmental protection, pollution control, and sustainable resource management. While specific laws vary by country, common elements include environmental protection acts, pollution control regulations, and provisions for environmental impact assessments. For instance, a robust framework, as exemplified by the Belize Environmental Protection Act, establishes a dedicated environmental authority (e.g., Department of the Environment, DOE) with broad regulatory and enforcement powers. This authority is typically tasked with monitoring implementation, enforcing provisions, and addressing environmental pollution. Their functions often extend to assessing water pollution, coordinating waste discharge activities, licensing environmentally impactful operations, and registering pollution sources. A critical aspect of such legislation is the empowerment of the environmental authority to approve Environmental Impact Assessments (EIAs), ensuring that proposed development activities consider and mitigate potential environmental harm [10]. Pollution control regulations are another cornerstone, addressing issues such as air, water, and soil contamination, including noise.

These regulations often set limits on emissions and discharge and define what constitutes harmful pollution to various environmental components like animals, wildlife, and vegetation. The enforcement of these regulations is usually vested in the same environmental authority responsible for the overarching environmental protection act [10]. Environmental Impact Assessment (EIA) regulations are crucial for proactive environmental management. They detail the processes for preparing and evaluating

EIAs, often categorizing projects based on their potential environmental impact.

These regulations typically mandate projects, programs, or activities to be assessed to protect human health, preserve ecosystems, and maintain biodiversity. They also often require public consultation and may impose conditions on development approvals to ensure environmental sustainability [10].

Beyond these core environmental laws, other sectoral legislation also contributes to the overall framework. For example, acts related to mines and minerals often regulate the extraction of natural resources and prohibit pollution of water bodies. Public health acts may include provisions for controlling nuisances that contribute to air, soil, or water contamination. Furthermore, national land acts provide a framework for land management, which indirectly supports environmental protection by regulating land use and development [10].

In essence, the foundational legal framework provides the necessary mandate and tools for local public administrations to manage environmental issues. It outlines the scope of their authority, the standards they must uphold, and the procedures they must follow to ensure environmental compliance and protection within their jurisdictions.

b. Enforcement Mechanisms and Policies

Effective environmental management is not solely about having comprehensive laws; it also requires robust enforcement mechanisms and policies to ensure compliance and deter environmental degradation. These mechanisms can be broadly categorized into administrative measures, judicial proceedings, and legislative frameworks, each playing a vital role in the environmental regulatory cycle [11]. Administrative Measures form the frontline of environmental enforcement. These include [11]:

- Inspections: Regular and systematic inspections are conducted to monitor compliance with environmental regulations and identify potential hazards. These can be routine checks or triggered by specific incidents or public complaints, allowing authorities to proactively identify non-compliance;
- Permits and Licenses: These are regulatory instruments issued to control activities with potential environmental impacts. They often come with specific conditions and requirements that must be met by the regulated entities to prevent environmental harm. Non-compliance with permit conditions can lead to administrative penalties or revocation;
- Administrative Orders: Environmental agencies can issue administrative orders to comply with regulations or to address specific environmental issues. These orders can mandate corrective actions, cessation of polluting activities, or remediation of environmental damage.

Judicial Proceedings serve as a critical backstop when administrative measures are insufficient or when severe violations occur. These can be either civil or criminal in nature:

- Civil Enforcement Actions: These are typically taken against individuals or organizations that have violated environmental regulations. Outcomes can include significant fines, penalties, injunctions requiring specific actions, or other forms of relief aimed at rectifying the environmental damage and deterring future violations [11].
- Criminal Enforcement Actions: Reserved for serious environmental offenses, these actions can result in substantial fines, imprisonment for individuals, or other severe penalties. Criminal enforcement aims to punish egregious violations and send a strong message about the importance of environmental protection [11].

Legislative Frameworks underpin all enforcement efforts by providing the legal authority and structure. Environmental laws establish the fundamental principles and standards for environmental protection, while detailed regulations provide the specific rules and requirements for implementing these laws. This hierarchical structure ensures that enforcement actions are legally sound and consistently applied [11]. For enforcement mechanisms to be truly effective, several strategies and best practices are employed:

- Targeted Enforcement Actions: Focusing enforcement efforts on high-risk activities or areas, such as industrial operations, mining, or construction, can maximize the impact of limited resources. This involves identifying activities with the greatest potential for environmental harm and prioritizing enforcement efforts accordingly;
- Economic Incentives and Disincentives: Beyond punitive measures, economic tools can promote compliance. Incentives, such as tax breaks or subsidies, can encourage environmentally friendly practices, while disincentives, like fines or pollution taxes, can deter non-compliance;
- Collaboration with Other Stakeholders: Engaging with non-governmental organizations (NGOs) and local communities can significantly enhance enforcement. NGOs often provide valuable expertise, monitor compliance, and advocate for environmental protection. Community engagement is crucial for gathering local insights and information about environmental issues, fostering a shared responsibility for environmental stewardship.

c. Overview of the Egal and Policy Framework

The legal and policy framework for enforced environmental management in local public administration is a multifaceted construct, essential for translating environmental aspirations into tangible outcomes. It comprises foundational legal instruments that define the scope of environmental protection and the powers of regulatory bodies, alongside a diverse array of enforcement mechanisms. These mechanisms,

ranging from administrative inspections and permits to civil and criminal judicial proceedings, are designed to ensure compliance and deter environmental degradation.

Effective implementation of this framework hinges on several critical factors: clear delegation of authority to local administrations, continuous capacity building for enforcement officials, transparent and accountable processes, and active engagement with all stakeholders, including the public and non-governmental organizations. Furthermore, the integration of economic incentives and disincentives can significantly enhance compliance rates, fostering a more proactive approach to environmental stewardship.

As environmental challenges continue to evolve, so too must the legal and policy frameworks. Continuous review, adaptation, and improvement of these frameworks are paramount to ensure they remain relevant, effective, and capable of addressing emerging environmental threats. By strengthening these pillars, local public administrations can play a more decisive role in safeguarding environmental quality and promoting sustainable development for their communities.

d. The case of the legal and policy framework in Romania

In the case of Romania, enforcement stems from multiple levels [3-9]:

- EU directives require proper wastewater treatment, stormwater management, and drinking water quality;
- Romanian legislation (Law 211/2011, 92/2021,2/2021,107/1996 195/2005 and their updates);
- Local council decisions approving technical documentation and financing for accessing and implementing environmental projects.

These instruments impose deadlines, bureaucracy, funding requirements, and compliance inspections, incentivizing administrative action to obtain national or European funds and avoid penalties, contrary to compliance the EU has other coercive measures like infringement for the states that do not comply in implementing the policies that were agreed upon [3-9].

IV. THE ROLE OF LOCAL ADMINISTRATION in ROMANIA – COMMUNE LEVEL

Most of the communes in Romania aligned to state policy and EU norms by implementing several projects under enforced mandates in several domains that affect environment like:

- Development of a potable water supply or expansion of potable water and centralized sewerage networks in Romania (Fig. 1), according to Environment Fund Administration the population covered by water supply areas in 2022 was estimated at 15.182.486 people, of whom 11.649.058 people live in settlements in large water supply areas an 3.533.428 people live in small water supply areas;

- Construction of stormwater infrastructure and rehabilitation of public lighting;

- Modernizing roads and public parks and green transport for bicycles (Table 1);

- Creating Voluntary drop-off centers, where inhabitants are allowed to bring some types of waste (Fig. 2);

- For local transportation and the community needs authorities have changed the old vehicles with combustion engines to electric cars and green transportation.

Local authorities secured technical and financial clarity for these actions with different partners both public and private (e.g., ADI intercommunity development associations AFIR, POIM, ADR, PNIAS and PNRR schemes) facilitating funding access, and by this time from the new European funding exercise, for sustainable development measures almost 14% is absorbed according to the Ministry of European Investments and Projects (Table 2).

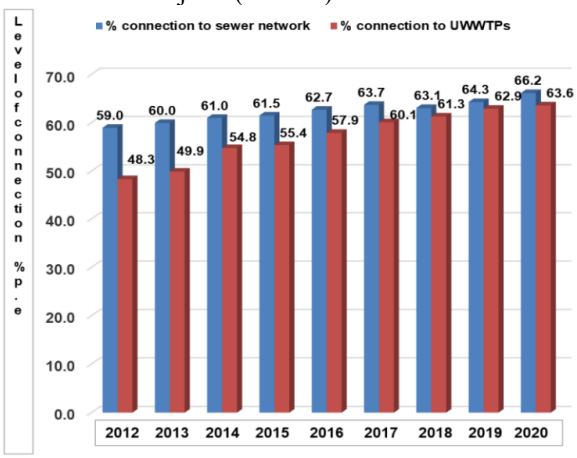


Fig. 1. Development of a potable water supply or expansion of potable water and centralized sewerage networks in Romania (according to the National Institute of Statistics in Romania)

Fig. 2. A voluntary drop-off center

Table 1. Modernizing roads and public parks and green transport for bicycles.

(1) Balanced response	(2) RST	(3) Growth, jobs…	(4) DNSH	(5) Green target	(6) Digital Objectiv	(7) Lasting impact	(8) Milestones and targets	(9) Cost setting	(10) Control systems	(11) Coherence	(12) REPowerEU	(13) Cross-border dimension
A	A	A	A	A (44,1 %)	A (21,8 %)	A	A	B	A	A	A	A

Source: https://mfe.gov.ro/ - This table reveals, at the 5th column, the fact that using European funds, within PNRR measures, that the green target shall be implemented in most of the projects.

Table 2. Absorption of European funds in different areas in the case of the Cohesion Fund (2021-2027).

Programe 2021-2027	ficiari	Prefinanțări primite de la CE		Sume solicitate CE în limita alocării UE a PO (rata de absorbție curentă)		Rambursări de la CE (rata de absorbție efectivă)		Total sumă primită de la CE	
	%	Valoare	%	Valoare	%	Valoare	%	Valoare	%
	3=(2/1)*100	4	5=(4/1)*100	6	7=(6/1)*100	8	9=(8/1)*100	10=4+8	11=(10/1)*100
P Transport	22,32%	116.262.884	2,50%	1.008.246.447	21,68%	468.257.841	10,07%	584.520.725	12,57%
P Dezvoltare Durabilă	40,46%	101.101.841	2,50%	915.562.255	22,64%	560.492.320	13,86%	661.594.161	16,36%
P Educație și Ocupare	5,55%	241.474.049	6,93%	47.512.973	1,36%	12.944.190	0,37%	254.418.239	7,30%
P Incluziune si Demnitate Sociala	17,07%	69.173.955	2,06%	513.390.223	15,25%	0	0,00%	69.173.955	2,06%
P Sănătate	2,39%	193.466.499	8,51%	0	0,00%	0	0,00%	193.466.499	8,51%
P Tranziție Justă	2,46%	674.010.393	31,50%	0	0,00%	0	0,00%	674.010.393	31,50%

Source: https://mfe.gov.ro/ (situation as of June 2, 2025)

Analyzing several cases of project implementation, and based on the informal discussions with different project managers and responsible people, some key obstacles have been identified, as follows [3-9]:

- Budget constraints: reliance on external grants (AFIR ADR, PNRR, county budgets). Internal budgets are insufficient, risking delays and infringement.
- Administrative capacity: small staff and poorly paid, needed external technical assistance for feasibility studies and compliance documentation.
- Community engagement: infrastructure works triggered temporary disruption (road closures, noise). Mitigation through public meetings and online petitions.
- Superficial compliance risk: Without monitoring, projects may tick the "compliance" box yet fail to long-term sustainability (e.g. operating costs and maintenance).
- Bureaucracy: slowing down decision-making and implementations of the project on all levels, from the local authorities to the funding organism
- Lack or very poor sustainability and ecological education in public schools.

V. CONCLUSIONS AND FINAL REMARKS

The synthesized set of conclusions of our study are presented in teh following:

1. **Enforcement Drives Local Change** Regulatory mandates - both from the EU and national legislation - have catalyzed significant environmental infrastructure improvements at the local level in Romania, especially in communes. These include water and sewage systems, stormwater management, waste collection, and green transport initiatives.
2. **Complexity Demands Capacity** Despite legal clarity and policy alignment, local authorities face systemic limitations: understaffing, financial dependency on external grants, and slow bureaucratic processes all hinder timely and effective implementation.
3. **Compliance ≠ Sustainability** While enforced compliance results in observable project initiation, long-term impact is not guaranteed. Risks include superficial adherence, lack of post-project monitoring, and insufficient maintenance budgets.
4. **Community Engagement is Critical** Projects that affect public space - like road modernizations and waste centers - require active involvement of residents. Public consultations and communication strategies help mitigate disruption and foster support.
5. **Balanced Governance is Essential** A mix of top-down enforcement with bottom-up support mechanisms (e.g., training, technical assistance, public participation) proves more effective than punitive compliance alone.
6. **Need for Continuous Evolution** Given the dynamic nature of environmental challenges, local enforcement frameworks must remain adaptive - integrating digital tools, transparent accountability systems, and climate resilience into their core strategies.

Enforced environmental management has triggered tangible infrastructure upgrades, whether is about sustainable sewage system, water pipes, public roads, waste services and many more, in the communes of Romania, still a lot of work to be done to comply to all

the norms. However, to bridge the gap between mandate and impact, the following are needed [3-9]:

1. Capacity building: Training and administrative grants for technical documentation;
2. Financial sustainability: Developing local environment funds and maintenance budgets;
3. Community involvement: Structured consultations and feedback loops;
4. Monitoring and evaluation: Regular impact assessments to ensure real environmental benefits.

The large volume of regulations and norms adopted at a very rapid pace in the EU and national laws of the member states, the small number of concrete and effective environmental management and of course enforcement measures have led to a poor implementation performance by the authorities. Local mandates drive- most of the time - change, but sustainable results require balanced support mechanisms integrating funding, expertise, and local participation.

VI. LIMITS OF THE RESEARCH

The presented study offers valuable insights, but like any research, it has its limitations. Here are the key ones:

1. **Scope Restriction to Romanian Communes** The research focuses exclusively on *commune-level administrations* in Romania, omitting large cities and urban municipalities. This narrows the generalizability of its findings.
2. **Descriptive, Not Evaluative** While it documents the existence of projects and challenges, the study stops short of conducting **quantitative evaluations** of environmental impact, efficiency, or long-term performance of enforcement strategies.
3. **Limited Empirical Grounding** Much of the evidence is based on policy analysis, secondary data, and anecdotal observations (such as informal discussions with project managers), rather than systematic surveys or field measurements.
4. **Absence of Community Perspective** Although it acknowledges community engagement as a factor, the study doesn't incorporate **direct voices from local residents**, which could offer insight into acceptance, resistance, or unintended consequences.
5. **Static Policy Snapshot** The legal and funding frameworks analyzed pertain primarily to **the 2021–2025 period**. Given the evolving nature of EU environmental policy, this temporal focus may miss emerging priorities like climate neutrality or nature-based solutions.
6. **Operational Metrics Are Missing** There's no assessment of **monitoring systems**, enforcement outcomes, or indicators tracking compliance beyond initial implementation stages.
7. **Limited Comparative Context** The study could benefit from **cross-country comparisons** or even cross-sectoral analysis (e.g. comparing environmental with health enforcement) to identify transferable best practices.

REFERENCES

[1] Andeobu, L., Wibowo, S., & Grandhi, S. (2021). An assessment of e-waste generation and environmental management of selected countries in Africa, Europe and North America: A systematic review. *Science of The Total Environment*, *792*, 148078.

[2] Appannan, J. S., Mohd Said, R., Ong, T. S., & Senik, R. (2023). Promoting sustainable development through strategies, environmental management accounting and environmental performance. *Business Strategy and the Environment*, *32*(4), 1914-1930.

[3] European Parliament & Council. (2000). Directive 2000/60/EC – Water Framework Directive.

[4] European Commission 2021

[5] Government of Romania. (2021). Legea 211/2011,OUG 92/2021, OUG 2/2021, OUG 107/1996 OUG 195/2005.

[6] The Enviroment Fund Administration of Romania - afm.gov.ro

[7] The Ministry for development, Public Works and Administration of Romania -National Investment Program Anghel Saligny mdlpa.ro

[8] https://mfe.gov.ro/

[9] European Commission. (2023). Environmental Implementation Review: Romania.

[10] Policy, Legal and Administrative Framework. Convention on Biological Diversity. Available at: https://www.cbd.int/doc/pa/tools/Policy,%Legal%and%Administrative%framework.pdf

[11] Lee, S. (). Enforcement Mechanisms in Environmental Law. Number Analytics. Available at: https://www.numberanalytics.com/blog/enforcement-mechanisms-environmental-law

[12] Shittu, O. S., Williams, I. D., & Shaw, P. J. (2021). Global E-waste management: Can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. *Waste Management*, *120*, 549-563.

[13] Singh, E., Kumar, A., Mishra, R., & Kumar, S. (2022). Solid waste management during COVID-19 pandemic: Recovery techniques and responses. *Chemosphere*, *288*, 132451.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Integrating Project Management and Nature-Based Solutions in Urban Ecosystem Planning

Valentin-Mihai VATAV[1], Lenuța-Zamfira HRIHOR[2], Ionel LUNGU[3], Izabela MACARIE[4]

Abstract - Nature-Based Solutions (NBS) have emerged as a vital strategy to enhance urban sustainability by integrating ecological functionality into the built environment. This paper explores the theoretical foundations of urban ecosystem services and the role of NBS in addressing contemporary environmental challenges. Drawing from recent interdisciplinary literature, it examines how structured project management can support the planning, implementation, and long-term success of NBS interventions. The analysis emphasizes the importance of adaptive planning, stakeholder engagement, and hybrid evaluation tools in ensuring ecological and social co-benefits. By integrating project management principles with nature-based approaches, cities can deliver scalable, measurable, and resilient ecosystem services. The findings offer a framework for aligning ecological innovation with institutional capacity, advancing the transition toward sustainable and livable urban futures.

Keywords: Urban ecosystem services, Nature-Based Solutions, project management, green infrastructure, climate resilience, adaptive governance, sustainable cities.

I. INTRODUCTION

Contemporary cities face increasing pressure to adapt to environmental challenges such as climate change, biodiversity loss, and the urban heat island effect. Traditional engineering approaches, while effective in the short term, have often failed to deliver long-lasting, socially inclusive, and ecologically sound results. In this context, Nature-Based Solutions (NBS) have emerged as a strategic alternative that leverages the power of ecosystems to address urban resilience and sustainability [1].

NBS are actions that protect, sustainably manage, and restore natural or modified ecosystems, simultaneously providing human well-being and biodiversity benefits [2]. In urban environments, they manifest through interventions such as green roofs, rain gardens, urban forests, or restored wetlands. These solutions are designed to enhance ecosystem services—including temperature regulation, stormwater management, air purification, and recreational value—thus improving the quality of urban life [3], [4].

Recent policy frameworks at the European level have emphasized the importance of scaling up NBS, highlighting their potential for mitigating climate risks, supporting green economic growth, and fostering social innovation [5]. However, the implementation of NBS at city scale remains fragmented. Often, these initiatives are limited to isolated pilot projects with insufficient institutional support, inadequate integration into urban planning, or a lack of long-term monitoring [6].

To address these limitations, the role of project management becomes increasingly critical. A structured project-based approach enables the coordination of technical, ecological, financial, and social components throughout the life cycle of NBS interventions. Project management methodologies can ensure that ecosystem-based projects meet strategic goals, respect timelines and budgets, and include mechanisms for stakeholder participation and adaptive learning [7], [8].

This paper aims to develop a theoretical and managerial framework for the integration of urban ecosystem services through project-managed NBS. It explores how project management principles can enhance the effectiveness and scalability of such interventions, while considering socio-ecological dynamics and institutional constraints.

By building on recent interdisciplinary research, the paper provides a synthesis of challenges and opportunities in aligning project management with ecosystem-based urban development [9].

[1] Politehnica University of Timisoara, Romania, valentin-mihai.vatav@student.upt.ro
[2] Politehnica University of Timisoara, Romania, lenuta.hrihor@student.upt.ro
[3] Politehnica University of Timisoara, Romania, ionel.lungu@student.upt.ro
[4] Politehnica University of Timisoara, Romania, izabela.macarie@upt.ro

II. THEORETICAL BACKGROUND

The conceptual foundation for Nature-Based Solutions (NBS) and urban ecosystem services stems from ecological economics, sustainability science, and adaptive urban governance. At the core lies the understanding that natural systems—if protected, restored, or integrated into the built environment—can provide a wide range of ecosystem services critical for urban sustainability [1], [2].

Urban ecosystem services are categorized into provisioning (e.g., food, water), regulating (e.g., climate, air quality), supporting (e.g., biodiversity, soil formation), and cultural (e.g., aesthetics, recreation) functions [2]. In dense urban settings, regulating and cultural services play a pivotal role in public health, well-being, and resilience against climate-related events. These services are typically mediated through green infrastructure, such as parks, vegetated facades, urban wetlands, and street trees [3].

Nature-Based Solutions, as a policy and scientific concept, advance the idea that these green systems can be purposefully designed to meet both ecological and societal needs. According to the European Commission, NBS are "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience" [2]. They differ from conventional green interventions by explicitly targeting multiple co-benefits, while being adaptable and locally contextualized [4], [5].

Recent typologies of NBS highlight their diversity, ranging from restorative (e.g., river rehabilitation), green retrofitting (e.g., rooftop vegetation), to hybrid solutions combining natural and engineered elements (e.g., permeable pavements) [4], [6]. The effectiveness of these interventions depends not only on ecological factors, but also on governance, spatial planning, and public acceptance [7].

Institutional studies emphasize that NBS are not “plug-and-play” technologies but require integrated planning frameworks, cross-sectoral collaboration, and long-term political commitment [6], [7]. The diffusion of NBS across cities in Europe has been uneven, with countries like Poland showing limited uptake due to governance fragmentation and insufficient coordination between municipal and regional agencies [8].

At the same time, the role of built surfaces (roofs, walls, and facades) is gaining attention, especially in high-density cities. These surfaces offer a latent potential for greening and improving energy efficiency, microclimate regulation, and biodiversity support [3], [9]. This architectural dimension of NBS further demonstrates the interdependence between ecological design and urban engineering.

In summary, NBS represents a convergence of ecological functionality and strategic urban development. Their implementation requires a comprehensive understanding of ecological processes, social systems, and institutional capabilities - making them a fertile ground for applied research and interdisciplinary management approaches.

III. PROJECT MANAGEMENT PERSPECTIVE ON URBAN ECOSYSTEM DEVELOPMENT

Despite the growing interest in Nature-Based Solutions (NBS), their implementation in urban environments remains inconsistent. One of the key challenges lies in the lack of structured project management frameworks tailored to ecological interventions. While traditional infrastructure projects benefit from well-established methodologies, NBS require adaptive and integrative approaches that can account for uncertainty, stakeholder diversity, and multi-dimensional outcomes [1], [2].

Project management offers tools and strategies for organizing resources, managing risks, and aligning objectives across teams and institutions. However, applying these principles to ecosystem-based interventions entails a shift from purely technical logic to a more systems-oriented and participatory approach [3], [4]. Effective NBS projects must integrate ecological complexity with social dynamics and institutional constraints - something that conventional project management often overlooks.

A first step toward this integration is scope definition and stakeholder mapping. Unlike linear infrastructure projects, NBS demand early involvement of local communities, planners, ecologists, and policy makers. Participatory co-design processes improve legitimacy, foster acceptance, and adapt solutions to local needs [1], [5]. For example, green corridor projects implemented in cities like Wrocław have shown better resilience outcomes when stakeholders were involved from the initiation phase [8].

Second, the planning and execution phases must incorporate flexibility and adaptive governance. Ecological processes are inherently dynamic; therefore, project timelines and resource allocations should be designed with feedback loops and contingency planning [6]. This involves iterative development, pilot testing, and monitoring phases that inform real-time decisions, like agile project models adapted from the software industry [7].

Third, performance evaluation poses a unique challenge in NBS projects. While traditional Key Performance Indicators (KPIs) may focus on budget and schedule, ecosystem-based interventions require multi-dimensional metrics: biodiversity gain, microclimate regulation, social cohesion, and aesthetic improvement [3], [9]. The use of hybrid evaluation tools—combining quantitative indicators (e.g., temperature reduction) with qualitative data (e.g., perceived well-being)—is necessary for a holistic assessment [4].

Moreover, financial planning in NBS projects must account for long-term maintenance, adaptive management, and cross-departmental budgeting. Green infrastructure investments often yield indirect benefits that are not captured in standard cost-benefit

analyses. Studies show that failing to recognize these values leads to underfunding and limited scalability [2], [7].

In sum, managing NBS as formal projects introduces both opportunities and complexities. A refined project management methodology—one that blends ecological awareness, stakeholder engagement, and adaptive monitoring—is critical to the success of nature-based urban interventions. Such a framework ensures not only that solutions are delivered on time and within scope, but also that they remain resilient, inclusive, and adaptable over time.

IV. DISCUSSION

The integration of Nature-Based Solutions (NBS) into urban development presents a compelling opportunity to address environmental, social, and economic challenges simultaneously. However, the operationalization of these concepts in practice reveals significant barriers related to institutional fragmentation, limited funding frameworks, and insufficient managerial integration [1], [6], [7].

A recurring theme in the literature is the need to move beyond isolated pilot projects and toward mainstream adoption through coordinated strategies. While many cities experiment with green roofs, urban gardens, or wetland restoration, these efforts are often disconnected from broader urban planning processes [2], [4]. Without robust project management tools, the potential of NBS remains underutilized. Long-term planning and post-implementation maintenance are rarely budgeted or monitored appropriately [7].

The role of governance is central to the scalability and impact of NBS. Studies show that cities with clearer institutional mandates and participatory governance structures are more likely to embed NBS into official strategies and regulatory instruments [6]. Conversely, in countries like Poland, where policy fragmentation and lack of vertical integration persist, the uptake of ecosystem services in planning remains low despite available funding [5], [8].

Furthermore, the value of ecosystem services is often underestimated in conventional cost-benefit analyses, which focus on short-term, measurable outcomes such as construction costs or energy savings [7]. Yet, NBS provide long-term co-benefits - like climate resilience, mental health improvements, and community engagement - that require new evaluation frameworks. The incorporation of hybrid metrics (quantitative and qualitative) enables more comprehensive assessments [3], [9].

From a managerial perspective, the shift toward adaptive project models is critical. Static planning processes fail to accommodate the dynamic nature of ecosystems. Instead, agile, feedback-based methods - characterized by iterative development and real-time learning - enhance the resilience and responsiveness of NBS projects [4]. Such approaches also improve stakeholder trust and increase the legitimacy of decisions, particularly when local communities are involved in co-creation [1], [6].

A promising but underexplored area is the use of urban surfaces—walls, roofs, and facades—as ecological assets. Studies highlight the multifunctionality of these spaces, from energy efficiency and biodiversity support to stormwater absorption [3], [9]. Including these features in urban project portfolios could dramatically increase the ecological footprint of NBS with minimal land-use conflicts.

Finally, there is growing recognition that nature-based approaches are not just environmental tools, but also strategic investments in economic transformation. As highlighted by Sorrell [7], the transition toward green growth demands integrated planning, systemic thinking, and a willingness to invest beyond short-term political cycles. Project managers, therefore, play a crucial role not only in delivery, but also in framing NBS as drivers of long-term urban sustainability.

V. FIVE BEST PRACTICES OF NATURE-BASED SOLUTIONS PROJECTS IN ROMANIA

In this chapter shall be discussed five NBS projects in Romania demonstrating the efforts of the local authorities for implementing such initiatives for mitigating the climate change effects in the cities or metropolitan areas.

1. Văcărești Natural Park Urban Wetland Management, located in Bucharest, Romania. This park represents Romania's first urban nature park, a 183-hectare area just 5 kilometers from Bucharest's city center. This former abandoned reservoir has naturally evolved into a flourishing urban wetland over three decades, providing cost-effective ecosystem services in the heart of Romania's capital.

The best practices demonstrated by this urban nature park are:

- Community-led conservation - The Văcărești Nature Park Association successfully advocated for protected status (achieved in 2016) and developed a volunteer-based management system that engages local citizens in conservation efforts;
- Urban biodiversity monitoring - The park implements systematic monitoring of over 150 bird species, numerous mammals, reptiles, and amphibians, creating a valuable biodiversity database in an urban context;
- Educational programming - Regular guided tours and educational programs for schools' help raise awareness about urban ecology and the importance of wetlands for climate resilience;
- Water management - The wetland serves as a natural water retention area, helping

to mitigate urban flooding while supporting diverse ecosystems.

2. Sustainable Forest Management in the Carpathian Mountains, located in the Carpathian Mountains, Romania. As is already known, Romania hosts some of Europe's largest areas of relatively untouched forests, particularly in the Carpathian Mountains. Several projects have implemented sustainable forestry practices that balance conservation with economic needs.

The best practices demonstrated by these NBS projects are:

- Continuous cover forestry - Moving away from clear-cutting to selective harvesting that maintains forest cover and structure, preserving ecosystem functions while still producing timber;
- Deadwood retention - Deliberately leaving dead trees and fallen logs in managed forests to support biodiversity, with Romania's projects demonstrating that 30-40 cubic meters of deadwood per hectare significantly increases forest biodiversity;
- Forest certification - Implementation of Forest Stewardship Council (FSC) certification across over 2.8 million hectares of Romanian forests, ensuring sustainable management practices;
- Old-growth Forest protection - Identification and special protection measures for Romania's remaining old-growth forests, which serve as biodiversity hotspots and carbon sinks.

3. Danube Floodplain Restoration is in the Lower Danube River, Romania. In a brief description, Romanian authorities have implemented several floodplain restoration projects along the Danube River, reconnecting former floodplains to the river system to restore natural flood protection and enhance biodiversity.

The collection of best practices underlined by these NBS projects are:

- Dike relocation - Strategic relocation of dikes to give rivers more room, creating space for natural flooding processes while protecting settlements;
- Wetland restoration - Rehabilitation of approximately 7,000 hectares of wetlands along the Danube, restoring natural water retention capacity;
- Cross-border collaboration - Joint management with neighboring countries (Bulgaria, Ukraine) for coherent floodplain restoration along the Lower Danube Green Corridor;
- Monitoring ecosystem services - Systematic assessment of multiple benefits including flood protection, improved water quality, enhanced biodiversity, and carbon sequestration.

4. Urban Blue-Green Infrastructure in Romanian Cities are in multiple cities across Romania. Furthermore, several Romanian cities have implemented integrated blue-green infrastructure projects to address urban challenges related to stormwater management, urban heat islands, and biodiversity loss.

The best practices demonstrated by this urban nature park are:

- Permeable surfaces - Replacement of impermeable surfaces with permeable alternatives in urban areas to reduce runoff and enhance groundwater recharge;
- Rain gardens and bioswales - Strategic implementation in urban areas to capture and filter stormwater while creating aesthetic green spaces;
- Green roofs and walls - Installation on public buildings to reduce energy consumption, mitigate urban heat island effects, and support biodiversity;
- Integrated planning - Coordination between water management, urban planning, and environmental departments to develop comprehensive blue-green infrastructure networks.

5. Ecological Connectivity in the Carpathian Region is in the Carpathian Mountains, Romania. Local and central authorities of Romania together with non-governmental organizations have implemented several projects to maintain and restore ecological connectivity in the Carpathian region, ensuring wildlife movement and ecosystem resilience.

The collection of best practices underlined by these NBS projects are:

- Wildlife corridors - Identification and protection of critical wildlife corridors, particularly for large carnivores like bears, wolves, and lynx that require extensive territories;
- Green bridge construction - Implementation of wildlife overpasses and underpasses at key transportation infrastructure to reduce habitat fragmentation and wildlife-vehicle collisions;
- Participatory mapping - Engagement of local communities and stakeholders in identifying and protecting ecological corridors through participatory mapping exercises;
- Cross-sectoral planning - Integration of ecological connectivity considerations into transportation, agriculture, forestry, and urban planning sectors.

VI. CONCLUSIONS

Nature-Based Solutions (NBS) offer an integrative and sustainable pathway to address the ecological,

social, and economic challenges of contemporary urban environments. This paper explored the theoretical foundations of urban ecosystem services and NBS, examined their application in real-world contexts, and emphasized the role of structured project management in enhancing their effectiveness.

The review of the literature reveals that while the ecological benefits of NBS are well documented - ranging from climate regulation to mental health and biodiversity support - their implementation remains hindered by fragmented institutional arrangements, limited evaluation capacity, and lack of strategic integration into urban development plans [2], [5], [6].

Integrating project management methodologies into the lifecycle of NBS interventions addresses many of these challenges. It provides a structured framework for stakeholder coordination, budgeting, adaptive planning, and performance monitoring. This approach improves not only operational efficiency, but also the legitimacy, durability, and scalability of ecosystem-based interventions [1], [4], [8].

A key insight is that effective NBS management requires multi-disciplinary collaboration and the adoption of hybrid evaluation tools that capture both tangible and intangible outcomes. Moreover, new urban opportunities - such as the ecological redesign of walls, rooftops, and facades - should be systematically included in planning efforts [3], [9].

For long-term transformation, NBS must be recognized not just as environmental solutions but as strategic investments in climate resilience, social inclusion, and green economic growth. This requires a shift in both political vision and institutional practice. Project managers can play a pivotal role in this transition by championing integrative approaches and by embedding sustainability goals throughout the project lifecycle [7].

In conclusion, embedding project management into the development of urban ecosystem services through NBS creates a powerful synergy. It ensures that nature-based interventions are not only visionary, but also deliverable, measurable, and adaptable - qualities essential for building truly resilient and livable cities.

REFERENCES

[1] N. Seddon, A. Chausson, E. A. Berry, C. A. Girardin, A. Smith, and B. Turner, "Getting the message right on nature-based solutions to climate change," *Global Change Biology*, vol. 27, no. 8, pp. 1518–1546, 2021.

[2] N. Kabisch, H. Korn, J. Stadler, and A. Bonn, *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages Between Science, Policy and Practice*. Springer, 2020.

[3] J. N. Wong, S. Jusuf, and L. Zhang, "Greenery as a mitigation and adaptation strategy to urban heat," *Renewable and Sustainable Energy Reviews*, vol. 147, 2021.

[4] J. Gao, H. Wang, and T. Zhang, "Urban nature-based solutions for climate adaptation: A typology and mapping framework," *Science of the Total Environment*, vol. 774, 2021.

[5] J. Kronenberg et al., "A brief overview of the current state of NBS implementation in Poland," in *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*, Springer, 2020, pp. 245–259.

[6] H. Bulkeley, V. Castán Broto, and M. Edwards, "Governing urban nature-based solutions: An institutional analysis," *Science of the Total Environment*, vol. 755, 2021.

[7] S. Sorrell, "Pathways to net zero: the role of green investments and systemic transition," *Renewable and Sustainable Energy Reviews*, vol. 156, 2022.

[8] V. Marando et al., "Nature-based solutions for flood mitigation and their effectiveness in urban planning," *Science of the Total Environment*, vol. 834, 2022.

[9] D. Enzi et al., "Nature-based solutions and buildings – the power of surfaces," in *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*, Springer, 2020, pp. 161–173.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Integrating New Emerging Technologies to Enhance User Experiences in Hospitality Industry. Developing Digital Tourism

Marius MIHUT[1], Hazem ABU-AWWAD [2] and Viorica BAESU[3]

Abstract – The hospitality industry is constantly changing, adapting to new customer preferences, adopting emergent technologies and increasing the intensive use and valorization of the local resources (e.g., accelerated digitalization, increased concern for versatile and sustainable solutions). The present research explores the impact and potential of digital technologies in transforming the hospitality industry, focusing particularly on the emergence and development of digital tourism, by analyzing its evolution, from the integration of virtual and augmented reality (VR/VA) technologies to the implementation of artificial intelligence (AI) and digital tokens, highlighting how these innovations are redefining tourists' experiences with destinations and service providers. Through a mixed methodology, which combines literature review (synthesis and analysis) with qualitative research, this article aims to provide a comprehensive perspective on the challenges and opportunities brought by digital tourism in the new context of the hospitality industry. Thus, a qualitative study, based on semi-structured interviews with hospitality industry professionals, provided valuable insights into the implementation and the future of technologies used in the development of digital tourism. The results of this study make significant contributions to the specialized literature by identifying key factors in the development of the digital tourism in Romania, proposing solutions for balancing digital innovation with a strong impact on increasing the authenticity of travel experiences, and improving relationships with service providers by attempting to provide solutions in managing excessive tourism.

Keywords: Digital tourism, technology, user experience, hospitality industry, services.

I. INTRODUCTION

After the Covid-19 pandemic the hospitality industry enter a new era of development, trying new strategies of sustainable development, resilience and being impacted by the accelerate introduction and use of the digital technologies (Ntounis, et al., 2022). In most areas, disruptive innovations have transformed the way processes are developed (Buhalis, et all., 2019; Lee, et al., 2021; Buhalis, et al., 2024; Chon & Hao, 2025). Thus, the integration of emerging technologies in the hospitality industry significantly enhances user experiences by optimizing service delivery and personalizing interactions.

Technologies such as artificial intelligence (AI), virtual and augmented reality (VR/AR), and the Internet of Things (IoT) are transforming traditional hospitality models, enabling hotels to offer tailored services and improve operational efficiency (Kannan, 2024; Chon & Hao, 2025). The key technologies enhancing user experience are already present to support different services and operations, as follows.

Artificial Intelligence (AI) applications, including chatbots and personalized recommendations, streamline guest interactions and automate routine tasks, leading to improved satisfaction (Budianto, et al., 2024; Chon & Hao, 2025). Virtual Reality (VR) platforms provide immersive previews of services, enhancing event experiences and facilitating better logistics (Sjukriana, et al., 2024). Augmented Reality (AR) has been introduced by touristic agencies to support pre-visualization of the offers (destinations, excursions, hotels interior visualization etc.). Technology significantly enhances the tourist experience by providing immersive, interactive, and personalized engagements that bridge the gap between the physical and digital worlds. This technology not only enriches the way tourists interact with their surroundings but also fosters emotional connections

[1] Politehnica University of Timisoara, Romania; marius.mihut@student.upt.ro
[2] The National University of Political Studies and Public Administration, Romania, hazem.abu93@yahoo.com
[3] "Ioan Slavici" University of Timisoara, Romania, viorica.baesu@islavici.ro

and deeper understanding of destinations (Almujareb, et al., 2024; Sánchez-Juárez & Paredes-Xochihua, 2024). IoT devices allow for smart room controls and personalized service delivery, anticipating guest preferences and optimizing resource management (Talukder, et al., 2024; Chon & Hao, 2025). Block chain technologies have the potential to revolutionize the tourism industry by bringing transparency, security and innovation to the forefront. These technologies can improve waste management, security of the transactions and improve overall the marketing of the services (Önder & Gunter, 2022).

The studies in literature are still in the beginning phase and more explain the use of these technologies in tourism services despite other articles provided by the internet-related technologies providers companies (Sarnacchiaro, et a., 2024). The same situation is in the case of using crypto currency in the hospitality industry.

The adoption of the digital technologies field must consider the challenges faced by human resources and managers (e.g., as investments pressure). Some important challenges presented in the literature are:

(a) balancing automation and human interaction because while technology enhances efficiency, maintaining a personal touch remains crucial for guest satisfaction (Kishore et al., 2024);

(b) data security and privacy because the integration of advanced technologies raises concerns regarding data protection, necessitating robust security measures (Talukder et al., 2024).

Despite the benefits, the hospitality industry must navigate challenges such as employment displacement and the need for significant investment in technology and training (Kishore et al., 2024). Balancing technological advancements with human elements will be essential for future success in this industry.

In this dynamic context of adoption, digital innovation in the hospitality industry, the present research aims to explore and characterize the impact and potential of digital technologies in transforming the hospitality industry, focusing particularly on the development of digital tourism. The mixed methodological approach aims to support investigations and provide a comprehensive perspective on the challenges and opportunities brought by digital tourism in the new context of the hospitality industry. In the end of the paper, a set of conclusions are presented.

II. LITERATURE REVIEW

Digital tourism development is a transformative force in the tourism industry, leveraging digital technologies to enhance efficiency, sustainability, and customer experience. This development is characterized by the integration of digital tools such as big data, mobile applications, e-commerce, and sharing economy platforms, which collectively contribute to the sustainable growth of tourism sectors across various regions (Bekele & Raj, 2024).

The first stage of digital tourism development led to the emergence of online travel agencies (OTAs) and comparison sites, gradually replacing traditional channels of services distribution. The rise of OTAs and search engines opened new possibilities for travelers, allowing them to compare prices, read reviews and easily make informed decisions. This change has not only given consumers more decision-making power but has also forced traditional intermediaries in the tourism industry to adapt.

Smart destinations use a network of interconnected systems to improve visitor experience and resource management. This includes the use of location-based services and the IoT to optimize resource management and improve tourist interactions (UNWTO, 2024). Furthermore, digital tourism has expanded into the realm of social media and user-generated content. Platforms such as Instagram, TripAdvisor, and YouTube have become essential tools for destination marketing and travel decision-making.

The ability of tourists to share their experiences in real time has given rise to a form of word-of-mouth marketing that can greatly influence travel trends and destination popularity (Han et al., 2018; Bekele & Raj, 2024; Chon & Hao, 2025). As a global overview, Table 1 presents a synthesis of the key aspects of digital tourism development, drawing insights from multiple studies presented in literature.

While digital tourism development offers numerous benefits, it also presents challenges that need to be addressed to realize its full potential. The digital divide, regulatory barriers, and the need for enhanced digital literacy are significant hurdles that must be overcome. However, with strategic policies and investments in technology infrastructure, digital tourism can significantly contribute to sustainable development and economic growth in the tourism sector, as supported by the European Commission, too (EC, 2025a).

Table 1. Key aspects of digital tourism development.

Key aspect	Field of actions, arguments and debates	References
Role of digital technologies in tourism	*Big Data and Predictive Analytics*: Big data analytics are used to predict consumer preferences, allowing tourism businesses to tailor services and improve customer satisfaction. This approach enhances service quality and operational efficiency, contributing to sustainable tourism practices *Mobile applications and e-commerce*: Mobile apps facilitate navigation and information access for tourists, while e-commerce platforms streamline booking and purchasing processes. These tools increase the availability and accessibility of tourism resources, particularly in transition economies	(Konar et al., 2024; Polukhina et al., 2025)

	Digital co-creation and personalization: Technologies such as AI and IoT enable personalized travel experiences, fostering a collaborative environment where tourists actively participate in creating their travel experiences. This shift from traditional to service-oriented approaches enhances authenticity and community building.	
Impact on sustainable development	*Environmental and economic benefits* - Digital solutions help reduce the environmental impact of tourism by optimizing resource use and promoting sustainable practices. They also drive economic growth by increasing tourism efficiency and competitiveness, as seen in regions like China and Greece. *Community empowerment and cultural preservation* - Digitalization supports community empowerment by creating new business models and preserving cultural heritage. This is particularly evident in alternative tourism markets, where digital tools enhance local ventures' competitiveness.	(Magoutas, et al., 2024; Zhang & Cheng, 2024)
Challenges and opportunities	*Regulatory and infrastructure barriers* -: In some regions, such as Indonesia, regulatory challenges and inadequate technological infrastructure hinder the full potential of digital tourism development. Addressing these issues through improved regulations and strategic policies is crucial for sustainable growth. *Digital literacy and education* - The integration of digital tools in tourism education enhances students' skills and adaptability in the digital landscape. However, there is a need for further development in media and digital literacy to maximize these benefits.	(Julianti & Pinpak, 2024; Rodríguez & Rodríguez, 2025)
The focus of future directions	*Smart development and innovation* - The future of digital tourism lies in the smart development of technologies that integrate deeply with the tourism economy. This includes the creation of new scenarios and modes of tourism that leverage digital intelligence for enhanced experiences. *Addressing the digital divide* - Bridging the digital divide is essential to ensure equitable access to digital tourism benefits. This involves expanding technology applications and overcoming challenges related to IT security and data privacy.	(Wu et al., 2024; Singh et al., 2024)

Source: Authors own development

III. RESEARCH METHODOLOGY

The research methodology has been designed having two specific stages:

(1) The analysis of the digital tourism indicators based on the EU Tourism Scoreboard (2025) supporting the analysis based on secondary data which has allowed a comparison of the Romania vs. EU27 status. It is well-known that, "the EU Tourism Dashboard offers interactive visualizations of data and indicators relevant for the European tourism ecosystem". The EU Tourism Dashboard operates with indicators related to the green, digital and socio-economic EU policy pillars which allow "profiling EU countries and monitoring their progress towards more sustainable tourism in environmental, digital and socio-economic terms". For the aim of this research, there have been considered and analyzed only the indicators related to the digital pilar. The research results interpretations are based on the graphical representation of the digital indicators for Romania and EU27;

(2) Qualitative research based on a semi-structured interview. At this stage of the research, the interest was to investigate operational aspects of Romania digital tourism, with a focus on security, user experience, and technological innovation. The main objectives followed by the qualitative research were:

- Understanding the current state and challenges in implementing digital tourism technologies from the information technology (IT) perspective;
- Exploring security measures and concerns related to digital tourism platforms;
- Investigating the role of emerging technologies (AI, VR/AR) in shaping the future of digital tourism;
- Identifying potential barriers and solutions for the wider adoption of digital tourism technologies;
- Collecting expert opinions on the integration of digital technologies with traditional tourism experiences.

The moderator has an interview guide available, containing a series of questions to be asked, to obtain as much relevant data for the research as possible. The research was addressed to professionals in the hospitality industry, from organizations in Romania. Since the research is exploratory, it was not aimed at obtaining a random statistical sample. Instead, participants who fit the objectives of the study were distinctly selected (20 professionals who accept the invitation that have more than five years of experience in the field and have different managerial positions). The data collection method was carried out through five online interviews organized with four participants each, via Zoom.

The data analysis (analysis of each interview) has been supported by the read.ai application connected to each Zoom meeting of interviews. This AI software act as a participant in the meeting, "taking notes" (record

each participant intervention time, including the moderator behavior) and creating a summary, and key take aways of the meeting. The results interpretation provided by read.ai has been refined by a focus group organized by the authors of this article. These results have been centralized and in-deep analyzed by each question.

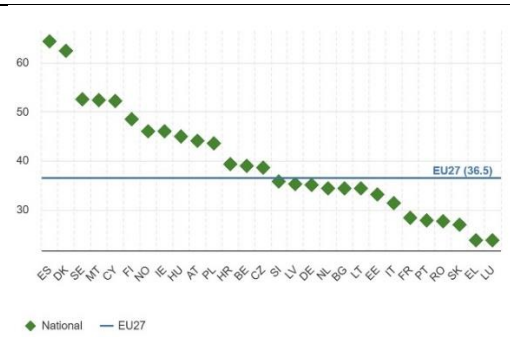
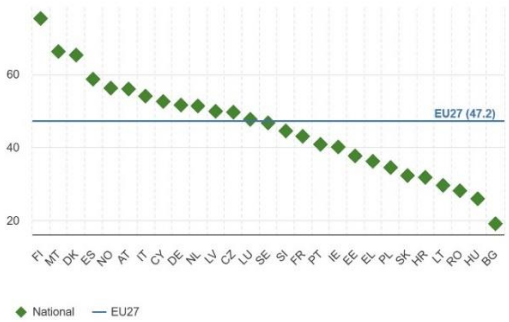
IV. RESULTS AND DISCUSSIONS

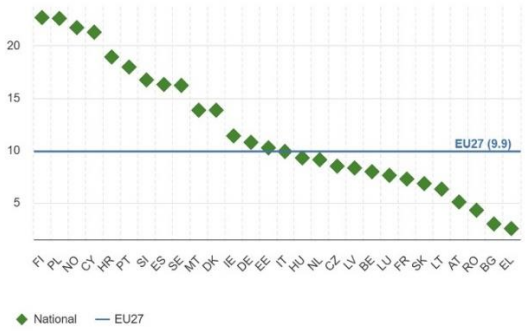
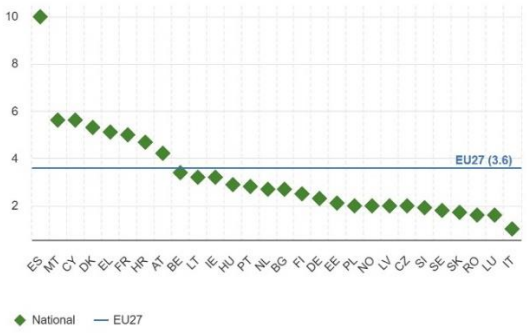
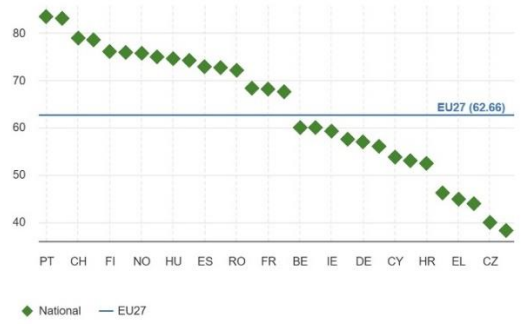
a. The Analysis of the Digital Tourism Indicators at the European Level

The EU Tourism Scoreboard (EC, 2025b) allows interactive access to data and indicators relevant to the European tourism ecosystem, including those related to the digitalization of tourism services. Thus, based on the functionalities of this online tool, an analysis (based on secondary data, provided by the Eurostat database) of the digital transition of European tourism was carried out, which provided a precise overview that can support operators in the field in developing evidence-based strategies. In addition, the platform also provides information on platforms, applications available at the level of each EU country in the field of digitalization of tourism services.

For this research, a comparative debate between Romania and the EU27 has been developed based on the allow profiling of EU countries and monitoring their progress towards the digital tourism. This secondary data analysis approach has been developed based on the EU Tourism Scoreboard and by considering only the digital tourism indexes (see Table 2). As can be observed, the only index in which Romania has a superior situation than the EU27 level is the “Internet speed at tourism destinations” (%). For the other analyzed indices, values far from the EU27 average are observed, which demonstrates that Romanian digital tourism is poorly developed, but as in the future, the situation can be maintained because of the "Personnel training on digital skills" (%) value and then due to the situations presented by the "Enterprise using social media" index (%) and the "Enterprises seeking ICT specialists" index (%) values.

Table 2. The digital pilar index characterizing the digital tourism development.

Index	Distribution per EU countries	Index for Romania	Index for EU27
E-commerce sales (%) based on the data available for 2023	 Source: ICT usage in enterprises, Eurostat (table: isoc_ec_eseln2, 2-digit NACE sectors considered: I55-I56, N79; weights from table: sbs_na_sca_r2).	27,7%	36,5%
Enterprise using social media (%) based on the data available for 2023	 Source: ICT usage in enterprises, Eurostat (table: isoc_cismt, 2-digit NACE sectors considered: I55-I56, N79; weights from table: sbs_na_sca_r2)	28,1%	47,2%

Personnel training on digital skills (%) based on the data available for 2022	 Source: ICT usage in enterprises, Eurostat (table: isoc_ske_ittn2, 2-digit NACE sectors considered: I55-I56, N79; weights from table: sbs_na_sca_r2).	4,3%	9,9%
Enterprises seeking ICT specialists (%) based on the data available for 2022	 Source: ICT usage in enterprises, Eurostat (table: isoc_ske_itrcrn2, 2-digit NACE sectors considered: I55-I56, N79; weights from table: sbs_na_sca_r2).	1,6%	3,6%
Internet speed at tourism destinations (%) based on the data available for 2023	 Source: JRC, based on: Ookla (internet speeds); TripAdvisor (location of tourism accommodation capacity).	72,02%	62,66%

Source: Authors synthesis based on the data available at (EU Tourism Dashboard, 2025).

Table 3. The qualitative research results (results from the five online semi-structured interviews)

Question	Comments synthesis, refined from those provided by read.ai after each online meeting	Interpretations and conclusions
What do you think are the biggest challenges in implementing digital tourism technologies?	User adoption and education represent a significant challenge. Respondents highlighted resistance to change and the need for training of both tourists and industry personnel. Financial and infrastructural aspects constitute another important barrier. The implementation of these technologies requires substantial investments, both in the development and maintenance phases. The lack of adequate infrastructure was also mentioned as a major impediment. Data security and the protection of personal information stand out as a central concern. The considerable volume of personal and financial data processed in the tourism sector accentuates this issue.	The successful implementation of digital solutions in tourism faces a multifaceted array of challenges. Overcoming resistance to change through comprehensive user adoption and education programs for both tourists and industry personnel is crucial. Significant financial investment and the development of adequate infrastructure are prerequisites for deployment. Furthermore, robust data security measures and the protection of personal information are paramount concerns that must be addressed proactively. Ensuring seamless integration and interoperability across

	Integration and interoperability of systems represent another major challenge. Effective coordination between various actors in the sector is necessary. Ensuring equitable access to technology for all stakeholders was identified as a major challenge in implementing digital solutions in tourism.	diverse systems and fostering equitable access to technology for all stakeholders are also essential for realizing the full potential of digitalization in the tourism sector. Addressing these interconnected challenges holistically will be key to unlocking the benefits of digital transformation and fostering a more efficient, sustainable, and inclusive tourism industry.
What are the main cybersecurity risks in digital tourism platforms?	Theft and exposure of personal data: Almost all respondents mentioned this risk, underlining the importance of protecting users' personal information. Phishing and social engineering attacks: Several respondents highlighted these types of attacks as significant risks. Vulnerabilities in payment and reservation systems have been mentioned as the risks associated with online payment and reservation systems. Identity theft was explicitly mentioned by two respondents, but implicitly in many other responses that refer to unauthorized access to personal data. Ransomware and Denial-of-service attacks (DoS) that can block the functioning of hardware infrastructure. Lack of necessary skills in the case of staff, which can lead to vulnerabilities in security systems. Impact on customer trust, referring to the long-term consequences of possible security breaches in hospitality establishments. Large-scale vulnerabilities, referring to the potential impact on many users in the event of a successful cyberattack.	Overall, the responses cover a wide range of cybersecurity risks relevant to digital tourism platforms. They reflect a good understanding of the security challenges in this area, from common risks such as phishing and data theft, to more specific concerns related to new technologies and the impact on customer trust. The diversity of responses provides a comprehensive picture of the perceptions of security risks of hospitality industry managers in adopting and promoting digital tourism, which is a valuable result for a qualitative study.
How do you see AI and machine learning transforming the hospitality industry?	Personalization was identified as a key aspect of the transformation brought by AI and ML in industry operations. This includes personalized offers, intelligent recommendations and experiences tailored to individual needs. The importance of AI-based recommendation systems to suggest suitable destinations, activities or offers was highlighted. Respondents mention improving operational efficiency by automating processes and analysing data in real time. The role of virtual assistants and chatbots in improving communication with customers and providing rapid information is highlighted. The ability of AI and ML to optimize prices and dynamically adjust offers, to analyse customer behaviour and trends (through the ability of AI and ML to analyse search patterns and tourist behaviours to anticipate trends) was highlighted. The usefulness of AI for automatic content generation to update and improve websites or social media presence of units in the hospitality industry was highlighted. Virtual tourism is associated with the concept of virtual travel, to help those who cannot travel physically. This is often overlooked, but technological advances can bring great benefits to such social categories. Security risks and threats are highlighted in the use of AI and ML in tourism, as well as the possibility of these technologies being used by cyber attackers.	Overall, the responses provide a comprehensive and nuanced picture of how AI and machine learning are perceived as transformative factors in the tourism industry, reflecting both the opportunities and challenges associated with these technologies.
How can VR/AR technologies be better integrated into the travel experience?	Pre-trip virtual tours are positively appreciated by most respondents as an important way to help tourists explore and choose destinations before traveling. Enriching cultural and historical experiences supports the potential of VR/AR to provide historical and cultural context, as well as interactive reconstructions of historical sites. The use of augmenting the on-site experience by using VR/AR to add interactive information and context during actual visits is highlighted. Improving tourism marketing is supported by using VR/AR to improve the presentation and promotion of destinations.	All the ideas presented are in line with current trends and the recognized potential of VR/AR in tourism. There is a broad understanding of the potential of VR/AR to enhance the tourist experience at all stages: pre-trip, during the trip and post-trip. Respondents emphasize the importance of balancing technology with the authenticity of real experience. The answers refer to specific applications (such as digital information boards, QR codes) to

	Navigation and orientation are mentioned as supporting interactive guide-type applications that can be accompanied by simulations and immersive experiences (for tourist activities and exploring inaccessible destinations). The wider possibility of personalizing the experience offered by the potential of VR/AR technologies. The association with mobile applications and reservation systems can be achieved by integrating VR/AR with other digital technologies in tourism. Providing more powerful post-travel experiences through VR/AR for creating digital souvenirs or memento experiences. The potential of VR/AR technologies to facilitate the documentation and sharing of travel experiences is mentioned.	broader concepts of enriching the cultural experience.
How can the digital divide be addressed in the context of tourism technologies in Romania?	Education and awareness - this aspect is seen as essential in reducing the digital divide by developing the digital skills of workers, including managers; the need to provide guidance and assistance for users is highlighted. Investments in digital infrastructure are aimed at improving access to technology. Development of accessible and easy-to-use applications - this includes adapting technologies to different needs and resources. Compatibility with older devices - ensuring that applications work on older hardware devices or in areas with poor connectivity but also optimizing applications for mobile devices. Collaboration and public-private partnerships between different sectors (from the IT and hospitality industries) to improve digital infrastructure and create a digital ecosystem including big data, innovation and smart tourism networks. Use of AI to create experiences adapted to different categories of users. The use of AI for automatic website generation, this specific solution to help reduce the digital divide, is also considered.	The analysis results outline several key strategies to reduce the digital divide and promote digital inclusion. Education and awareness initiatives are crucial for developing digital skills among workers and providing user support. Investments in digital infrastructure are necessary to improve technology access. The development of accessible and user-friendly applications, including adaptation to different needs and compatibility with older devices and mobile platforms, is essential. Collaboration and public-private partnerships are vital for enhancing digital infrastructure and creating a smart tourism ecosystem. Finally, the use of AI to personalize experiences and even automate website generation is highlighted as a potential solution to bridge the digital divide.
What emerging technologies do you think will have the biggest impact on tourism in the next 5-10 years, in Romania?	• AI and ML are seen as having a major impact in personalizing experiences, improving customer relationships and optimizing operations. • VR/AR are perceived as technologies that will transform tourism experiences, offering immersive tours and contextualized information. • Blockchain is mentioned for securing transactions and identity management. • IoT and 5G are seen as technologies that will improve connectivity and enable the development of smarter and more personalized services. • Robotization and automation for customer service and streamlining operations. • Voice search technologies mentioned interact more naturally with tourism services. • Facial recognition is mentioned in the context of security and • personalization of services. • Big Data technologies are used for analyzing and effectively using data in the hospitality industry. • Cybersecurity issues mentioned in the general context of the increasing importance of data security in the digital age. • Decentralized Technologies, without a specific specification.	The research results offer several key insights into the perceived impact of emerging technologies on the tourism and hospitality industries. In summary, the insights point towards a future of tourism are characterized by more personalized and immersive experiences, enhanced operational efficiency, greater security, and data-driven decision-making, all enabled by the integration of these advanced technologies.

Source: Author's own development.

b. The Qualitative Research Results

Since the indices presented in Table 2 refer to the situation in 2023 and 2022 and are based on data reported by the Romanian Ministry of Tourism, the intention of the research was to discover other facets of reality in the development of digital tourism in Romania. Thus, qualitative research was developed with hospitality industry managers, which was carried out from September 2024 – February 2025 and was based on semi-structured interviews. This research has provided valuable insights into the implementation and the future of technologies used in the development of digital tourism. The research results are centralized in Table 3.

Qualitative research highlighted a significant increase in the adoption and use of digital technologies in tourism. Mobile travel apps, booking platforms have recorded high adoption rates, demonstrating their deep integration into the modern travel experience. This trend reflects a fundamental change in the way tourists plan, book and experience travel (as perceived by the managers involved in the research). Furthermore, the research results revealed a predominantly positive attitude towards digital tourism technologies. Most managers consider that these technologies improve travel experience, facilitate planning and offer a greater degree of personalization. However, some reluctance was also observed, especially regarding data privacy and cybersecurity. Another aspect observed during the online interviews was the reluctance towards the novelty of technology, especially regarding the use of AI and how it will reflect and influence the behavior of the traditional consumer.

VII. CONCLUSIONS

The paper explores the impact and potential of digital technologies in transforming the hospitality industry, focusing on digital tourism. It highlights the integration of technologies like VR/AR, AI, and IoT, and their role in redefining tourist experiences. The research underlined the accelerated digitalization in the hospitality industry during the post-COVID-19 period focuses on the role of emerging technologies (such as AI, VR/AR, and IoT) in enhancing user experiences by optimizing service delivery and personalizing interactions. In the research context several key technologies have been discussed based on the literature review. Several challenges for the digital tourism development have been discovered (identified via the secondary data analysis and the qualitative research): balancing automation and human interaction (with a lor of efforts for maintaining the "personal touch" while enhancing efficiency in the process of services provided by the hospitality industry); data security and privacy to ensure robust security measures; urgent investment pressure which are required for technology and training. In addition, the study uses a mixed methodology combining literature review with qualitative research through semi-structured interviews with industry professionals. This approach provides insights into the implementation and future of digital tourism technologies.

The main research results are related to the analysis of the digital tourism indicators done based on the EU Tourism Scoreboard data and creating a comparative analysis of the digital tourism in Romania vs. EU27. Furthermore, qualitative research based on a semi-structured interview has highlighted challenges in user adoption, financial barriers, infrastructure, and data security in the case of digital tourism development. The study identifies key factors for developing user-friendly digital tourism platforms and proposes solutions for balancing digital innovation with authentic travel experiences. It emphasizes the importance of improving relationships with service providers and managing excessive tourism.

Several contributions of the presented research should be mentioned in compared to the analyzed literature: (a) the study focuses on the impact of digital technologies like AI, VR/AR, and IoT in transforming the hospitality industry, providing a detailed analysis of their implementation and future potential. The study specifically addresses the development of digital tourism, analyzing its evolution and the integration of technologies to enhance user experiences. This focus on digital tourism is a relatively new and rapidly evolving area in literature; (b) unlike many studies that rely solely on literature reviews, this research combines a comprehensive literature review with qualitative research based on semi-structured interviews which provides a more holistic view of the current trends and challenges.

REFERENCES

[1] Almujareb, Y. J., Aljuwaihel, H. S., AlTahous, R. A., Almaghrabi, A. K., & Karar, A. S. (2024, December). Enhancing Tourist Experiences with AI: The Integration of LLMs and Audio Augmented Reality. In 2024 IEEE 21st International Conference on Smart Communities: Improving Quality of Life using AI, Robotics and IoT (HONET) (pp. 44-49). IEEE.

[2] Bekele, H., & Raj, S. (2024). Digitalization and digital transformation in the tourism industry: a bibliometric review and research agenda. Tourism Review.

[3] Budianto, I. R., Supina, S., Fajri, F., & Hadita, H. (2024). The New Hospitality Paradigm: Leveraging Absorptive Capacity for AI and 5G-Enabled Innovation. Dinasti International Journal of Education Management & Social Science, 6(1).

[4] Buhalis, D., Harwood, T., Bogicevic, V., Viglia, G., Beldona, S., & Hofacker, C. (2019). Technological disruptions in services: lessons from tourism and hospitality. Journal of service management, 30(4), 484-506.

[5] Buhalis, D., Efthymiou, L., Uzunboylu, N., & Thrassou, A. (2024). Charting the progress of technology adoption in tourism and hospitality in the era of Industry 4.0. EuroMed Journal of Business, 19(1), 1-20.

[6] Chon, K. K. S., & Hao, F. (2025). Technological evolution in tourism: a Horizon 2050 perspective. Tourism Review, 80(1), 313-325.

[7] EC, (2025a). The Digital Transition of Tourism [Online] Available at: https://single-market-economy.ec.europa.eu/sectors/tourism/eu-tourism-transition/digital-transition-tourism_en#data-management-for-tourism [Accessed 13th March 2025].

[8] EC (2025b). Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, EU Tourism Dashboard (2025). [Online] Available at: https://tourism-dashboard.ec.europa.eu/?lng=en&ctx=tourism [Accessed 13th March 2025].

[9] Han, W., McCabe, S., Wang, Y., & Chong, A. Y. L. (2018). Evaluating user-generated content in social media: an effective approach to encourage greater pro-environmental behavior in tourism?. Journal of Sustainable Tourism, 26(4), 600-614.

[10] Julianti, L., & Pinpak, A. (2024). The Digitalization of Investment Impact on Developing Tourism Industry. Journal of Human Rights, Culture and Legal System, 4(3), 655-681.

[11] Kannan, R. (2024). Revolutionizing the Tourism Industry through Artificial Intelligence: A Comprehensive Review of AI Integration, Impact on Customer Experience, Operational Efficiency, and Future Trends. International Journal for Multidimensional Research Perspectives, 2(2), 01-14.

[12] Kishore, D., Raju, S. S., & Rana, V. (2025). Exploring the Impact of Emerging Technologies on the Hospitality Industry. In Marketing Technology-Infused Hospitality: Upskilling Frontline Employees for Competitiveness (pp. 337-364). IGI Global Scientific Publishing.

[13] Konar, R., Islam, M. T., Kumar, J., & Bhutia, L. D. (2025). Empowering tourists through technology: Co-creative destination experiences in the Malaysian tourism sector. In Tracking tourism patterns and improving travel experiences with innovative technologies (pp. 135-152). IGI Global.

[14] Lee, M., Ahn, J., Shin, M., Kwon, W., & Back, K. J. (2021). Integrating technology to service innovation: Key issues and future research directions in hospitality and tourism. Journal of Hospitality and Tourism Technology, 12(1), 19-38.

[15] Magoutas, A. I., Manolopoulos, D., Manouka, M., & Dimitropoulou, M. (2024). Digitalization of the Alternative Tourism Marketspace: Evidence from an EU Peripheral Economy. Tourism and Hospitality, 5(4), 1151-1166.

[16] Ntounis, N., Parker, C., Skinner, H., Steadman, C., & Warnaby, G. (2022). Tourism and Hospitality industry resilience during the Covid-19 pandemic: Evidence from England. Current Issues in Tourism, 25(1), 46-59.

[17] Önder, I., & Gunter, U. (2022). Blockchain: Is it the future for the tourism and hospitality industry?. Tourism Economics, 28(2), 291-299.

[18] Polukhina, A., Sheresheva, M., Napolskikh, D., & Lezhnin, V. (2025). Digital Solutions in Tourism as a Way to Boost Sustainable Development: Evidence from a Transition Economy. Sustainability, 17(3), 877.

[19] Rodríguez, G. I. G., & Rodríguez, E. R. (2025). Entre redes sociales y digitalización: estrategias para impulsar las trayectorias formativas en estudiantes de turismo. Revista de Investigación en Tecnologías de la Información, 13(29), 1-10.

[20] Sánchez-Juárez, I. R., & Paredes-Xochihua, M. P. (2024). Augmented reality as a support for tourism promotion. ECORFAN Journal-Republic of Paraguay, 10(18), 1-10.

[21] Sarnacchiaro, P., Luongo, S., Sepe, F., & Corte, V. D. (2024). The role of blockchain technology in the tourism industry: analyzing the factors affecting its adoption. Quality & Quantity, 1-28.

[22] Singh, K., Kumar, S., & Talukder, M. B. (2025). Digital Transformation and Its Impact on Tourism Business in India. In Tracking Tourism Patterns and Improving Travel Experiences With Innovative Technologies (pp. 215-230). IGI Global Scientific Publishing.

[23] Sjukriana, J., Hanafiah, M. H., Asyraff, M. A., & Kusumah, G. (2024). Unveiling the landscape of event technology

adoption in hospitality and tourism industry: insights from a systematic literature review. International Journal of Event and Festival Management.
[24] Talukder, M. B., Rahman, M. Z., & Khan, M. R. (2025). Enhancing Guest Experience Through Smart Hotel Technologies. In Adapting to Evolving Consumer Experiences in Hospitality and Tourism (pp. 301-324). IGI Global.
[25] UNWTO (2024). Digital Transformation. [Online] Available at: https://www.unwto.org/digital-transformation [Accessed 15th March 2025].
[26] Wu, W., Xu, C., Zhao, M., Li, X., & Law, R. (2024). Digital Tourism and Smart Development: State-of-the-Art Review. Sustainability, 16(23), 10382.
[27] Zeqiri, A. (2024). From Traditional to Digital: The Evolution of Business Models in Hospitality Through Platforms. Platforms, 2(4), 221-233.
[28] Zhang, F., & Cheng, Q. (2024). Spatio-temporal effects and influence mechanism of digital technology on tourism efficiency in Chinese provinces. Scientific Reports, 14(1), 22975.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Investigating Tourist Perceptions of Digital Tourism Experiences: A Comparison Between Romania and Spain

Marius MIHUT[1] and Anca DRAGHICI[2]

Abstract – This research investigates and compares tourist perceptions of digital tourism experiences between Romania and Spain. Through comprehensive analysis of academic studies, industry reports, and market data, the research identifies significant similarities and differences in how tourists from these two European countries perceive and interact with digital tourism tools and experiences. Key findings include:

- Generational patterns are remarkably consistent across both countries, with Generation Z seeking shareable, technology-enhanced experiences and Millennials valuing sustainability and authenticity (Poruțiu et al., 2024; Álvarez-García et al., 2024).
- COVID-19 served as a significant catalyst for digital adoption in tourism across both countries, accelerating pre-existing trends (Poruțiu et al., 2024; Álvarez-García et al., 2024).
- Digital adoption rates differ significantly, with Spain (66.2%) having higher digital literacy than Romania, influencing expectations for digital tourism experiences (European Commission, 2024).
- Digital tourism infrastructure is more developed in Spain, which has been implementing smart destination approaches for over a decade (Cuomo et al., 2021).
- Sustainability is increasingly important to tourists from both countries, particularly younger generations (Caballero et al., 2023).
- Authentic experiences remain highly valued by both Romanian and Spanish tourists, with digital tools seen as enhancers rather than replacements (Lupu et al., 2023).

The research concludes that while digital tools and platforms are increasingly important in tourism for both Romanian and Spanish tourists, the specific implementation and emphasis should be adapted to account for different levels of digital sophistication, infrastructure development, and cultural preferences in each country. Tourism stakeholders should consider both the similarities and differences identified when developing digital tourism offerings for these markets.

Keywords: Tourism perceptions, Romanian tourism, Spanish tourism.

I. INTRODUCTION

Digital transformation has fundamentally changed how tourists discover, experience, and share their travel journeys. From virtual reality tours and mobile applications to social media platforms and online booking systems, digital tools have become integral to the modern tourism experience. However, the perception and adoption of these digital tourism experiences can vary significantly across different countries and demographic groups.

This research focuses on comparing tourist perceptions of digital tourism experiences between Romania and Spain – two European countries with distinct digital landscapes, tourism sectors, and cultural contexts. Romania, an emerging tourism destination in Eastern Europe, has been steadily growing its digital economy over the past decade.

Spain, one of the world's leading tourism destinations, has been at the forefront of implementing smart city and smart destination approaches (Cuomo et al., 2021).

By examining how tourists from these two countries perceive and interact with digital tourism tools and experiences, this research aims to provide valuable insights for tourism stakeholders seeking to enhance digital offerings for these markets. The comparison is particularly relevant in the post-pandemic context, as COVID-19 has accelerated digital adoption in tourism and potentially reshaped tourist perceptions and expectations (Álvarez-García et al., 2024; Poruțiu et al., 2024).

The research addresses several key questions: - How do Romanian and Spanish tourists perceive digital tourism experiences? - What are the key similarities and differences in these perceptions? - What factors influence these perceptions in each

[1] Politehnica University of Timisoara, Romania; marius.mihut@student.upt.ro
[2] Politehnica University of Timisoara, Romania; anca.draghici@upt.ro

country? - What are the implications for digital tourism development targeting these markets?

Through a comprehensive analysis of these questions, this research contributes to the understanding of how cultural, economic, and technological factors shape tourist perceptions of digital tourism experiences in different European contexts.

II. RESEARCH METHODOLOGY

This research employed a comprehensive methodology to investigate tourist perceptions of digital tourism experiences in Romania and Spain.

Data collection includes the following

1. Academic Literature Review: Extensive review of academic studies on digital tourism, tourist perceptions, and country-specific tourism research for both Romania and Spain. This included studies on generational differences (Porutiu et al., 2024), COVID-19 impact (Álvarez-García et al., 2024), virtual reality in tourism, and smart destinations (Cuomo et al., 2021);
2. Industry Reports Analysis: Examination of tourism industry reports, market forecasts, and digital transformation analyses from sources such as Statista (2025), McKinsey (Caballero et al., 2023), and the European Commission (2024);
3. Digital Adoption Statistics: Collection of digital adoption and skills data from official sources, including the EU's Digital Decade Country Reports (European Commission, 2024);
4. Tourism Market Data: Analysis of tourism market trends, online booking statistics, and digital service adoption rates in both countries (Statista, 2025; World Travel Tourism Council, 2019).

The research utilized a multi-layered analytical framework to examine tourist perceptions:

1. Country-Level Analysis: Individual examination of digital tourism landscapes and tourist perceptions in Romania and Spain.
2. Comparative Analysis: Systematic comparison of perceptions between the two countries, identifying key similarities and differences.
3. Contextual Analysis: Examination of factors influencing perceptions in each country, including economic, cultural, and technological contexts.
4. Implications Assessment: Evaluation of the implications of findings for various tourism stakeholders.

The research faced several limitations:

1. Data Availability: More comprehensive data was available for Spain's tourism sector compared to Romania, potentially affecting the depth of analysis.
2. COVID-19 Impact: The pandemic has significantly disrupted tourism patterns and potentially accelerated digital adoption, making it challenging to distinguish temporary changes from long-term trends (Álvarez-García et al., 2024).
3. Regional Variations: Both Romania and Spain have significant regional variations in tourism development and digital adoption that could not be fully captured in this broad comparison.
4. Language Barriers: Some country-specific research was available only in Romanian or Spanish, potentially limiting access to certain insights.

Despite these limitations, the methodology provided a robust framework for comparing tourist perceptions of digital tourism experiences between the two countries and drawing meaningful conclusions for tourism stakeholders.

III. RESEARCH RESULTS ON THE DIGITAL TOURISM LANDSCAPE

a. Romania's Digital Tourism Landscape

Romania's digital tourism landscape has been evolving rapidly in recent years, characterized by growing digital adoption and emerging innovative initiatives:

Digital Infrastructure and Adoption - Romania has been steadily growing its digital economy over the past decade, though it still lags the EU average in several metrics. According to the EU's Digital Economy and Society Index (DESI), Romania ranks among the lower-performing EU member states in terms of overall digital performance but has shown improvement in connectivity and digital public services (European Commission, 2024).

The Romanian hospitality market has been impacted by the rise of online travel agencies (OTAs) and vacation rental platforms, making it easier for travelers to book accommodations, compare prices, and read reviews. However, the digital infrastructure supporting tourism varies significantly across regions, with major cities and popular tourist destinations generally offering better digital services than rural areas.

Digital Tourism Initiatives - Several notable digital tourism initiatives have emerged in Romania:

1. Virtual Tourism Experiences: The case study on "The Use of Virtual Reality to Promote Sustainable Tourism: A Case Study of Wooden Churches Historical Monuments from Romania" highlights how virtual reality is being used to provide informational support and improve decision-making for potential visitors to fragile tourist attractions.
2. Digital Nomad Infrastructure: Romania has emerged as a significant destination for digital nomads, ranking 7th globally according to the VisaGuide Digital Nomad Index for 2025. Factors contributing to this include affordable cost of living, low taxes, and a six-month tax-free period for digital nomads.
3. Mobile Applications: Various mobile applications have been developed to enhance tourist experiences in Romania, including city guides,

translation tools, and cultural heritage information platforms.

4. Online Booking Systems: While traditional booking methods still play a role in some segments, online booking platforms are gaining traction, particularly among younger travelers and international tourists visiting Romania (Porutiu et al., 2024).

Challenges and Opportunities - Romania's digital tourism landscape faces several challenges:

- Regional Disparities: Significant variations in digital infrastructure and services across different regions of Romania.
- Seasonality: Tourism in Romania is highly seasonal, affecting the consistency of digital service provision.
- Digital Skills Gap: Lower levels of digital literacy compared to Western European countries, potentially limiting adoption of advanced digital tourism tools (European Commission, 2024).

However, these challenges also present opportunities:

- Growth Potential: Significant room for growth in digital tourism adoption and innovation.
- Authentic Experiences: Digital tools can help showcase Romania's rich cultural heritage and authentic experiences to a global audience (Lupu et al., 2023).
- Digital Nomad Market: The growing digital nomad community presents opportunities for developing specialized digital tourism services.

b. Spain's Digital Tourism Landscape

Spain has established itself as a leader in digital tourism innovation, with a well- developed digital infrastructure and numerous cutting-edge initiatives:

Digital Infrastructure and Adoption - Spain demonstrates strong digital adoption rates, with 66.2% of the Spanish population having at least a basic level of digital skills in 2023, above the EU average of 55.6%.

According to the EU's Digital Decade Country Report, Spain has made notable progress in the use of Artificial Intelligence (AI) by enterprises, with 9.2% of Spanish enterprises having adopted AI solutions in 2023 (European Commission, 2024).

The Spanish tourism sector has embraced digital transformation, with projections that 90% of total tourism revenue will be generated through online sales by 2029. The rise of digital platforms and online booking services has made it easier for travelers to plan and customize their trips, while the popularity of sharing economy services has transformed the accommodation sector (Statista, 2025).

Digital Tourism Initiatives - Spain has implemented numerous innovative digital tourism initiatives:

1. Smart Destinations: Spain has been developing a highly ambitious programme for the promotion of smart destinations for more than ten years. These initiatives use technology to improve efficiency in management, enhance tourist experiences, and address challenges related to tourism.
2. Big Data and Co-Design: Research on "Digital transformation and tourist experience co-design" highlights how Spanish tourism providers are using big social data to organize tourists' value propositions and engage them in co- designing valuable cultural tours (Cuomo et al., 2021).
3. Virtual and Augmented Reality: Spanish destinations have implemented VR and AR experiences to enhance visitor engagement with cultural and historical sites.
4. Destination Marketing Organizations (DMOs): Spanish DMOs have embraced digital platforms, including social media (Facebook, Twitter, Instagram, and YouTube), as customer services and marketing tools (Andronikidis et al., 2023).

Challenges and Opportunities - Despite its advanced digital tourism landscape, Spain faces several challenges:

- Overtourism: Digital tools have facilitated both the mobility and concentration of visitors in cities, contributing to overtourism in certain hotspots (Caballero et al., 2023).
- Climate Change: Rising temperatures and increasing risk of drought, water stress, wildfires, and floods pose challenges to Spanish tourism, requiring digital solutions for sustainability (Caballero et al., 2023).
- Seasonality: High seasonality in core tourism destinations leads to peaks and troughs in employment, affecting the consistency of digital service provision.

These challenges have spurred opportunities:

- Sustainability Focus: Digital tools are increasingly being used to promote sustainable tourism practices and manage visitor flows (Caballero et al., 2023).
- Personalization: Advanced data analytics enable highly personalized tourism experiences tailored to individual preferences (Cuomo et al., 2021).
- Diversification: Digital platforms help showcase lesser-known destinations, potentially reducing pressure on overtourism hotspots.

c. Romanian Tourist Perceptions

Generational Differences in Digital Tourism Adoption - Research on Romanian generational preferences in tourism reveals significant differences between Generation Y (Millennials, born 1980-1995) and Generation Z (born 1996-2012) in their approach to digital tourism experiences:

Generation Z Romanians:

- Seek interactive, personalized experiences that can be shared on social media platforms;
- Are attracted to "Instagrammable" experiences and spectacular landscapes;
- They pPrefer tourism services with easy access to technology, such as mobile applications to plan and manage trips;

- Conduct extensive research online before making tourism decisions;
- Prefer purchasing through social media compared to other generations.

According to the study "Understanding Romanian Generational Preferences and Travel Decision-Making When Choosing a Rural Destination" (2024), Generation Z Romanians demonstrate distinct characteristics in their tourism preferences, with technology significantly impacting their views on travel destinations (Poruțiu et al., 2024).

Generation Y Romanians (Millennials):

- Have the highest education rate, with over 60% possessing a bachelor's degree;
- Search for unique and personalized experiences that are ecologically sustainable;
- Support local communities and cultural diversity;
- Are attracted to adventure tourism;
- Are willing to pay more for unique and authentic experiences due to their higher income levels (Poruțiu et al., 2024).

These generational differences significantly impact how digital tourism tools and experiences are perceived and utilized by Romanian tourists.

Impact of COVID-19 on Digital Tourism Perceptions - The COVID-19 pandemic has substantially altered Romanian tourist perceptions of digital tourism. Before the pandemic, Romanian travelers prioritized experiences and adventure, often overlooking health and safety concerns in their digital tourism interactions (Poruțiu et al., 2024). However, during and after the pandemic, several shifts occurred:

- Health, hygiene, and COVID-19 situation information became crucial factors in digital tourism research;
- Economic considerations gained importance in digital tourism decision-making;
- Virtual tourism experiences gained acceptance as alternatives to physical travel;
- Online booking platforms and digital tools for checking health and safety measures became essential.

The study by Poruțiu et al. (2024) identified two primary factors influencing Romanian tourists' decisions about choosing destinations in the post-pandemic context: 1. "Sanitary and administrative" factors 2. "Economic and social" factors. These factors now significantly influence how Romanian tourists interact with digital tourism platforms and tools.

Creative Tourism and Digital Experiences - The study "Analysis of the Perception of Romanian Consumers Regarding the Practice of Creative Tourism and Its Role in Sustainable Local Development" provides insights into how Romanians perceive creative tourism experiences, which increasingly incorporate digital elements. Key findings include:

- Romanian tourists are interested in practicing activities integrated into creative tourism;
- They value the experiences created through interactions with locals or other participants;
- Digital tools that facilitate these interactions are viewed positively;
- The impact of creative tourism practices at the local level (both economic and social) is recognized by Romanian tourists.

Interestingly, the study found that while Romanian tourists practice creative tourism, the concept itself is not widely known or understood. This suggests an opportunity for digital tourism tools to better educate and inform Romanian tourists about creative tourism opportunities.

Virtual Reality and Digital Tourism Experiences - The case study on "The Use of Virtual Reality to Promote Sustainable Tourism: A Case Study of Wooden Churches Historical Monuments from Romania" provides valuable insights into how Romanian tourists perceive virtual reality experiences in tourism. Key findings include:

- Virtual reality is seen as complementary to traditional tourism rather than replacing it;
- Romanian tourists value VR as a tool for providing informational support to improve decision-making;
- The Bihor360° website, which offers virtual tourism experiences of wooden churches, is viewed positively as a bridge for potential visitors to fragile tourist attractions;
- VR is perceived as a tool for active knowledge and raising awareness about cultural heritage.

The study emphasizes that "VT is not aimed at replacing traditional tourism but rather at complementing and revitalizing it by providing informational support, which can improve the decision-making process regarding visiting a tourist destination." This suggests that Romanian tourists view digital tourism tools like VR as enhancements rather than replacements for physical tourism experiences.

Digital Nomad Tourism - Romania's emergence as a significant destination for digital nomads (ranking 7th globally according to the VisaGuide Digital Nomad Index for 2025) has influenced how Romanian tourists perceive digital tourism. Factors contributing to Romania's attractiveness for digital nomads include:

- Affordable cost of living;
- Low taxes (between 0% and 10%);
- A six-month tax-free period for digital nomads.

This positioning as a digital nomad-friendly destination indicates Romania's growing digital infrastructure and its appeal to tech-savvy travelers. For Romanian tourists, this creates a more digitally oriented tourism environment where digital tools and experiences are increasingly normalized and expected.

d. Spanish Tourist Perceptions

Digital Transformation and Tourism Experience Co-Design - According to research on "Digital transformation and tourist experience co-design: Big social data for planning cultural tourism," Spanish tourists are increasingly involved in co-creating their tourism experiences through digital

platforms. The study highlights several key aspects of how Spanish tourists perceive digital tourism:

- Spanish tourists actively participate in the co-design of their tourism experiences through user-generated content;
- "Big social data" and user-generated content have become key sources of knowledge that influence Spanish tourists' perceptions and decisions;
- Digital transformation has completely changed the demand/offering interaction in the Spanish travel industry;
- Spanish tourists value personalized experiences that can be facilitated through digital tools;
- The study of the Pompeii Archaeological Site revealed that Spanish tourists use digital platforms to share their perceptions and experiences, which in turn influences other potential visitors (Cuomo et al., 2021).

The research emphasizes that "the active participation of the traveler – regardless of his/ her awareness – engenders a process of co-design in terms of construction of tourists' value propositions for precious experiences" (Cuomo et al., 2021). This suggests that Spanish tourists are not merely passive consumers of digital tourism content but active participants in shaping tourism experiences through their digital interactions.

Perceived Destination Images Through Digital Channels - Research on "Differences of Perceived Image Generated through the Web Site: Empirical Evidence Obtained in Spanish Destinations" provides valuable insights into how Spanish tourists perceive destination images through digital channels.

Key findings include: - Spanish tourists are significantly influenced by the information offered by promotional travel websites, particularly Destination Marketing Organizations (DMOs) - The digital content of DMOs shapes individuals' perceived destination image (PDI), which in turn affects their consumer choices - Spanish DMOs have begun using popular social media platforms (Facebook, Twitter, Instagram, and YouTube) as customer services and marketing tools - Spanish tourists are exposed to two differing streams of digital content: official DMO web-based communication and electronic word of mouth (eWOM) facilitated by user-generated content - DMOs could provide more accurate information on destination location and accessibility, attractive products, service offerings, and community support - However, Spanish tourists may identify more easily with the personal content (comments, stories, and experiences) found on social media platforms, travel blogs, and consumer empowerment sites (Andronikidis et al., 2023; Blazquez-Resino et al., 2016)

The research suggests that while DMOs' digital web-based content can form a favorable image that influences future consumer behavior, it is only part of the broader picture where eWOM and social media significantly shape Spanish tourists' perceptions and behaviors (Andronikidis et al., 2023).

COVID-19 Impact on Digital Tourism Perceptions - The study "Exploring the Spanish Tourists' Intentions to Travel to Zones That Have a Low-Impact of COVID-19" provides insights into how the pandemic has affected Spanish tourists' perceptions and use of digital tourism tools.

Key findings include: - Spanish tourists increasingly rely on digital platforms to assess the safety of potential destinations - The cognitive and affective dimensions of perceived risk about the pandemic significantly influence Spanish tourists' travel intentions - Past behavior and the core variables of the theory of planned behavior (TPB) have a positive effect on the behavioral intentions of Spanish tourists - Spanish tourists' cognitive risk perception has a negative impact on these core variables - Digital tools that provide information about the COVID-19 situation in potential destinations are valued by Spanish tourists (Álvarez-García et al., 2024)

This research is particularly relevant as Spain is "a very touristic country and a paradigmatic case" due to being the second most visited country in the world by international tourists, with tourism making a significant contribution to its GDP (Álvarez- García et al., 2024; World Travel Tourism Council, 2019).

Sustainability Focus - According to the McKinsey report "Next stop for Spanish tourism excellence: Sustainability," sustainability is becoming increasingly important to Spanish tourists, with digital tools playing a crucial role in facilitating sustainable tourism choices.

Key insights include: - More than 70% of global travelers (including Spanish tourists) intend to travel more sustainably - 35% said that the sustainability efforts of accommodation and transport providers play a strong role in their booking decisions - Gen Z Spanish travelers, in particular, want to see sustainability in practice rather than just in marketing messages - 38% of Gen Zs across the world (including Spain) would consider staying in green accommodation on their next holiday - Digital platforms that highlight sustainable tourism options are increasingly valued by Spanish tourists (Caballero et al., 2023)

The report emphasizes that "sustainability could become a key differentiator" for Spanish tourism, and digital tools that facilitate sustainable tourism choices are likely to be well-received by Spanish tourists (Caballero et al., 2023).

Smart Destinations and Digital Tourism Infrastructure - Spain has been at the forefront of implementing smart city and smart destination approaches to tourism management, which has shaped Spanish tourists' perceptions of digital tourism experiences:

- Spain has been developing a highly ambitious programme for the promotion of smart destinations for more than ten years;
- The smart city and smart tourist destination approaches aim to improve efficiency in management, the quality of life of residents, and tourist experiences;

- Technology is part of the smart solutions addressing urban challenges derived from tourism;
- Digital transformation has facilitated both the mobility and concentration of visitors in cities;
- Spanish tourists have been exposed to smart destination technologies in their domestic travel, potentially raising their expectations for digital experiences in other destinations (Cuomo et al., 2021).

This experience with smart destinations has likely influenced how Spanish tourists perceive digital tourism experiences both domestically and internationally.

IV. COMPARATIVE ANALYSIS

The key similarities discovered by the study will be presented in the following.

1. Generational Differences in Digital Tourism Adoption

Both Romanian and Spanish tourists show significant generational differences in their approach to digital tourism:

Generation Z (born 1996-2012) in both countries:

- Seek interactive, personalized experiences that can be shared on social media;
- Are attracted to "Instagrammable" experiences and spectacular landscapes;
- Prefered tourism services with easy access to technology;
- Conduct extensive research online before making tourism decisions;
- Prefer purchasing through social media compared to other generations;
- Have heightened awareness of sustainability issues (Porutiu et al., 2024; Caballero et al., 2023).

Generation Y/Millennials (born 1980-1995) in both countries:

- Search for unique and personalized experiences that are ecologically sustainable;
- Support local communities and cultural diversity;
- Are attracted to adventure tourism;
- Are willing to pay more for unique and authentic experiences;
- Are digitally savvy but place less emphasis on social media shareability compared to Gen Z (Porutiu et al., 2024).

These generational patterns are remarkably consistent across both Romanian and Spanish tourists, suggesting that age may be a more significant determinant of digital tourism preferences than nationality in some respects.

2. COVID-19 Impact on Digital Tourism Perceptions

The COVID-19 pandemic has substantially altered tourist perceptions of digital tourism in both countries:

- Before the pandemic, tourists from both countries prioritized experiences and adventure, often overlooking health and safety concerns;
- During and after the pandemic, health, hygiene, and COVID-19 situation information became crucial factors in digital tourism research;
- Economic considerations gained importance in digital tourism decision-making;
- Virtual tourism experiences gained acceptance as alternatives to physical travel;
- Online booking platforms and digital tools for checking health and safety measures became essential (Porutiu et al., 2024; Álvarez-García et al., 2024).

The pandemic served as a significant catalyst for digital adoption in tourism across both countries, accelerating trends that were already underway.

3. High Value Placed on Authentic Experiences

Despite the increasing digitalization of tourism, tourists from both Romania and Spain continue to value authentic, in-person experiences:

- Digital tools are seen as enhancers rather than replacements for physical tourism experiences;
- Both Romanian and Spanish tourists view virtual reality as complementary to traditional tourism;
- Tourists from both countries value digital tools that facilitate authentic interactions with locals and other tourists;
- There is a shared appreciation for digital platforms that help discover lesser- known, authentic destinations (Lupu et al., 2023; Cuomo et al., 2021).

This suggests that successful digital tourism offerings for both markets should focus on enhancing rather than replacing authentic, in-person experiences.

4. Growing Importance of Sustainability

Sustainability is becoming increasingly important to tourists from both countries:

- Romanian and Spanish tourists, particularly younger generations, are increasingly concerned about the environmental impact of tourism;
- Digital tools that facilitate sustainable tourism choices are valued in both markets;
- Tourists from both countries expect transparency about sustainability practices;
- There is growing interest in digital platforms that highlight eco-friendly accommodation options;
- Both Romanian and Spanish tourists value digital tools that help them support local communities (Porutiu et al., 2024; Caballero et al., 2023).

This shared focus on sustainability presents opportunities for digital tourism offerings that emphasize environmental and social responsibility.

The key differences discovered by the study are:

1. Digital Adoption and Skills

There are notable differences in digital adoption rates between the two countries:

- Spain has higher digital adoption rates, with 66.2% of the population having at least basic digital skills (above the EU average of 55.6%);
- Romania has lower digital adoption rates, though it has been steadily growing its digital economy over the past decade;
- Spanish tourists may have higher expectations for sophisticated digital tourism experiences due to greater familiarity with digital tools;
- Romanian tourists may place higher value on digital tourism tools that are intuitive and accessible to users with varying levels of digital literacy (European Commission, 2024).

These differences suggest that digital tourism offerings may need to be tailored to different levels of digital sophistication in each market.

2. Digital Tourism Infrastructure

The digital tourism infrastructure in the two countries differs significantly:

- Spain has been at the forefront of implementing smart city and smart destination approaches for more than ten years;
- Romania is still developing its digital tourism infrastructure, with significant regional variations;
- Spanish tourists have been exposed to smart destination technologies in their domestic travel, potentially raising their expectations;
- Romanian tourists may have less experience with advanced digital tourism infrastructure, potentially leading to greater appreciation when encountered (Cuomo et al., 2021).

These differences in domestic digital tourism infrastructure likely influence how tourists from each country perceive digital tourism experiences abroad.

3. Online Booking and Digital Services Adoption

There are differences in the adoption of online booking and digital services:

- Spain shows very high adoption of online booking, with projections that 90% of total tourism revenue will be generated through online sales by 2029;
- Romania has growing but lower adoption of online booking platforms, with traditional booking methods still playing a significant role in some segments;
- Spanish tourists may have higher expectations for seamless online booking experiences;
- Romanian tourists may place higher value on hybrid booking options that combine digital convenience with personal service (Statista, 2025).

These differences suggest that digital tourism offerings may need to provide varying levels of personal support depending on the market.

4. Co-creation and Participation in Digital Tourism

The level of active participation in co-creating tourism experiences differs:

- Spanish tourists actively participate in co-creating tourism experiences through digital platforms and user-generated content;
- Romanian tourists are increasingly engaging with user-generated content but may be less active in creating content themselves;
- Spanish tourists may have higher expectations for interactive digital experiences that allow for personalization;
- Romanian tourists may place higher value on curated digital experiences from trusted sources (Cuomo et al., 2021; Lupu et al., 2023).

These differences suggest varying approaches to user engagement in digital tourism platforms depending on the target market.

The factors influencing perceptions in each country are presented in the following.

Romania:

1. Economic factors: Romania's lower average income compared to Spain may influence price sensitivity and value expectations in digital tourism offerings.
2. Digital infrastructure development: The ongoing development of Romania's digital infrastructure affects accessibility and reliability of digital tourism services (European Commission, 2024).
3. Cultural heritage emphasis: Romania's rich cultural heritage and focus on authentic experiences influences how digital tools are perceived as enhancers of these experiences (Lupu et al., 2023).
4. Digital nomad growth: Romania's emergence as a significant destination for digital nomads (ranking 7th globally) is normalizing digital tourism experiences for domestic tourists.
5. Regional disparities: Significant regional variations in digital adoption and infrastructure within Romania create diverse perceptions of digital tourism.

Spain:

1. Tourism dependency: Spain's high economic dependence on tourism (contributing around 14% of GDP pre-pandemic) drives significant investment in digital tourism innovation (World Travel Tourism Council, 2019).
2. Climate change concerns: Spain's vulnerability to climate change (increasing temperatures, drought risk) heightens awareness of sustainability in tourism, including digital solutions (Caballero et al., 2023).
3. Smart destination leadership: Spain's pioneering role in smart destination development shapes expectations for sophisticated digital tourism experiences (Cuomo et al., 2021).
4. Overtourism management: Digital tools for managing overtourism in popular Spanish destinations influence perceptions of how technology can address tourism challenges (Caballero et al., 2023).
5. Strong domestic tourism market: Spain's robust domestic tourism market provides extensive exposure to digital tourism innovations.

V. IMPLICATIONS FOR TOURISM DEVELOPMENT

For Tourism Providers

Based on the research findings, tourism providers targeting Romanian and Spanish tourists should consider the following implications:

1. Generational targeting: Digital tourism strategies should prioritize generational differences over nationality in some respects, particularly regarding social media integration and sustainability messaging. Generation Z tourists from both countries respond well to shareable, technology-enhanced experiences, while Millennials value sustainability and authenticity (Porutiu et al., 2024; Caballero et al., 2023).
2. Tiered digital sophistication: Offerings should accommodate different levels of digital sophistication, with intuitive interfaces for Romanian tourists and cutting- edge features for Spanish tourists. This might include providing both basic and advanced versions of digital tools or ensuring that advanced features are optional rather than required (European Commission, 2024).
3. Authentic experience enhancement: Digital tools should focus on enhancing rather than replacing authentic experiences for both markets. Virtual reality, augmented reality, and other digital technologies should be positioned as complements to physical experiences rather than substitutes (Lupu et al., 2023; Cuomo et al., 2021).
4. Hybrid support models: Varying levels of personal support alongside digital tools may be appropriate, with potentially more human touchpoints for the Romanian market. This could include options for human assistance within digital platforms, particularly for complex bookings or inquiries.
5. Post-pandemic reassurance: Digital platforms should continue to provide clear health and safety information for both markets, as the COVID-19 pandemic has heightened awareness of these factors among tourists from both countries (Porutiu et al., 2024; Álvarez-García et al., 2024).

For Destination Marketing Organizations

Destination Marketing Organizations (DMOs) targeting Romanian and Spanish tourists should consider these implications:

1. Dual content strategies: DMOs should develop content strategies that address both official promotional content and user-generated content, recognizing that tourists from both countries are influenced by both sources but may weigh them differently (Andronikidis et al., 2023; Blazquez-Resino et al., 2016).
2. Sustainability emphasis: Digital platforms should highlight sustainable options and practices for both Romanian and Spanish tourists, with particular emphasis for younger travelers. This could include sustainability certifications, carbon footprint information, and highlighting eco-friendly activities (Caballero et al., 2023).
3. Regional adaptation: DMOs should adapt digital offerings to account for regional variations within both countries, recognizing that digital adoption and preferences may vary significantly between urban and rural areas.
4. Cultural heritage digitization: Digital tools that showcase cultural heritage in engaging ways are likely to appeal to tourists from both countries, who value authentic cultural experiences. This could include virtual tours, augmented reality historical reconstructions, and interactive cultural heritage applications (Lupu et al., 2023).
5. Cross-market learning: DMOs can facilitate cross-market learning by sharing successful digital tourism initiatives between Romania and Spain, potentially accelerating digital tourism development in Romania while providing fresh perspectives for Spanish tourism innovation.

For Technology Developers

Technology developers creating digital tourism tools for Romanian and Spanish markets should consider these implications:

1. Accessibility design: Develop digital tourism tools with varying levels of complexity and accessibility to accommodate different levels of digital literacy, particularly important for the Romanian market (European Commission, 2024).
2. Co-creation capabilities: Incorporate features that enable user participation and co-creation, particularly for the Spanish market where tourists are more accustomed to actively shaping tourism experiences (Cuomo et al., 2021).
3. Offline functionality: Ensure that digital tourism tools have robust offline functionality to accommodate areas with limited connectivity, particularly relevant for rural tourism in Romania.
4. Sustainability integration: Integrate sustainability features into digital tourism tools, such as carbon footprint calculators, sustainable transportation options, and eco-friendly accommodation filters (Caballero et al., 2023).
5. Personalization capabilities: Develop advanced personalization features for the Spanish market, where tourists have higher expectations for customized experiences, while ensuring that basic personalization is available for the Romanian market (Cuomo et al., 2021).

VI. CONCLUSIONS

This research has provided a comprehensive comparison of tourist perceptions of digital tourism experiences between Romania and Spain, revealing both significant similarities and notable differences. The findings highlight the complex interplay of cultural, economic, and technological factors that shape how tourists from these two European countries

perceive and interact with digital tourism tools and experiences.

The similarities identified – particularly regarding generational patterns (Poruțiu et al., 2024), COVID-19 impact (Álvarez-García et al., 2024), value placed on authentic experiences (Lupu et al., 2023), and growing importance of sustainability (Caballero et al., 2023) – suggest that certain aspects of digital tourism development can be approached similarly for both markets. These shared characteristics provide a foundation for cross-market strategies and learning opportunities between the two countries.

However, the differences in digital adoption rates (European Commission, 2024), digital tourism infrastructure (Cuomo et al., 2021), online booking adoption (Statista, 2025), and co-creation participation highlight the need for tailored approaches that account for the specific context of each country. These differences suggest that while digital tools and platforms are increasingly important in tourism for both Romanian and Spanish tourists, the specific implementation and emphasis should be adapted to account for different levels of digital sophistication, infrastructure development, and cultural preferences.

The research also underscores the dynamic nature of tourist perceptions, which continue to evolve in response to technological advancements, global events such as the COVID-19 pandemic, and changing societal values such as the growing emphasis on sustainability. Tourism stakeholders must remain adaptable and responsive to these evolving perceptions to effectively engage with tourists from both countries.

In conclusion, understanding the similarities and differences in how Romanian and Spanish tourists perceive digital tourism experiences provides valuable insights for tourism stakeholders seeking to develop effective digital tourism offerings for these markets. By recognizing both the common ground and the unique characteristics of each market, digital tourism experiences can be tailored to meet the specific needs and expectations of tourists from both Romania and Spain, ultimately enhancing the overall tourism experience and contributing to the sustainable development of the tourism sector in both countries.

REFERENCES

[1] Álvarez-García, B., Monje-Amor, A., & Abeal Vázquez, J. P. (2024). Exploring the Spanish Tourists' Intentions to Travel to Zones That Have a Low-Impact of COVID-19 by Taking into Account Their Cognitive and Affective Risk Perceptions About the Pandemic. SAGE Open, 14(2).

[2] Andronikidis, A., Bellou, V., Stylos, N., & Vassiliadis, C. A. (2023). Commentary: Differences of Perceived Image Generated through the Web Site: Empirical Evidence Obtained in Spanish Destinations. Frontiers in Psychology, 11, 735.

[3] Blazquez-Resino, J. J., Molina, A., & Esteban-Talaya, Á. (2016). Differences of Perceived Image Generated through the Web Site: Empirical Evidence Obtained in Spanish Destinations. Frontiers in Psychology, 7, 1861.

[4] Caballero, J., Constantin, M., & Riefer, D. (2023). Next stop for Spanish tourism excellence: Sustainability. McKinsey & Company.

[5] Cuomo, M. T., Tortora, D., Foroudi, P., Giordano, A., Festa, G., & Metallo, G. (2021). Digital transformation and tourist experience co-design: Big social data for planning cultural tourism. Technological Forecasting and Social Change, 162, 120345.

[6] European Commission. (2024). Spain 2024 Digital Decade Country Report. Digital Strategy.

[7] Lupu, C., Rodrigues, A. I., & Gallarza, M. G. (2023). Using travel blogs to explore the image of Romania as an emerging tourism destination. European Journal of Tourism Research, 34, 3406.

[8] Manente, M. (2019). Tourism in Italy: Economic value, trends and perspectives. Statista.

[9] Poruțiu, A. R., Brata, A. M., Dumitras, D. E., Oros, O. P., & Muresan, I. C. (2024). Understanding Romanian Generational Preferences and Travel Decision-Making When Choosing a Rural Destination. Sustainability, 16(10), 4074.

[10] Statista. (2025). Travel & Tourism - Spain | Statista Market Forecast. World Travel Tourism Council. (2019). Economic Impact Reports.

[11] Xiang, Z., & Gretzel, U. (2010). Role of social media in online travel information search. Tourism Management, 31(2), 179-188.

[12] Zeng, B., & Gerritsen, R. (2014). What do we know about social media in tourism? A review. Tourism Management Perspectives, 10, 27-36.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Absorption of European Funds in the 2014–2020 Financial Framework and Solutions for Efficient Implementation in the 2021–2027 Financial Framework

Sebastian-Norbert HOJDA[1] and Marian MOCAN[2]

Abstract - The article analyzes the main types of European structural and investment funds, emphasizing their role in promoting economic, social, and territorial cohesion within the European Union. The objectives and areas of intervention for each fund are detailed: ERDF, ESF, CF, EAFRD, and EMFF. The study highlights the absorption rate of European funds by Romania in the 2014–2020 financial period, which reached 97.3%, equivalent to more than 27 billion euros attracted. It also examines the regional and county-level distribution of funds, outlining both achievements and challenges. Finally, concrete proposals are made to improve the absorption rate for the 2021–2027 period, including digitalization, increased administrative capacity, realistic planning, secured co-financing, and a clear focus on results and impact.

Keywords: Cohesion Policy, ERDF, ESF, CF, EAFRD, EMFF, absorption rate of European funds in Romania.

I. INTRODUCTION

The European Union's cohesion policy is one of its most important financial instruments, aimed at reducing economic and social disparities between member states and their regions [1]. Since 1970s, the European Union has developed increasingly complex mechanisms to support less developed regions, strengthening the principle of solidarity among member states [10]. Following the EU's eastern enlargement in 2004, these funds became essential for integrating new member states and ensuring balanced development across the continent [11].

The European Structural and Investment Funds (ESI) finance projects across all regions of the Union, but the largest allocations are directed toward less developed regions [1]. Through its cohesion policy, the European Union supports investments in infrastructure, regional development, employment, the environment, education, and economic competitiveness [3].

Romania, as a member state of the European Union since 2007, has benefited from a significant allocation of European funds, which have served as a key driver for infrastructure development, public administration modernization, and increased economic competitiveness. The European Structural and Investment Funds have directly contributed to transforming Romania into an emerging economy within the Union, with visible progress in multiple areas of national and regional interest [2], [8].

Moreover, Romania's growing experience in managing European funds has led to a significant improvement in the absorption rate, in-creasing from 72.8% during the 2007–2013 period to a record level of 97.3% in the 2014–2020 period [2], [9]. This evolution highlights institutional maturity and the enhanced capacity of Romanian authorities to attract and efficiently use European resources.

II. TYPES OF EUROPEAN FUNDS

The European Union's Cohesion Policy has been and continues to be financed through five European Structural and Investment Funds: the European Social Fund (ESF), the European Regional Development Fund (ERDF), the Cohesion Fund [3] (CF), the European Agricultural Fund for Rural Development (EAFRD) [5], and the European Maritime and Fisheries Fund (EMFF) [5].

The European Regional Development Fund [5] (ERDF) aimed to correct imbalances between regions by enabling investments in a smarter, greener, more connected and more social Europe, closer to its citizens. The ERDF is managed under shared responsibility between the European Commission, national and regional authorities in member states. National administrations select projects for funding and assume responsibility for their day-to-day management.

The European Social Fund [1] (ESF) was designed to support employment-related projects across Europe and to invest in the EU's human capital (workers,

[1] Politehnica University of Timisoara, Romania, Norbert_sebastian@yahoo.com
[2] Politehnica University of Timisoara, Romania, marian.mocan@upt.ro

young people, and job seekers). The Cohesion Fund [3] (CF) provided support to EU member states with a gross national income (GNI) per capita of less than 90% of the EU average, to strengthen the Union's economic, social, and territorial cohesion. It follows the same programming, management, and monitoring rules as the ERDF and ESF under the Common Provisions Regulation.

For the 2014–2020 period, the Cohesion Fund targeted Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, and Slovenia.

The Cohesion Fund [3] allocated a total of €63.4 billion to activities in the following areas:

- Trans-European transport networks, especially priority projects of European interest as identified by the EU. The fund supported [3] infrastructure projects under the Connecting Europe Facility.
- Environment: the fund also supported projects related to energy or transport, as long as they clearly benefited the environment in terms of energy efficiency, use of renewable energy, rail transport development, support for intramodality, and strengthening public transport.

Financial assistance from the Cohesion Fund may be suspended by a Council decision (taken by qualified majority) if a member state runs an excessive public deficit and fails to take appropriate corrective measures.

The European Agricultural Fund for Rural Development (EAFRD [5]) supported the vitality and economic viability of rural areas through funding and actions promoting rural development. It is the "second pillar" of the Common Agricultural Policy (CAP), complementing the "first pillar" of income support and market measures by enhancing social, environmental, and economic sustainability in rural areas.

The EU's rural development policy supports the rural areas of the EU in addressing the wide range of economic, environmental, and social challenges and opportunities they face. Known as the "second pillar" of the Common Agricultural Policy (CAP), it was enhanced for the 2014–2020 period through the broader CAP reform process. The EU EAFRD [5] allocations for 2021 and 2022 are included in the 2014–2020 rural development pro-grammes, which were extended until 2022 un-der transitional rules. (The 2014–2020 EAFRD [5] programmes also received an allocation under the European Union Recovery Instrument (EURI).)

The European Maritime and Fisheries Fund (EMFF [5]) – supported fishermen in adopting sustainable practices and helped coastal communities diversify their activities for better livelihoods.

III. ABSORPTION OF FUNDS AT THE EUROPEAN UNION LEVEL

During the 2014–2020 financial framework, Romania benefited from significant European funds, recording an absorption rate of over 97% of available allocations. According to official statements, by the end of 2024, Romania had attracted more than €27 billion through the Cohesion Policy, reaching an absorption rate of 97.3%, placing it 18th out of 29 countries.

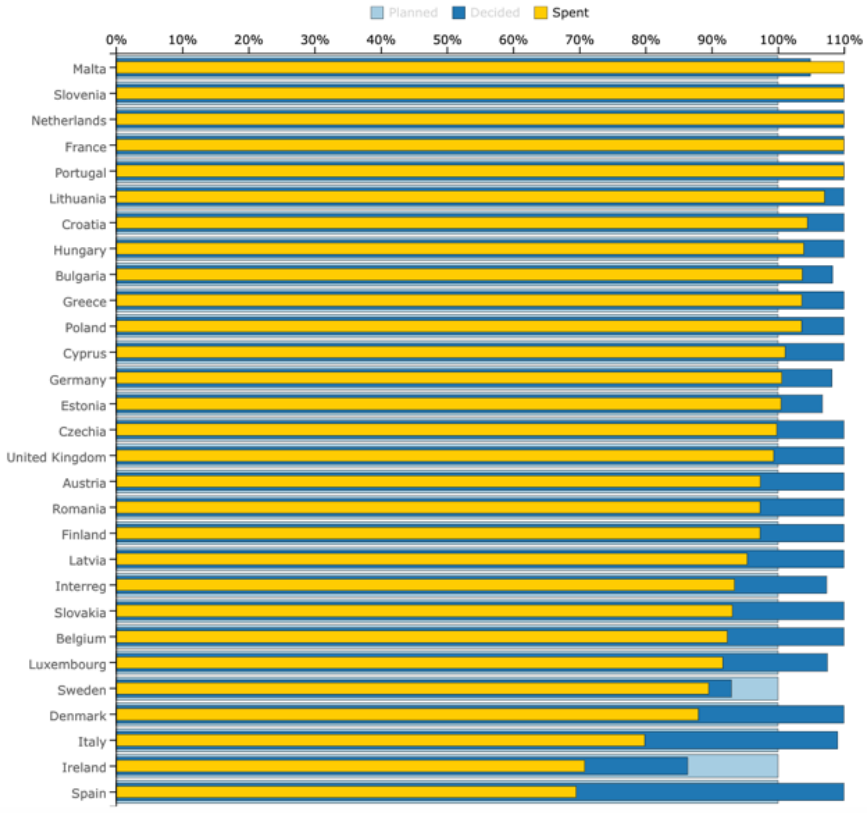


Fig. 1. Financial implementation of the cohesion policy by country [3].

Table 1

Financial allocations in the 2014–2020 financial framework for each Member State of the European Union. [3].

Member states	Total allocation of the 2014-2020 operational programme (million euros)	Member states	Total allocation of the 2014-2020 operational programme (million euros)
Belgium	4 694 736 243	Greece	20 428 360 921
Bulgaria	8 700 725 709	Spain	42 441 119 299
Czech Republic	29 544 467 130	France	28 501 806 801
Denmark	810 178 396	Croatia	9 921 375 168
Germany	30 366 253 079	Italy	53 257 045 945
Estonia	4 665 144 886	Cyprus	873 633 561
Ireland	1 977 710 171	Letonia	5 192 727 708
Hungaria	25 420 619 357	Lithuania	7 887 717 226
Malta	865 226 493	Luxemburg	88 283 382
Netherlands	2 399 304 517	Portugal	27 554 810 814
Austria	2 977 566 143	Romania	26 873 144 609
Poland	90 592 769 609	Slovenia	3 818 092 784
Slovakia	17 399 739 144	Sweden	3 467 697 138
Finland	2 620 478 202	United Kingdom	19 617 168 835
TOTAL	**472 957 903 270**		

In total, these funds were used to finance more than 18,500 projects. These projects targeted areas such as transport infrastructure, regional development, environment, health, education, and support for the business environment.

It is important to note that due to the "n+3" rule, the implementation and reimbursement of projects financed under the 2014–2020 framework could continue until the end of 2023. Thus, Romania managed to use its allocated funds efficiently, avoiding the risk of decommitment.

Between 2014 and 2020, Romania contributed €13.76 billion to the EU budget over seven years. These figures show that Romania was a net beneficiary of EU funds (over +€14 billion), meaning it received more than it paid in, with the main goal being to reduce development gaps compared to Western EU countries.

The highest absorption rates among the countries presented were in Malta (116.5%, totaling €1,143,754,175) and Slovenia (116.3%, totaling €4,750,924,499). The lowest absorption rates were found in Ireland (70.9%, €1,502,504,175) and Sweden (89.6%, €3,430,155,640).

Comparing the 2007–2013 financial framework with the 2014–2020 financial framework, Romania managed to reach an absorption rate target of 72.8% by the end of 2013, whereas in the 2014–2020 period, Romania achieved a record absorption rate of 97.3%.

With the help of European funds, Romania achieved the following between 2007 and 2023:

- Registered one of the highest economic growth rates in the European Union;
- The GDP per capita increased by ap-proximately 5–6% annually;
- European funds accounted for over 60% of public investments during 2014–2020;
- Over 500,000 jobs were created or supported;
- More than 2,500 km of roads were modernized;
- Over 1 million beneficiaries took part in inclusion/training programmes;
- Hundreds of communities were connected to modern utility networks.

IV. THE SITUATION OF EUROPEAN FUNDS IN ROMANIA BY REGIONS

European funds have been a driving force behind public investment in Romania, directly contributing to: economic growth, infrastructure modernization, improved quality of life, and balanced regional development.

The top cities in Romania that benefited from European fund investments were:

- Ilfov – approximately 13.7 billion lei;
- Cluj – approximately 10.5 billion lei;
- Constanța – approximately 10.3 billion lei;
- Dolj – approximately 9.6 billion lei;
- Bucharest – approximately 8.5 billion lei;
- Timiș – approximately 8.4 billion lei;
- Bihor – approximately 7.3 billion lei;
- Brașov – approximately 6.9 billion lei;
- Satu Mare – approximately 3.7 billion lei;
- Iași – approximately 3.5 billion lei.

These counties received significant investments in infrastructure, education, health, and regional development. At the opposite end of the spectrum, with the lowest absorption of European funds, were:

- Giurgiu – approximately 0.5 billion lei;
- Teleorman – approximately 0.6 billion lei;
- Călărași – approximately 0.7 billion lei.

These counties faced challenges in project implementation, which led to lower absorption rates of European funds.

V. PROPOSALS FOR IMPROVING THE ABSORPTION OF EUROPEAN FUNDS

To improve the implementation of European Funds during the 2021–2027 financial framework, the following are needed:

- Simplifying procedures through full digitalization of the application, evaluation, and reporting processes, implementing clear and stable guidelines regarding conditions and deadlines, and providing technical assistance and support for beneficiaries.
- Increasing administrative capacity through continuous training of personnel involved in project management, establishing dedicated teams and long-term specialist allocations and creating centers of excellence in project management.
- Realistic planning and proactive management by developing clear implementation plans with deadlines and measurable indicators, periodic monitoring and interim reporting for timely interventions, and using digital tools to track project progress.
- Securing co-financing by identifying clear sources of co-financing before launching projects, supporting beneficiaries through credit facilities or guarantee funds, and promoting projects that include public-private partnerships.
- Preventive and transparent control by implementing multi-phase audits and controls (not just at the end), ensuring process transparency and public reporting of project status, and applying rapid correction mechanisms for irregularities.
- Results and impact orientation by prioritizing projects with a clear and measurable long-term impact, defining relevant indicators and closely tracking them, involving communities and stakeholders in project evaluation.

REFERENCES

[1] Comisia Europeană. (2023). Fondurile structurale și de investiții europene (ESIF). Disponibil la: https://ec.europa.eu/regional_policy/ro/funding/

[2] Ministerul Investițiilor și Proiectelor Europene (MIPE). (2024). Rata de absorbție a fondurilor europene 2014–2020. Disponibil la: https://mfe.gov.ro

[3] Comisia Europeană. (2021). Politica de coeziune 2014–2020. Raport de sinteză. Disponibil la: https://ec.europa.eu/regional_policy/ro/information/publications/

[4] Parlamentul European & Consiliul UE. (2013). Regulamentul (UE) nr. 1303/2013 privind dispozițiile comune ale fondurilor ESI. Jurnalul Oficial al Uniunii Europene.

[5] Fondul European de Dezvoltare Regională (FEDR). (2020). Investiții în regiunile Europei. Ghid informativ. Disponibil la: https://ec.europa.eu/regional_policy/ro/funding/erdf/;

[6] Eurostat. (2024). Statistici privind contribuțiile și beneficiile statelor membre UE din bugetul UE

[7] Curtea de Conturi Europeană. (2023). Rapoarte privind performanța utilizării fondurilor structurale în România

[8] OECD. (2021). Public Investment and EU Funds in Romania. Raport de analiză economică.

[9] Ministerul Finanțelor din România. (2023). Execuția bugetară privind contribuția la bugetul UE și absorbția fondurilor europene.

[10] Molle, W. (2015). European Cohesion Policy (3rd ed.). Routledge.

[11] Bachtler, J., Berkowitz, P., Hardy, S., & Muravska, T. (2016). EU Cohesion Policy: Reassessing Performance and Direction. Routledge.

[12] Allen , D. (2022). The EU Budget and European Integration. Palgrave Macmillan.

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Transition to Industry 5.0 and beyond

Andrada-Denisa BECA[1] and Ilie Mihai TAUCEAN[2]

Abstract – This paper examines how industrial revolutions have changed throughout time, focusing mostly on the new Industry 5.0 framework that brings an adaptable, sustainable, and human-centered component to the advancement of technology. Industry 5.0 is positioned as a strategic extension of Industry 4.0 and is defined by the incorporation of innovative technologies, including Big Data, collaborative robots, and Artificial Intelligence, into systems that place an importance on ethical design, human involvement, and long-term social value.

Keywords: Industry 5.0, Industry 4.0, artificial intelligence (AI), digitalization

I. INTRODUCTION

Advanced technologies like automation, artificial intelligence (AI), the Internet of Things (IoT), and big data analytics have caused a remarkable shift in industrial processes worldwide during the last several decades. These technological advancements, which are sometimes grouped under The Industry 4.0, have completely changed the way that items are made, increasing accuracy, productivity, and efficiency. But as these developments progress, they have also raised questions about job displacement, the morality of automation, and the changing role of the human worker in industrial processes [1].

Industry 5.0, which highlights the combination of human intelligence with advanced technology to build a more equitable, sustainable, and balanced industrial environment, has become an appealing concept in response to these issues [2].

II. THE EVOLUTION OF THE INDUSTRIAL REVOLUTIONS

The First Industrial Revolution

Mechanized manufacturing replaced manual labor in Industry 1.0, which started in the late 18th century. Textiles and mining were transformed with the introduction of steam power and mechanical instruments like the power loom and spinning jenny. Efficiency and manufacturing capacity were greatly enhanced by these improvements. Mechanization increased employment as well as wage growth, according to empirical research looking at the spread of steam power in the 19th century. Industries that adopted steam had up to 94% more workers and paid salaries up to 5% more than their non-steam alternatives [3].

The Second Industrial Revolution

The development of assembly lines and electricity production in the 19th century marked the start of the Second Industrial Revolution. The idea of mass processing was adapted by Henry Ford (1863–1947) from a Chicago slaughterhouse where each butcher only performed a portion of the cow slaughtering duties and the pigs were suspended on conveyor belts. These concepts have been used by Henry Ford in the production of automobiles, and he has substantially improved the method of manufacturing [4].

It was marked by the widespread use of electricity, which paved the way for the creation of assembly lines and mass manufacturing methods. Faster production with consistent procedures and more effective machinery operation were made possible by

electrification. A case study examining the development of production systems demonstrated the flexibility and efficiency gains made possible by the implementation of flow line production and the Toyota Production System (TPS), which optimized supply to satisfy changing customer demands [5].

The Third Industrial Revolution

The third industrial revolution started in the 1970s [4], (1950s from other sources [28]) with computers and memory programmable controls for partial automation. Given that these advancements have been made, researchers can optimize the whole development process without the need for human intervention.

Robots that execute program sequences without human intervention are examples of this. Henry Ford's desire for increased productivity and the intelligent procedures that are beginning to appear under Industry 4.0 are connected by Industry 3.0. Not only were procedures like those at Ford made simpler, but automation also increased the safety and efficiency of crucial production processes [4].

[1] Politehnica University of Timisoara, andrada.beca@student.upt.ro
[2] Politehnica University of Timisoara, ilie.taucean@upt.ro

The Fourth Industrial Revolution

The German government first announced Industry 4.0 as the start of the fourth industrial revolution during the 2011 Hannover Fair [6].

Comparably, to fully understand irreversible changes, a thorough understanding of the shift from Industry 3.0 to Industry 4.0 is required. This transformation has several components that also have social consequences. Among them is the Internet of Things (IoT). Machine-to-machine (M2M) communication is made possible by this technology. A more human-free industrial environment is produced by this capacity. The second significant factor behind these shifts is "autonomy." The systems are increasingly acting on their own initiative. Cyber physical systems (CPS) and a few sensors are additional crucial components of this change. They make it easier for machines to communicate with one another. More reliable, flexible, and intelligent production systems are created when CPS, IoT, M2M connectivity, and autonomy work together [7].

Industry 4.0 refers to the way production processes are organized using technology and autonomously communicating devices along the value chain. This represents a model of the future "smart" factory, where computer-driven systems keep an eye on physical processes, create a virtual environment, and make decentralized choices using self-organization mechanisms. The notion considers the growing computerization of manufacturing sectors, where tangible items are easily incorporated into information networks [8].

The Fifth Industrial Revolution

The need for productivity, efficiency, and technical improvement has continuously fueled the development of industrial paradigms. Nevertheless, Industry 5.0 represents a dramatic change toward a more human-centered strategy, merging human intelligence with innovative technologies to build inclusive, sustainable, and resilient industrial systems [9].

Industry 5.0 places more emphasis on human-machine collaboration than its predecessor, Industry 4.0, which mainly dealt with automation and digitalization. It does this by using technologies like robotics, the Internet of Things, and artificial intelligence (AI) to improve human capabilities rather than replace them. This paradigm shift highlights the benefits of human creativity, critical thinking, and adaptation in complex industrial situations, as well as the limits of a solely technological approach [10].

III THE IMPORTANCE OF INDUSTRY 5.0

It has been observed that the goal of maintaining customer pleasure by mass production modifications is no longer enough in the setting of Industry 4.0. However, if people are actively involved in the production processes, consumer satisfaction may rise when mass production and customized manufacturing are combined. Consequently, there is an increasing need to establish an Industry 5.0 environment. Industry 5.0 promotes active participation in smart factories and human-machine collaboration to enhance product customization and boost production capacity [11].

Data analysis by artificial intelligence and value creation allows the custom manufacture of items based on each customer's demands, considering the various needs of users and consumers. It is possible to do the following:

- Stability and adaptability in production scheduling and ideal inventory control in response to the client's present needs.
- Increase production efficiency, save expenses, and optimize labor use, timely and appropriate product or service delivery.
- Reduce shipping delays and deliver goods to clients quickly.

The implementation of these solutions will boost industry competition and consumer happiness, lower costs, and enhance environmental circumstances [12].

IV. CHARACTERISTICS OF INDUSTRY 5.0

Implementation of intelligent technologies in Industry 5.0 significantly boosts innovation and creativity. In this phase, organizations employ tools, equipment, and intelligent materials to enhance smart manufacturing, enhancing productivity, quality, and flexibility. Enhanced customer satisfaction is related to high-quality products as well as services. Utilization of tools and sensors in the industrial revolution increases a system's processing ability, enhancing its ability to meet customer expectations. By simplifying the decision-making process in complex procedures, modern technology and software also ease operations [11]. The four main elements of Industry 5.0 are elaborated further in Table 1.

Through the implementation of smart materials, Industry 5.0 offers a change of produced product qualities to meet specific requirements and standards. Since software is the foundation of digital manufacturing, understanding this field is crucial for creating sophisticated, high-tech products. During this revolutionary time, the creation of innovative and creative products is prioritized, which reduces the need for inventory and physical storage [11].

Table 1

Main characteristics of Industry 5.0 [12]

No.	Elements	Description	References
1	Intelligent materials	• Smart materials have changeable properties that change with temperature, humidity, light, etc. • These materials are used in various industries such as textiles, medicine and electronics and aerospace industries • In the 5.0 industry, smart material capabilities play an important role	(X. Li, Shang, & Wang, 2017),(Hakanen & Rajala, 2018),(Yang et al., 2019),(Haleem & Javaid, 2019a)
2	Intelligent devices	• Computing capabilities are a prominent feature of smart devices in the Industry 5.0. • Ability to connect in smart devices for effective management and monitoring. • Internet-connected cameras in smart devices improve the operation control system.	(Crutzen, 2005),(Derby et al., 2007),(Matindoust, Baghaei-Nejad, Abadi, Zou, & Zheng, 2016),(Shammar & Zahary, 2019)
3	Intelligent automation	• This element integrates different aspects of humans, software and machinery and improves their participation. • Automation system is effective for detecting process errors. • Machine learning in this system increases productivity in complex tasks and processes and is useful in reducing process time.	(Mekid, Schlegel, Aspragathos, & Teti, 2007),(Butner & Ho, 2019),(Pagliosa, Tortorella, & Ferreira, 2019)
4	Intelligent systems	• Intelligent systems can be used in various parts of the supply chain, such as transportation, logistics, research and development, etc. • In industry 5.0, this system increases the ability to interact and react to environmental changes • Intelligent systems allow the customer's personalized needs to be met at the required time	(Dragcevic et al., 2007),(Sykora, 2016),(Xie, Liu, Fu, & Liang, 2019),(Sakamoto, Barolli, Barolli, & Okamoto, 2019)

Table 2

The benefits and risks of Industry 5.0

Benefits	Risks
Human centric focus The focus on human-centric cooperation, in which people and robots collaborate in a synergistic way, is a fundamental component of Industry 5.0 [13]. This paradigm change puts human innovation and decision-making at the forefront, departing from Industry 4.0's automation-centric approach [14].	**Cybersecurity vulnerabilities** The attack surface for cyber-attacks is enhanced in Industry 5.0 environments due to the increasing interdependence of devices. To protect sensitive data and maintain system integrity, the integration of AI, IoT, and other cutting-edge technologies calls for strong cybersecurity measures [18].
Resource efficiency and sustainability Industry 5.0 technology adoption supports environmentally friendly production methods [15].	**Workforce skill gaps** Employees must learn new skills to work with modern technology, involving the ability to comprehend and control complex robots and advanced technology [19].
Improvement of customer satisfaction Mass manufacturing gives way to mass personalization with Industry 5.0, allowing producers to customize goods to each customer's tastes without compromising productivity [16].	**Financial and investment** Industry 5.0 will necessitate a large financial outlay. Particularly for SMSs, high expenses of hiring new staff, updating infrastructure, and purchasing new technology can be a major deterrent. Financial risk is increased by the possibility of a delayed ROI [20][21].

V. COMPARING THE BENEFITS AND POTENTIAL RISKS OF INDUSTRY 5.0

It's essential to take into consideration both the potential advantages and disadvantages of Industry 5.0, as it continues to influence discussions about the future direction of manufacturing and innovation. [22]. Understanding its deeper implications from a technological, economic, and social perspective requires a balanced approach. The main benefits and risks of Industry 5.0 will be shown in Table 2.

Future perspectives on human-centricity include improving human-robot interaction in dynamic and complex industrial systems and achieving the balance and fullness of human-machine collaboration, which aims to empower humans and human operators by enhancing their individual capabilities and skills [14].

Businesses may minimize their environmental impact, save waste, and maximize resource consumption by utilizing real-time monitoring and sophisticated analytics. This encourages ethical production and consumption and is consistent with global environmental goals [15].

Industries may quickly modify manufacturing lines to produce personalized goods at scale by using cutting-edge technology like artificial intelligence (AI), the Internet of Things (IoT), and collaborative robots (cobots). In addition to improving customer happiness, this strategy gives businesses a competitive edge in industries where customization is becoming more and more important. By utilizing smart technology, items are produced with greater quality and consistency, which increases consumer loyalty and confidence [17].

To enable the safe adoption of Industry 5.0 concepts, studies have shown how inadequate current industrial implementation frameworks are at resolving these cybersecurity issues. Accordingly, new frameworks focused on cybersecurity are required [18].

Increasing the skills of the workforce is a major concern, especially in emerging nations where training resources may be scarce [19].

VI. FUTURE PERSPECTIVE ON INDUSTRIAL REVOLUTIONS BEYOND INDUSTRY 5.0

Discussions concerning how future developments could impact industries and societies continue to be caused by the development of revolutions in industry. Researchers argue that in future Industry 6.0 could have technologies such as improved biotechnology and quantum computing, making industries more adaptable, sustainable, and responsive to concerns about the environment [23]. Some academics wonder if Industry 4.0 and 5.0 are really revolutions or perhaps these are just little steps toward greater transition. Alongside technological innovation, an actual industrial revolution often involves significant systemic transformations, such as social, economic, and political conflicts [24]. Although they attempt to solve urgent global challenges like climate change and ethical concerns in automation, the changes anticipated for Industry 6.0 and beyond could be considered more revolutionary in nature [25].

Beyond automation and digitalization, Industry 6.0 is envisioned as an innovative phase in the development of industry. It places an extreme value on excessive personalization, emotional intelligence in machines, and harmonious human-AI interaction using technologies like virtual twins, quantum computing, and autonomous systems [26]. Although still theoretical, Industry 7.0 expands on these concepts by putting ahead a post-industrial, regenerating society in which industries function in harmony with ecological systems [27].

Looking ahead, these future revolutions will likely require new frameworks for governance and collaboration among governments, businesses, and communities. The success of these changes will depend not only on technology but also on how well industries align their goals with societal needs and sustainability principles. [24]

The trajectory of industrial revolutions suggests that more profound transformations are on the horizon, potentially redefining the concept of what an industrial revolution truly means.

VII. CONCLUSIONS

Industry 5.0 is a value-driven development that combines resilient systems, sustainability, and human empowerment. Through cobots, it improves human-machine collaboration, promotes skills investments, and reinterprets success in terms of mindfulness of the environment. It must be implemented strategically and inclusively, though, because it confronts significant challenges in the areas of investment, skills, and security. Organizations can move toward a responsible future by using human-centered design, pilot-based expansion, thorough training, and cyber-sustainable governance. This continuous change encourages cross-sector movement and collaborative studies to achieve a future in where technology promotes human potential in a flexible, caring industrial society.

REFERENCES

[1] Folgado, F. J., Calderón, D., González, I., & Calderón, A. J. (2024). Review of Industry 4.0 from the Perspective of Automation and Supervision Systems: Definitions, Architectures and Recent Trends. Electronics, 13 (4), 782. https://doi.org/10.3390/electronics13040782

[2] Enose Kamalabai, N., Hannola, L., Donoghue, I. (2025). Role of Industrial Artificial Intelligence in Advancing Human-Centric Sustainable Development of Industry 5.0. In: Aaltonen, P.,

Kurvinen, E. (eds) Contemporary Issues in Industry 5.0. Technology, Work and Globalization. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-031-74779-3_12

[3] Salvo, C., Weisdorf, J., & Ridolfi, L. (2022, July 17). The impact of mechanisation on wages and employment: Evidence from the diffusion of steam power. CEPR. https://cepr.org/voxeu/columns/impact-mechanisation-wages-and-employment-evidence-diffusion-steam-power

[4] Sharma, A., & Jit Singh, B. (2020). Evolution of Industrial Revolutions: A Review. Regular, 9(11), 66–73. https://doi.org/10.35940/ijitee.i7144

[5] Yin, Yong & Stecke, Kathryn & Li, Dongni. (2017). The evolution of production systems from Industry 2.0 through Industry 4.0. International Journal of Production Research. 56. 1-14. 10.1080/00207543.2017.1403664. Yin, Yong & Stecke, Kathryn & Li, Dongni. (2017). The evolution of production systems from Industry 2.0 through Industry 4.0. International Journal of Production Research. 56. 1-14. 10.1080/00207543.2017.1403664.

[6] Salkin, C., Oner, M., Ustundag, A., Cevikcan, E. (2018). A Conceptual Framework for Industry 4.0. In: Industry 4.0: Managing The Digital Transformation. Springer Series in Advanced Manufacturing. Springer, Cham. https://doi.org/10.1007/978-3-319-57870-5_1

[7] Oztemel, E., Gursev, S. Literature review of Industry 4.0 and related technologies. J Intell Manuf 31, 127–182 (2020). https://doi.org/10.1007/s10845-018-1433-8

[8] Osman, C.-C., & Ghiran, A.-M. (2019). When Industry 4.0 meets Process Mining. Procedia Computer Science, 159, 2130–2136. https://doi.org/10.1016/j.procs.2019.09.386

[9] Tóth, A., Nagy, L., Kennedy, R., Bohuš, B., Abonyi, J., & Ruppert, T. (2023). The human-centric Industry 5.0 collaboration architecture. MethodsX, 11, 102260. https://doi.org/10.1016/j.mex.2023.102260

[10] Eriksson, K. M., Anna Karin Olsson, & Carlsson, L. (2024). Beyond lean production practices and Industry 4.0 technologies toward the human-centric Industry 5.0. Technological Sustainability. https://doi.org/10.1108/techs-11-2023-0049

[11] Kumar, A., & Kumar, R. (2024). The Development of Manufacturing Industry Revolutions from 1.0 to 5.0. Journal of Informatics Education and Research, 4(1). https://doi.org/10.52783/jier.v4i1.710

[12] Yavari, F., & Pilevari, N. (2020). Industry Revolutions Development from Industry 1.0 to Industry 5.0 in Manufacturing. Journal of Industrial Strategic Management, 5(2), 44–63. https://mgmt.firuzkuh.iau.ir/article_678926.html

[13] Božić, Velibor. (2024). Industry 5.0: A Future of Human-Machine Collaboration and Sustainability.

[14] Alves, J., Lima, T. M., & Gaspar, P. D. (2023). Is Industry 5.0 a Human-Centred Approach? A Systematic Review. *Processes*, *11*(1), 193. https://doi.org/10.3390/pr11010193

[15] Hassan, M. A., Zardari, S., Farooq, M. U., Alansari, M. M., & Nagro, S. A. (2024). Systematic Analysis of Risks in Industry 5.0 Architecture. Applied Sciences, 14(4), 1466. https://doi.org/10.3390/app14041466

[16] Ashiq, M. (2024). Industry 5.0 – the human centric solution and personalization: challenges and opportunities for libraries. Library Hi Tech News. https://doi.org/10.1108/lhtn-10-2024-0176

[17] Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. Journal of Cloud Computing, 11(1). https://doi.org/10.1186/s13677-022-00314-5

[18] Santos, B., Costa, C., & Santos, L. (2024). Cybersecurity in Industry 5.0: Open Challenges and Future Directions. 1–6. https://doi.org/10.1109/pst62714.2024.10788065

[19] Valette, E., Bril El-Haouzi, H., & Demesure, G. (2023). Industry 5.0 and its technologies: A systematic literature review upon the human place into IoT- and CPS-based industrial systems. Computers & Industrial Engineering, 184, 109426. https://doi.org/10.1016/j.cie.2023.109426

[20] Restrepo-Morales, J. A., Ararat-Herrera, J. A., López-Cadavid, D. A., & Camacho-Vargas, A. (2024). Breaking the digitalization barrier for SMEs: a fuzzy logic approach to overcoming challenges in business transformation. Journal of Innovation and Entrepreneurship, 13(1). https://doi.org/10.1186/s13731-024-00429-w

[21] Laddha, S., & Agrawal, A. (2024). Unveiling barriers to Industry 5.0 adoption in supply chains: a DEMATEL approach. RAUSP Management Journal. https://doi.org/10.1108/rausp-08-2023-0146

[22] Nahavandi, S. (2019a). Industry 5.0—A Human-Centric Solution. Sustainability, 11(16), 4371. https://doi.org/10.3390/su11164371

[23] Duggal, A. S., Malik, P. K., Gehlot, A., Singh, R., Gaba, G. S., Masud, M., & Al-Amri, J. F. (2021). A sequential roadmap to Industry 6.0: Exploring future manufacturing trends. IET Communications, 16(5). https://doi.org/10.1049/cmu2.12284

[24] Ferrari, A., Bacco, M., Gaber, K., Jedlitschka, A., Hess, S., Kaipainen, J., Koltsida, P., Toli, E., & Brunori, G. (2022). Drivers, barriers and impacts of digitalisation in rural areas from the viewpoint of experts. Information and Software Technology, 145, 106816. https://doi.org/10.1016/j.infsof.2021.106816

[25] Chourasia, S., Tyagi, A., Pandey, S. M., Walia, R. S., & Murtaza, Q. (2022). Sustainability of Industry 6.0 in Global Perspective: Benefits and Challenges. MAPAN. https://doi.org/10.1007/s12647-022-00541-w

[26] Reddy C, Kishor & Reddy, Aendra & Doss, Srinath & Priyanka, Kalyani. (2024). Human-Machine Collaboration and Emotional Intelligence in Industry 6.0: Concepts, Challenges, and Future Directions. 10.4018/979-8-3693-1515-6.ch009

[27] Arturo, M. (2024, January 26). The Seventh Industrial Revolution (IR 7.0). https://doi.org/10.13140/RG.2.2.14881.17763/2

[28] Perez, C. (2010). Technological revolutions and techno-economic paradigms. Cambridge Journal of Economics, 34(1), 185–202. https://doi.org/10.1093/cje/bep051

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Study on Optimizing Energy Consumption of an Energy. Independent House Project

Diana BALUTI[1], Lavinia BOGDANOVICI[2], Matei TAMASILA[3]

Abstract - The ability of a residence to completely meet its energy needs from renewable sources on its own, hence lowering reliance on traditional networks, is known as energy independence. In this paper, concrete solutions will be analyzed and proposed for optimizing electricity consumption in the particular case of an autonomous house project. To achieve the objective, three short, medium and long-term solutions will be proposed which will be analyzed using the principles of economic engineering.

Keywords: Energy consumption, Electric energy, Autonomous house, Energy-independent.

I. INTRODUCTION

Considering the current energy crisis and the increasing dependence on electricity networks, especially in the current context of Romania where the capping of electricity prices is being stopped, I have chosen to address the subject of optimizing residential electricity consumption in this paper. Only by expanding electricity from renewable sources, such as the use of photovoltaic panels, will we be able to cover this energy need. For this reason, we should focus on using green energy in our homes and also find alternative solutions to reduce energy consumption [9].

Renewable sources play a significant role because in the near future they will contribute to the world's electricity consumption, since energy production from fossil fuels is not a sustainable practice, both because of the negative impact on the environment and because the fuels are available in limited quantities. However, there is an inexhaustible and clean source of energy, namely solar energy [4].

II. CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1 The importance of perception towards energy-independent house

Human demand for energy is constantly increasing. A home that produces at least as much energy as it consumes is considered energy independent.

The foundation of an energy-independent home is an integrated strategy that optimizes consumption through modified architectural design and the utilization of renewable resources, fusing the concepts of smart technology and passive energy efficiency [10]. This entails implementing sustainable technical and architectural solutions that optimize local resources, managing energy efficiently, and guaranteeing long-term comfort. Therefore, by lowering consumption and improving the home's total energy performance, the idea encourages energy autonomy [11].

A passive house and a practically zero-energy house are integrated energy efficiency concepts that combine sustainable technologies, efficient systems, and optimal architecture to guarantee the home's energy autonomy and drastically cut energy usage [2].

2.2 Energy-efficient appliances

By avoiding energy waste while in use, energy-efficient appliances, are essential to lowering domestic power consumption. By reducing greenhouse gas emissions, these appliances not only save household energy expenditures but also make a substantial contribution to environmental sustainability. Adopting them is a sensible and efficient way to maximize household energy use, directly assisting initiatives to improve energy autonomy and lower overall consumption in residential structures [3].

2.3 Integration of photovoltaic systems

Since integrated photovoltaic systems enable local energy generation from renewable sources and significantly lessen reliance on the traditional grid, their installation in homes is crucial to achieving energy

[1] Politehnica University of Timisoara, Romania, diana.baluti@student.upt.ro
[2] Politehnica University of Timisoara, Romania, lavinia.bogdanovici@student.upt.ro
[3] Politehnica University of Timisoara, Romania, matei.tamasila@upt.ro

autonomy. According to latest research, PV systems with storage of batteries have the ability to significantly reduce building carbon emissions and meet up to 90% of a home's energy needs. Therefore, a strong technical-economic option for effective consumption in self-sufficient households is photovoltaic technology [8].

2.4 Other solutions to reduce electricity consumption

Additionally, an effective and environmentally friendly way to lower the amount of power needed for home heating and cooling is to install high-performance thermal insulation for exterior walls and roofs. Depending on the situation, climate, and technical features of the building, investments in high-performance thermal insulation materials can lower energy consumption by 60% to 81%, according to studies by Amani (2025) and Shahee, Abdoos, and Aslani (2024).

In the context of the shift to energy-autonomous homes, such actions also help to lower CO_2 emissions and improve indoor thermal comfort, proving their economic and environmental effectiveness [1],[5].

III. METHODOLOGIES

This paper focuses on the analysis of the electricity consumption of an independent house in Romania, Timis County. A single-family house with 4 members is considered. The house design, the parameters of the house structure and construction are described and illustrated, the electricity consumption for heating the house and water, the use of consumables, the energy needs and the availability of solar energy are taken into account. The methodology used involves theoretical documentation regarding autonomous house and energy consumption, as well as practical analysis of the independent house.

To carry out this study, the principles of economic engineering were used, more precisely the construction of cash-flow variants for each of the 3 alternatives, followed by the comparison of the alternatives and the selection of the optimal variant through the global utility method. Finally, the critical path method will be used to know the duration of the implementation process, the necessary resources and the cost of implementation.

IV. RESULTS

The main economic problem faced by the residents of the house is the high price and consumption of electricity and its ever-increasing costs. Many people find themselves in this situation, especially residents of houses with many consumers.

4.1 Technical details of the house

I chose to optimize the electricity consumption of a specific house in Timiș County and transform it into an energy independent house.

House structure

The house has an area of 210 m^2, with 150 m2 of usable space, consisting of a ground floor and an attic. On the ground floor there is a kitchen and a living room. In the attic there are 3 bedrooms and a bathroom. The outdoor courtyard has 600 m2 with a swimming pool, gazebo and a pond. It also has a pantry.

Consumers

- Kitchen consumers: dishwasher, LED interior lighting, microwave oven, juicer, toaster, electric oven, hob, coffee maker, refrigerator.
- Living room consumers: television, LED interior lighting, internet, air conditioning
- Bedroom consumers: television, air conditioning, iron, LED interior lighting, laptop, etc.
- Bathroom consumers: washing machine, hairdryer, LED interior lighting, etc.
- Outdoor consumers: outdoor lighting, heat pump pool, pond, gazebo

Sources for producing light

The main source for producing light inside the house are LED bulbs (wall lamp, mirror, lamp, panel, chandelier, strip) and outside there are both LEDs (spots, garlands, garden lamp) and incandescent bulbs (in the pantry) [6].

Average consumption per home

Following the calculations made for each room in the house (kitchen, bathroom, living room, bedrooms, exterior) with specific consumers depending on their power, average usage and consumption over time, we have the following results:

- Total consumption in the kitchen is 5,262KW/day, 157.86KW/month, 1894.32 KW/year
- Average total consumption in the living room and hallway is 2,448KW/day, 73.44KW/month, 881.28KW/year
- Average total consumption in the bedrooms is 3,530KW/day, 105.9KW/month, 1270.8KW/year
- Average total consumption in the bathroom is 2,614KW/day, 78.42 KW/month, 941.04KW/year
- Average outdoor consumption is 1,822KW/day, 54.66 KW/month, 655.9 KW/year
- Total KW/day ≈ 15.676, total KW/month 470.28, total KW/year 5,643.34

Considering the invoice price formula = active electricity price + mandatory additional taxes (transportation tariff + distribution tariff + cogeneration contribution + green certificates + excise duties + VAT etc.) and the sum of the components per kWh: 0.65 (active energy) + 0.2361 (distribution) + 0.013

(transportation) + 0.00333 (cogeneration) + 0.0725 (green certificates) + 0.005 (excise duties) = 0.97993 Ron/kWh.

We have the following observations, according to ANRE website at the current price on the free electricity market, it would be estimated to pay:

• The cost per day with VAT is 18.26 Ron/day
• The cost per month with VAT is 548,442 Ron/month
• The cost per year with VAT is 6,580.56 Ron/year

4.2 Solving the problem in the short, medium and long-term using the principles of Economic Engineering

a. Defining alternatives

In order to solve the problems found, I propose the following alternatives:

1. Calling on a program to replace worn-out equipment with more efficient and effective ones.

2. Purchasing and implementing a photovoltaic system.

3. Investing in solutions to reduce electricity consumption.

b. Development of alternatives

1. New electrical and electronic household equipment with energy efficiency class A+, A++ and even A+++ will be purchased. The following categories are proposed: washing machine, refrigerator, air conditioner, built-in electric oven (see Table1).

The total investment for a single appliance in each category is 12,598 RON, in total approximately 62KW of energy are saved monthly, i.e. 41,893 Ron saved per month and 15,290,945 Ron/year.

2. Purchase and implementation of a photovoltaic system.

The offer available for purchasing the system is illustrated below (Table 2).

Table 1: Comparative energy consumption of equipment

Equipment	Consumption of old equipment	Consumption of new equipment (Class A++)	Energy depreciation
Washing machine	60KW/month	38KW/ month	22KW
Refrigerator	36KW/ month	24KW/ month	12KW
Air conditioning	45KW/ month	32KW/day	13KW
Built-in oven	30KW/ month	15KW/ month	15KW

Table 2: Offer 6kW single-phase photovoltaic system

Total value with VAT - Materials	25.743 lei
Total value with VAT - Green stamp duty	191 lei
Total value with VAT - Prosumer file	1.600 lei
Grand total with VAT	27.535 lei
Total value other materials	1.000 lei
Total value – Labor	5.000 lei
Total labor VAT	6.000 lei

Project implementation

A photovoltaic system was installed for the house, consisting of:

• 14 photovoltaic panels LONGI SOLAR tip LR5-66HIH 500-0.500kWp (d.c.) = 7.00 kWp (d.c.)

• 1 three-phase inverter Marea SOLAX type SOLAX X3-MIC-6K-G2 400V 6KW (d.c.)

The following is an illustration of the GANT diagram (see Fig.1), with the activities, resources, and time available for implementing the home's photovoltaic system.

The technical information of the system is illustrated below (Table 3).

The production capacity of the system throughout the year is favorable (see Fig. 2) and the amortization of the investment is satisfactory (Table 4), after a few years it implies a considerable profit (Fig. 3) as shown by the simulation results.

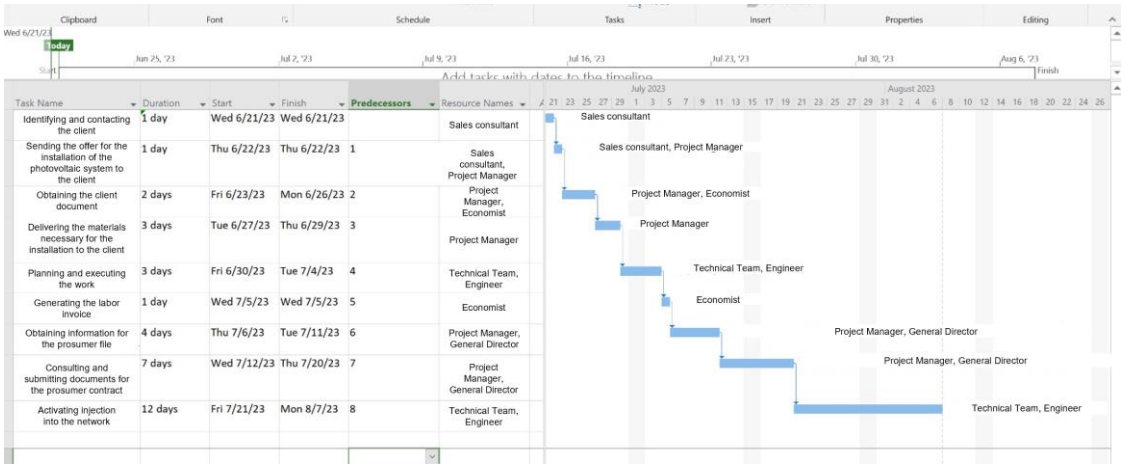


Fig. 1. Gantt chart of PV system installation stages.

Table 3: Project information

Project information			
Project name	C.P House	Project number	1
Location	Romania/Timisoara	AC Grid Voltage:	Single-phase~230 V
Ambiental temperature	-	Low Temperature Record:	-20◦ C 25◦ C 42◦ C
Application	-	Average High Temperature:	250.0kWh/month
Total number of PV modules	14	High Temperature Record:	6.37kWp
Number of inverters	1	Other Consumed Loads:	6 kW
Annual energy yield	6.768,08 kWh	PV Peak Power	0.95%

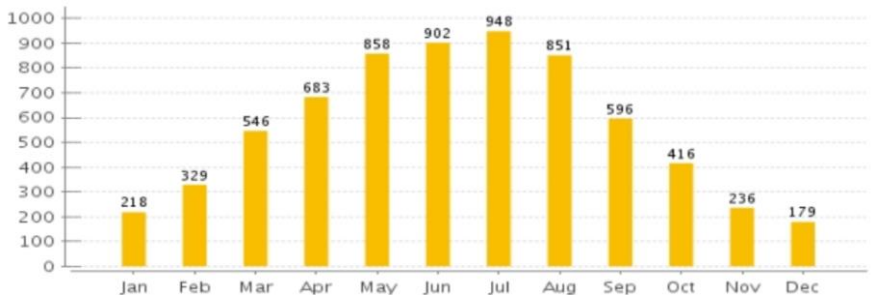


Fig. 2. Annual capacity in kWh.

Table 4: Return on Investment

Personal Investment	5.500 €	Load Ratio	0%
Loan Amount	0 €	Interest Rate:	0 €
System Lifespan:	25 years	Output Power Reduction Rate:	0.8% /year
Annual Power Output:	6,825.68 kWh/year	Electricity Price:	0.27 € /kWh
Electricity Subsidy:	0.1 € /kWh	Total Profit:	34,469.684 €
Annual Profit:	1,378.787 € /year	Net Profit:	28,969.684 €
ROI:	526.72%	Annual ROI:	21.07%

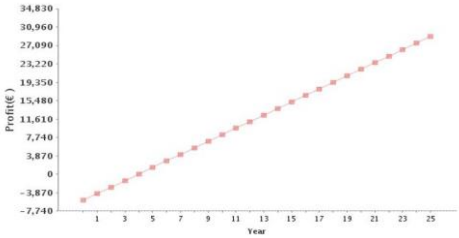


Fig. 3. Profit chart.

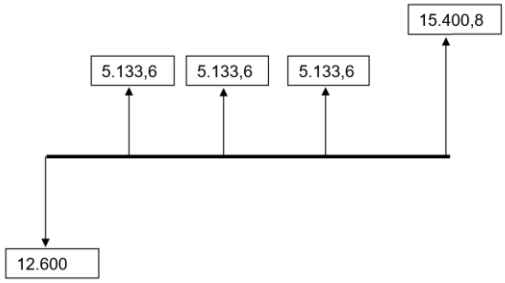


Fig. 4. Cash flow diagram for Table 5.

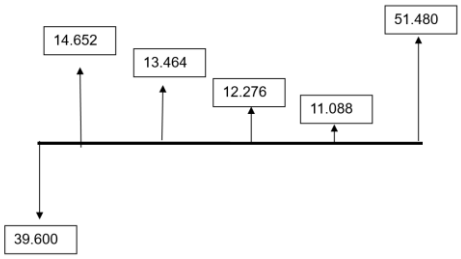


Fig. 5. Cash flow diagram for Table 6.

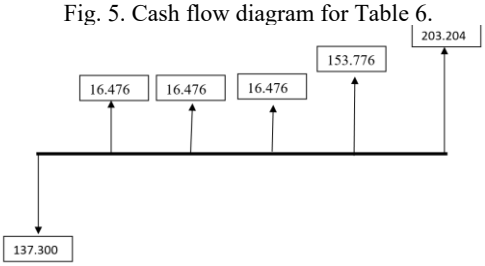


Fig. 6. Cash flow diagram for Table 7.

3. Investing in solutions to reduce electricity consumption

• Replacing exterior joinery with thermally insulated joinery;

Cost: thermally insulated joinery according to calculations = 15,000 euros

Materials: trypan and insulating window joinery

• Thermal insulation of exterior building elements (exterior walls, terraces, roof covering and other similar elements);

Cost: thermos-system facade with labor + materials = 12,000 euros

Materials: polystyrene, mesh, adhesive

• Thermal insulation of hot water distribution pipes;

Materials: polystyrene thermally insulated pipe

Total estimated price 27,450 €

c. Building cash flow scenarios for each alternative

Cash flow diagrams and tables indicate the level of financial resources that are formed because of the efficient execution of the activity and that are available, that is, found in the form of liquidity. The level of liquidity of the company is usually different from that of potential financial resources that result from the surplus of profitable activities, due to the circulation of liquidity through the company [7].

1. I apply for a personal loan with a fixed interest rate from Raiffeisen Bank (Table 5, Fig.4):

Interest rate of 10.75% for a period of 3 years

Total=12,598 LEI

Bank loan=12,600 LEI

$$A=P*[i*(1+i)N/(1+i)N-1] = 12,600*[0.1075*(1+0.1075)3/(1+0.1075)3-1] =5,133.6 \text{ LEI}$$

P – represents the initial amount invested or the value of the loan obtained.

N – the number of periods for which the loan is obtained (e.g. months, years, etc.).

i – the interest rate for the period for which the loan was obtained.

2. A fixed-interest personal loan is applied for from CEC Bank (Table 6, Fig. 5):

Interest rate of 12% for a period of 4 years

Total=39,535 LEI

Bank loan=39,600 LEI

3. A fixed-interest personal loan is applied for from CEC Bank (Table 7, Fig. 6):

Interest rate of 12% for a period of 4 years

Total=137,250 LEI

Bank loan=137,300 LEI

Table 5: Repaying at the end of each year a portion of the loan plus the related interest so that the total annual amounts paid are equal

Year	Amount due at the beginning of the year	Interest/Year	Amount due at the end of the year	Interest-free payment	Total annual payment
1	12.600	1.354,5	13.954,5	3.779,1	5.133,6
2	8.820,9	948,24	9.769,14	4.185,36	5.133,6
3	4.635,54	498,32	5.133,86	4.635,28	5.133,6
Total		2.801,06	-	12.599,74	15.400,8

Tabel 6: Repayment at the end of each year of the amount of 9,900 lei and the interest for that year

Year	Amount due at the beginning of the year	Interest/Year	Amount due at the end of the year	Interest-free payment	Total annual payment
1	39.600	4.752	44.352	9.900	14.652
2	29.700	3.564	33.264	9.900	13.464

3	19.800	2.376	22.176	9.900	12.276
4	9.900	1.188	11.088	9.900	11.088
Total		11.880	-	39.600	51.480

Table 7: Repayment of the loan in a single installment at the end of 4 years and payment of interest at the end of each year

Year	Amount due at the beginning of the year	Interest/Year	Amount due at the end of the year	Interest-free payment	Total annual payment
1	137.300	16.476	153.776	0	16.476
2	137.300	16.476	153.776	0	16.476
3	137.300	16.476	153.776	0	16.476
4	137.300	16.476	153.776	137.300	153.776
Total		65.904	-	137.300	203.204

d. Analysis, comparison of alternatives and selection of the optimal variant (global utility method)

To determine the optimal alternative, the global utility method will be used (Table 8). Therefore, for the three proposed variants (alternatives), 5 selection criteria will be established, with the help of which the matrix of inhomogeneous consequences will be created (Table 9).

Table 8: Global utility method

Nr. Crt. / Criteria / Alternatives		C1 Available balance	C2 Cost of implementing alternatives	C3 Payback period (years)	C4 Implementation time (days)	C5 Forecast of improvement of the house's activity
1	Replacement of worn equipment	13.000	12.598	8 years	8	3
2	Implementation of photovoltaic system	27.800	27.535	20 years	34	1
3	Consumption reduction solutions	140.000	137.250	10 years	90	2

Table 9: Global utility method

Criteria Alternatives	C1 Available balance	C2 Cost of implementing alternatives (lei)	C3 Payback period (days)	C4 Implementation period (days)	C5 Forecast regarding the improvement of the house's activity	Ug
1. Replacement of worn equipment	0	1	1	1	0	3
2. Implementation of photovoltaic system	0,11	0,88	0	0,68	1	1,67
3. Solutions to reduce consumption	1	0	0,83	0	0,5	2,33

V. RESEARCH RESULTS AND LIMITATIONS

The global utility method's findings show that replacing obsolete household appliances with energy-efficient A++ models (Ug = 3) is the most efficient way to achieve a balance between minimal investment and quantifiable monthly savings. Though it is less ideal because of their greater costs and longer payback times, the solar system (Ug = 1.67) and thermal insulation (Ug = 2.33) are both feasible.

The cost of replacing high-efficiency appliances, the large initial investment needed for photovoltaic systems and building insulation, and the lack of customer education and knowledge on long-term energy and cost benefits are the limitations.

The originality of the research is given by the way the content is presented, the realistic simulation of an actual residential building, complete with technical details daily, monthly, and annual energy use per room. With the help of original tables, graphs, and figures, the problem is tackled utilizing the concepts of economic engineering for three customized alternatives. Each alternative is assessed using the global utility approach, critical path analysis, and customized cash flow diagrams.

VI. CONCLUSIONS AND FINAL REMARKS

After analyzing the energy usage of a 210 m² home with an attic and ground floor, we discovered that,

given the state of the energy market, the annual consumption would be roughly 5,643 kWh, with an estimated cost of more than 6,500 RON. The kitchen was found to be the main source of consumption, and households with high consumption profiles are more financially strained due to the complicated power tariff system. This thorough investigation supported the necessity of putting certain energy-saving and autonomy-boosting ideas into practice.

Reducing consumption was directly impacted by the first suggested option, which was to replace outdated home appliances with A++ energy class models. The ensuing monthly savings, which total about 41 RON, cause the investment to recoup quickly and result in yearly savings of more than 490 RON.

The second option, which involved installing a 6 kWp photovoltaic system, has shown itself to be incredibly energy-efficient. The system can achieve energy independence and fully meet the demands of the residence with an average monthly production of 484 kWh. The ROI of 526.72%, the predicted net profit of about €29,000 over 25 years, and the annual recovery rate of more than 21% demonstrate the durability and profitability of this kind of project from a financial standpoint. According to the global utility technique, this option was the best one since it had the most balanced costs, benefits, and degree of immediate feasibility.

The third option, which entails significant upfront costs, improves the building's overall efficiency and lowers energy losses during the colder months by replacing the woodwork and insulating the exterior walls and pipes. With significant long-term benefits in terms of thermal comfort and passive energy efficiency, this solution is essential for a comprehensive energy independence package even though it has no immediate effect on the electricity bill.

Using the global utility method, it was shown that the best course of action is to replace appliances with energy-efficient models, then install a photovoltaic system and thermal insulation. The three solutions must be viewed as complimentary components of an integrated system, where efficiency, local production, and loss reduction work in concert, in order to truly attain energy independence.

However, the implementation of the independent system is necessary for significant energy production, and for this we have created a Gantt chart with the activities necessary for the implementation of the project, the duration of each activity and the available human resources.

REFERENCES

[1] Amani, N. (2025). Energy efficiency of residential buildings using thermal insulation of external walls and roof based on simulation analysis. Energy Storage and Saving, 4(1), 48-55.

[2] Chwieduk, D., & Chwieduk, M. (2020). Determination of the Energy Performance of a Solar Low Energy House with Regard to Aspects of Energy Efficiency and Smartness of the House. Energies, 13(12), 3232.

[3] Olatunde, T. M., Okwandu, A. C., & Akande, D. O. (2024). Reviewing the impact of energy-efficient appliances on household consumption. International Journal of Science and Technology Research Archive, 06(02), 001–011

[4] Răboacă, M. S. (2023). Contribuții privind realizarea unei case pasive utilizând sisteme de energie hibridă (Doctoral dissertation, Universitatea Tehnica din Cluj-Napoca, Romania).

[5] Shahee, A., Abdoos, M., Aslani, A., & Zahedi, R. (2024). Reducing the energy consumption of buildings by implementing insulation scenarios and using renewable energies. Energy Informatics, 7(1), 18.

[6] ŞVEŢ, L. (2020). Contribuția driverelor în eficientizarea consumului de energie electrică în sistemele de iluminat cu utilizarea LED-urilor (Doctoral dissertation, Universitatea Tehnică a Moldovei).

[7] Tămășilă M. (2021). Inginerie Economică

[8] Tu, R., Guo, Z., Liu, L., Wang, S., & Yang, X. (2025). Reviews of Photovoltaic and Energy Storage Systems in Buildings for Sustainable Power Generation and Utilization from Perspectives of System Integration and Optimization. Energies, 18(11), 2683.

[9] Vîrlan, A., & Voloșin, O. (2023). Eficientizarea și crearea unei locuințe independente. In Conferinţa tehnico-ştiinţifică a studenţilor, masteranzilor şi doctoranzilor (Vol. 3, pp. 85-88)

[10] Construct Intelligence. (2024, noiembrie 5). Cum se realizează o casă pasivă? Studiu de caz șantier Corbeanca.https://construct-intelligence.ro/cum-se-realizeaza-o-casa-pasiva-studiu-de-caz-santier-corbeanca/

[11] Universitatea Politehnica din Timișoara. (n.d.). Casă aproape zero energie și casă pasivă – soluții sustenabile pentru clădiri rezidențiale. https://www.ct.upt.ro/centre/reco/nezebuild.htm

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Applying Total Productive Maintenance to Body Control Modules (BCM) in the Automotive Industry: Optimizing Reliability and Preventing Failures

Lavinia BOGDANOVICI[1], Diana BALUTI[2], Matei TĂMĂȘILĂ[3]

Abstract - The paper analyzes the application of the Total Productive Maintenance (TPM) method on the Body Control Module (BCM), used in the automotive industry. By integrating preventive maintenance and reliability analyses, the aim is to reduce unplanned shutdowns and optimize system performance. The study is based on real data and highlights the benefits of TPM in the context of automotive electronics, but also the limitations encountered in practice. The contribution of the paper consists in highlighting an approach model applicable to the maintenance of complex electronic components.

Keywords: Total Productive Maintenance (TPM), Body Control Module (BCM), preventive maintenance

I. INTRODUCTION

In the context of the modern automotive industry, the efficiency and reliability of electronic equipment and components are becoming increasingly important, both for manufacturers and users. The Total Productive Maintenance (TPM) model is used by scholars and practitioners alike to avoid losses and increase productivity [1].

A prime example is the Body Control Module (BCM), an essential module that controls numerous electronic functions of the vehicle body, ensuring comfort, safety and optimized communication between various vehicle systems. This important part has been researched over the years, with the purpose of improving the testing part or focusing on it in the security analysis [2], [3], [4].

The present study aims to apply TPM to BCM to ensure optimal operation and minimize downtime. In this line of reasoning, a rigorous maintenance strategy is required, and the Japanese concept of TPM provides a complete framework for achieving this goal.

II. METHODOLOGY

This paper presents applicative research, focused on the analysis of the implementation of the Total Productive Maintenance (TPM) concept within a maintenance department of an automotive component manufacturing company, located in western Romania. The methodology used involves theoretical documentation regarding TPM and BCM, direct analysis of the processes within the company, as well as practical observation of the maintenance of BCM modules.

This paper aims to analyze the implementation of TPM principles in the maintenance process of BCMs, focusing on reducing downtime and improving product quality and safety. Through a thorough understanding of preventive maintenance processes and specific BCM issues, effective solutions can be identified to ensure an extended component life and optimized production.

III. THE RESEARCH APPROACH

3.1 Conceptual aspects regarding TPM

The TPM concept became an innovative Japanese concept in the 1950s, a concept taken from the United States. Thus, preventive maintenance combined with maintenance prevention and maintenance improvement came to a new concept called productive maintenance. The goal of productive maintenance was to maximize the efficiency of facilities and equipment to achieve reliable and optimal life cycles of production equipment. [5]

The types of preventive maintenance are as follows:

- Systematic maintenance - is carried out through maintenance activities, current repairs, revisions, established in a specific ethnic plan for each type of equipment.
- Conditional maintenance - carried out by monitoring the wear parameters of the elements, using specific tools, so that

[1] Politehnica University of Timisoara, Romania, lavinia.bogdanovici@student.upt.ro
[2] Politehnica University of Timisoara, Romania, diana.baluti@student.upt.ro
[3] Politehnica University of Timisoara, Romania, matei.tamasila@upt.ro

maintenance is carried out before the appearance of the defect.

- Predictive maintenance - allows the delay and planning of interventions, preventive maintenance being subordinated to the analysis of the evolution following the degradation of the asset [6].

The initial objective of TPM is to return the equipment to its new condition and to prevent any further deterioration. The implementation of preventive maintenance (PM) programs is the first step towards eliminating deterioration. A four-stage approach to PM programs is presented in Fig. 1 [5].

In the four-phase PM program development, the first phase consists of inspecting the target equipment, using customized checklists, and labeling and documenting the problems. The second phase involves prioritizing the identified problems and identifying the causes of the highest priority problems. Tools commonly used in this phase include brainstorming, data collection, and maintenance/operator experience. In phase 3, the focus is on developing inspection standards and building PM programs. Inspection standards should be written standards. These are essential for developing accurate PM programs. They should communicate the procedure required to perform PM effectively. Finally, the fourth phase consists of providing training, implementing PM programs, and monitoring and adjusting. Effective training should be developed and provided to the targeted operators and maintenance personnel. This is necessary for effective PM implementation.

Autonomous maintenance involves the development of preventive maintenance practices. For equipment improvement, equipment activities should focus on eliminating all failures through physical equipment analysis (PEA) techniques to aim for zero failures. For preventive maintenance systems, the organization should develop an information system that contains all TPM activities. Equipment-related decisions are then based on maintenance and performance data. Finally, quality maintenance focuses on eliminating equipment-related failures through physical quality analysis (PQA). The goal is zero defects [5]

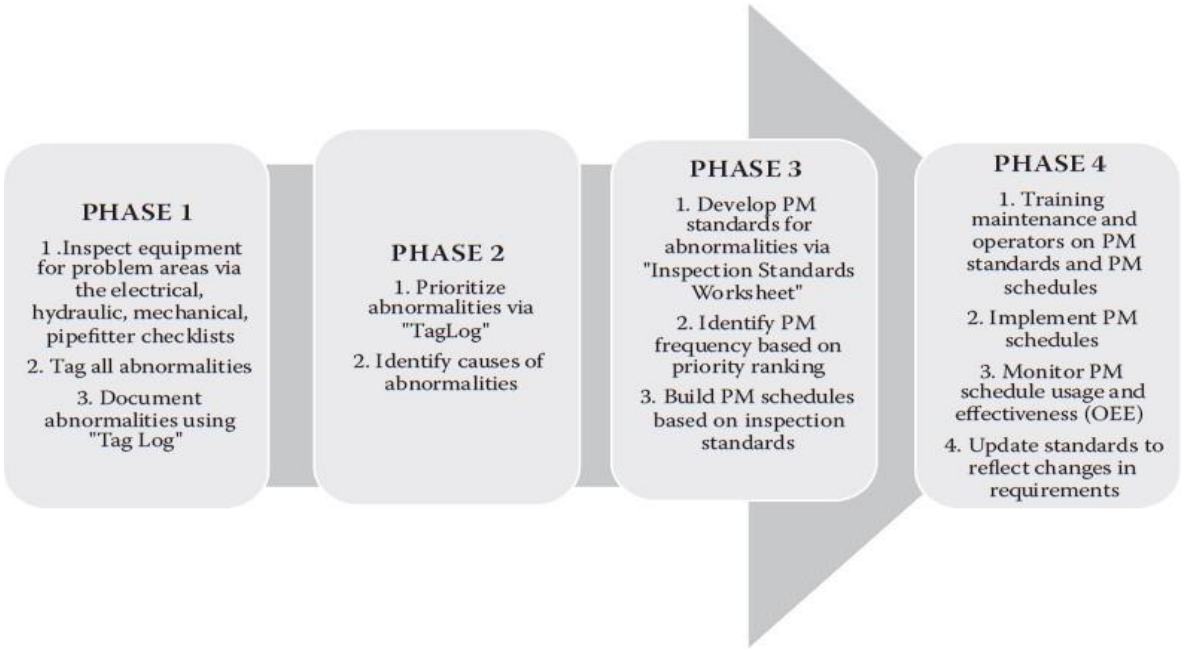


Fig. 1. Four-phase preventive maintenance approach [5]

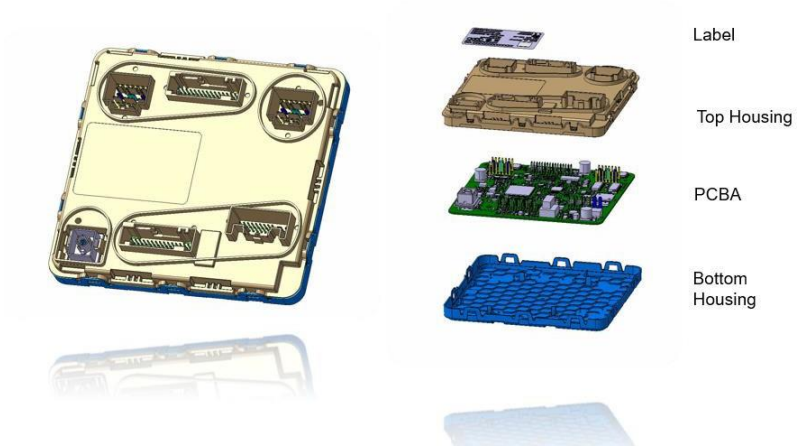


Fig. 2. Body Control Unit

3.2 Presentation of BCM modules

The product that is assembled in the said production line is an electronic control unit. ECU (electronic control unit) is responsible for monitoring and controlling various electronic accessories in the body of a vehicle.

Typically, in a car, the BCM (Fig. 2) controls the power windows, power mirrors, air conditioning, immobilizer, central locking. The BCM communicates with other on-board computers via the vehicle bus, and its main application is to control load drivers - actuating relays that, in turn, perform actions in the vehicle, such as locking the doors, turning on the signals (in older cars), or dimming the interior light.

The electronic control unit is responsible for monitoring and controlling various electronic accessories in a vehicle's body. If installed in the engine compartment, BCMs can control the headlights, turn signals, and windshield washer system. If installed in the rear, they can control the taillights, rear window wiper, and door lock assist. A BCM in a car allows a vehicle to use fewer wires and electronic modules, reducing the weight of the car, improving fuel economy and energy efficiency, and lowering manufacturing costs as well as the total cost of ownership. Related to the overall vehicle electronic architecture, BCMs provide maximum reliability and economy by reducing the number of connections and wiring required. [7], [8]

3.3 BCM product operation process

As mentioned above, the BCM is a multi-faceted electronic unit that controls certain comfort and safety features in a car: windows, mirrors, temperature, wipers, etc. and supports multiple functions, the main one being the management of a range of electronic body components.

The BCM consists of both a hardware and a software part:

When it comes to hardware, the BCM has two types:

- Input devices: represent all sensors that transmit data to the BCM.
- Output devices: these generate a response to signals received from input devices.

For example, a person presses the power window switch and an input signal reaches the BCM. This, in turn, sends an output response to the small motor that executes the command and lowers or raises the car window. As a result, the window opens. Although the process involves several steps, a simple exchange like this takes less than a second [9].

When it comes to software, it hosts a multitude of algorithms, being a complex system that must consider a lot of variables. It generally connects to other components of the BCM with an API (application programming interface). An API is a way for two or more components to communicate with each other. The software must also comply with standards (ISO, AUTOSAR, SPICE). [9]

For example, if a person wants to unlock their vehicle with a remote key, the encrypted signal from the key is tied to a specific car. When the vehicle sensor detects it, the code is subjected to a decryption algorithm, and the doors are unlocked.

At the same time, the BCM software is responsible for calculating the current/total distance traveled, calculating and monitoring fuel consumption, deciding the most appropriate gear for the current speed, and displaying this information to the driver [9].

3.4 BCM problems and improvement solutions

In general, a vehicle's body control module facilitates the functions of the wipers, lighting, air conditioning, heating, and the anti-theft system. The BCM is also responsible for communicating with the vehicle's other control modules. This communication allows for simplified integration of a vehicle's vital systems for more efficient operation [10].

A BCM is typically located under the dashboard. This location tends to be standardized, with typical BCMs located near this area. However, the location of the BCM varies from one vehicle model to another. In some cases, partial disassembly of the dashboard is required to access the BCM [10].

There are several possible causes for the BCM to fail. The most common are the following:

- The BCM is electrocuted in an accident shaken violently by the shock, it can be destroyed, the wiring harness can be pulled out - one or more wires can come out, and if a single bare wire touches another wire or touches a metal part of the vehicle, then it will cause a short circuit.
- Excessive heating of the vehicle engine: this cause can damage the BCM or melt the insulation of the wiring.
- A flooded BCM will most likely fail. If the sensors are clogged with water, the BCM will not be able to execute the command, such as remotely opening the door locks, etc.
- Excessive vibration can cause the BCM to wear out. For example, an unbalanced tire can vibrate the vehicle. And simple wear will eventually lead to the failure of the BCM [11].

The BCM rarely presents serious operational problems or total damage, which is why there are several signs associated with BCM failure, with some of these symptoms tending to be more prevalent than others. [10]

1. Repeated battery drain

The most common symptom of a BCM failure is repeated battery drain, also known as parasitic drain. Excessive battery drain is a sign of BCM damage, and it occurs when a BCM continues to supply power to a specific part/accessory at incorrect times.

2. Erratic electrical function

A BCM failure can cause various electrical functions, such as a vehicle's horn, lights, and wipers, to operate intermittently. Another sign of failure can be the instrument cluster's sweeping dials and erratic door lock and radio functionality. Such problems are more likely to be BCM-related when several of these symptoms are present at the same time.

3. Security system problems

The BCM generally operates the security system of a vehicle. So, it is easy to assume that if there are consistent issues with a vehicle's security system, it is a result of a faulty body control module. This can also include issues with keyless entry functions.

4. Dash warning lights

Another sign of a BCM failure is when the dash appears to have a dash and starts to resemble a Christmas tree. This occurs when a BCM can no longer communicate with one of the additional control modules of a vehicle, such as the transmission control module, powertrain control module, or airbag control module.

5. Failure to start

A faulty body control module can also prevent a vehicle from starting in some cases. The lack of communication between the BCM and other control modules can lead to starting difficulties when a faulty BCM fails to identify the key's transponder chip or simply cannot provide a "start" signal from a vehicle's ignition switch. [10]

Next, we will present some solutions to the challenges faced by BCM:

- Regarding battery life, from a software perspective, competent architecture design can prevent the system from being overloaded and using more power than necessary. From a hardware perspective, consider using quad flat packages when building a more cost-effective BCM.
- Regarding performance, processing speed, but also response times, depend a lot on the architecture. It is certain that sometimes the performance of the software proves the skills of the developer. An industry-resistant application architecture is a huge advantage. To give the BCM more speed, separate processors for inputs and outputs can be equipped.
- Another solution is the increasing complexity, namely the number of input and output channels that the BCM must connect to. This varies from car to car. As vehicles become smarter and more powerful, the number of sensors and processors that BCM must deal with will also increase. There are two solutions to this. First, eSwitches with an SPI can help manage PWM channels when a lot of inputs and outputs are involved. Second, rapid prototyping for BCMs can help deliver more complex modules in shorter cycles [10].

Steps for the diagnostic and repair procedure:

1. Locate the BCM using the appropriate workshop manual for your vehicle.
2. Determine the problem by observing what is not working (example: door locks). Check fuses and relays for malfunction. Then check the wiring connections. Carefully rotate the connector to ensure it is not dangling. Check the individual pins for looseness.
3. Check for power at each terminal. Use the BCM diagnostic code reader to determine which pin or pins are having problems. If any of the terminals are not receiving power, the problem is most likely in the wiring. If power is being applied to the terminals, then the problem is in the BCM itself.
4. Before replacing the BCM, it is recommended to consult with your dealer or preferred technician.

It is important to note that only a portion of the BCM can be damaged; so the remote control may work, but the power door locks will not work [11].

It is possible to drive with a damaged BCM, but it is not recommended. However, in some situations a BCM can be reset to restore full functionality. This, of course, depends on the internal circuitry of a module being in proper working order, as no reset will fix compromised internal electrical circuitry. The procedure for resetting a BCM generally differs from one make and model of vehicle to another. In many cases, this is done by disconnecting a vehicle's battery, while other vehicles require a specialized fuse to remove.

In the event of a BCM failure, the cost of replacing the body control module varies from one vehicle make and model to another. However, the average cost of replacing a BCM ranges from 1,300 RON to 2,800 RON. The largest variable in this price is the actual cost of the failed module itself. Currently, the transportation costs associated with locating and procuring such modules can also affect the outcome of these repairs, as module availability has become somewhat of an issue [10].

3.5 Application of TPM on BCM in the analyzed company - Maintenance Plan

In the following table we will describe the individual maintenance plan for each process of the analyzed company in western Romania. A rule valid for each process is the first step, namely: check the safety elements: emergency stop buttons, optical barriers, sensors, protective doors, scanners and other protective elements of the machine and test their functionality, and where necessary, check the entire compressed air installation for air leaks and fix any defects (connections, hoses, regulators, cylinders, decanters, control islands and valves).

Next, we will present in tabular form (Table 1), the individual maintenance plan in steps, both monthly and every three months, where necessary.

Table 1. Maintenance plan of the analyzed company

Process/ Equipment	Maintenance type	Main activities
A.Selective soldering	Monthly	Linear bearing lubrication; check for flux, nitrogen, air leaks; container pressure; cylinder adjustment; check solder level; cabin filter
	Once every 3 months	Cleaning ionizer nozzles
B.Pin Insertion	Monthly	Greasing the slide and bearing rail (NLGI 3); cleaning + greasing the pneumatic guide; greasing the cams, rollers, mechanisms (NLGI 000/00); checking sensors, clamping systems, control panel
	Once every 3 months	Checking transmission, running rails, ball cages, springs; cleaning bearings; checking belts, knives and dies
C.Milling	Monthly	Cleaning + lubricating X,Y axes; emptying pneumatic condensers; checking air filters
	Once every 3 months	Cleaning particle system nozzles
D.Circuit Testing	Monthly	Machine cleaning, electrical + mechanical visual checks; corrosion inspection
	Once every 3 months	Check pneumatic connectors, sensor positions, functionality
E.Case assembly	Monthly	PCB glass cleaning, vacuum cups, emergency buttons, light; dust extraction; capacitor emptying
	Once every 3 months	Lubricate the vertical axes of the press with NLGI 2 grease; wipe off excess.
F.Radio Frequency Testing	Monthly	Blower cleaning, coupling/socket check, power unit cleaning
G. Kessy Testing	Monthly	Blower cleaning, coupling/socket check, power unit cleaning
	Once every 3 months	Cleaning ionizer nozzles
H.End of Line	Monthly	Technician announcement, test pin check
	Once every 3 months	Checking the pneumatic circuit, filters, bearings and lubrication
I.Automatic optical inspection	Monthly	Backup engineer announcement; tightening lens screws
J.Immobilization process	Monthly	Cleaning fan guard; cleaning/changing electrical panel filters
K.Logistics Box	Monthly	Checking and changing electrical panel filters

IV. RESEARCH RESULTS AND LIMITATIONS

The implementation of TPM led to a 30% reduction in the average downtime of equipment involved in BCM testing, as well as an increase in the meantime between failures. However, the analysis was limited by the lack of complete data series on BCM failure history, as well as the difficulty in accurately measuring the influence of autonomous maintenance outside of standard TPM components.

The originality of the presented research lies in the practical application of a well-established Japanese model (TPM) in the context of a Romanian company in the automotive industry, on a complex electronic module such as the BCM. Most studies on TPM focus on mechanical equipment or standard production lines; instead, this work extends the applicability of TPM to sensitive electronic components, thus contributing to the development of good maintenance practices adapted to new technological realities.

VI. CONCLUSIONS

The application of the Total Productive Maintenance (TPM) method to Body Control Module (BCM) modules highlighted the high potential of this approach in reducing downtime and increasing the reliability of electronic systems in the automotive industry. By integrating preventive maintenance and fault cause analysis, TPM contributes to optimizing maintenance processes and extending the life of components.

The case study demonstrated that, despite the increased complexity of BCMs, the rigorous implementation of a TPM program allows for the anticipation of critical problems, the reduction of unplanned costs and the improvement of the overall performance of the vehicle. At the same time, the paper highlighted the specific challenges, such as difficult access to the module or its architectural limitations, offering applicable and current solutions.

The main contribution of the research consists in providing an applicable model of intelligent maintenance for complex electronic components, supported by good technical and analytical practices.

REFERENCES

[1]. Morales Méndez, J. D., & Rodriguez, R. S. (2017). Total productive maintenance (TPM) as a tool for improving productivity: a case study of application in the bottleneck of an auto-parts machining line. *The International Journal of Advanced Manufacturing Technology*, *92*, 1013-1026.

[2]. Yang, X., Lin, Y., Gao, F., Wang, G., & Zhang, Y. (2014, April). Automated test system design of body control module. In *2014 International Conference on Information Science, Electronics and Electrical Engineering* (Vol. 3, pp. 1542-1546). IEEE.

[3]. Ding, Z. (2019). Designing on a Vehicle Body Control Module Performance Tester. *International*

Journal of Pattern Recognition and Artificial Intelligence, *33*(08), 1959026.
[4]. Groza, B., Gurban, H. E., & Murvay, P. S. (2016, June). Designing security for in-vehicle networks: a Body Control Module (BCM) centered viewpoint. In *2016 46th Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshop (DSN-W)* (pp. 176-183). IEEE.
[5]. Tina Kanti Agustiady, Elizabeth A. Cudney - *Total Productive Maintenanca - Strategies and Implementation Guide*, editura CRC Press Taylor & Francis Group, 2015
[6]. Note luate din cursul de *Mentenanța Sistemelor de Producție*, Ș.l. dr. ing. Olivia Giuca, 2023
[7]. https://www.continental-automotive.com/en-gl/Passenger-Cars/Architecture-and-Networking/Control-Units/Body-Control-Modules
[8]. https://intellias.com/body-control-module-bcm-in-automotive/
[9]. https://bambooapps.eu/blog/body-control-module
[10]. https://cartreatments.com/bad-body-control-module-symptoms/#:~:text=A%20non%2Dfunctioning%20or%20faulty,switch%2C%20thereby%20preventing%20starter%20engagement.
[11]. https://ro.avtotachki.com/u0141-narushena-svyaz-s-modulem-upravleniya-kuzovnym-oborudovaniem-a/

Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Continuous Improvement of Support Services in Romanian Universities – A Methodological Approach

Ioan Mihai COSTA[1], Matei TĂMĂȘILĂ[2], Maria Elena BOATCĂ[3]

Abstract – In the current landscape, universities face new challenges that affect the overall institutional success and, implicitly, the academic excellence of students. Research in the past years proved that integration of students' perception and satisfaction with support services and the quality of the educational experience are adamant for achieving improved performance. The paper presents a statistical analysis regarding the assessment of students' satisfaction with support services and key results obtained in a Romanian university. The paper outlines how the proposed model reveals relevant data for decision-making process.

Keywords: University support services, continuous improvement, students' satisfaction, statistical analysis.

I. INTRODUCTION

Continuous improvement management is a key concept in quality management. It is a process based on identification, analysis and implementation of measures for improvement of systems, products and services [1]. If the university is regarded as a system whose main output is the delivery of educational services, then continuous improvement management process reflects the essence of the adaptation and response strategy for the specific needs of teachers and students alike.

In the context of the preoccupation for improving the quality of support services provided by universities for their students, the assessment of students' satisfaction with these services is essential for gathering valuable information aimed at supporting decision makers.

The paper presents a case study targeted at a Romanian university, where the level of students' satisfaction with support services was assessed through a questionnaire, followed by the statistical analysis of the data collected. Also, the paper presents key takeaways based on the data collected and how these data have the potential of founding the decisional process in the university. Finally, conclusions and study limitations are presented.

II. CONTINUOUS IMPROVEMENT IN THE CONTEXT OF HIGHER EDUCATION

The principles of continuous improvement management are focused on improving processes, products and services within an organization [2]. Among these principles are the process-oriented approach, data-driven decision-making, involvement of employees, customer focus, delimitation of steps for the improvement process and standardization [3, 4].

Carvalho [5] highlights that continuous improvement is not only based on principles, processes, standards and steps, but is also based on the organizational culture of change. Adaptation of improvement strategies is another key direction to address the changes derived from technologies, consumer preferences and ever-changing social and economic landscape [6, 7].

In higher education, the main service provided by universities is education. However, education has multiple dimensions and its provision required multiple resources, roles and responsibilities.

International Standardization Organization (ISO) conceived a standard dedicated to quality in education management: ISO 21001:2025 for defining requirements of a management system for educational organizations [8].

Without standards, quality would be solely a relative concept. Standardization enables a clear definition of quality. In the case of educational services quality, its multidimensional definition derives from the numerous stakeholders involved in the educational process: providers (universities), funding organizations and institutions, students, parents, the labor market, employees (not only teachers, but also support personnel), employers [9].

When exploring the extent to which continuous improvement management is applied in educational organizations, with a particular focus on university support services, the authors identified a knowledge gap regarding application of total quality management

[1] Politehnica University of Timisoara, Romania, ioanmihai.costa@upt.ro
[2] Politehnica University of Timisoara, Romania, matei.tamasila@upt.ro
3 Politehnica University of Timisoara, Romania, maria.boatca@upt.ro

as a set of evaluation and continuous improvement practices for university performance.

There is a legal European framework for quality assurance in higher education, along with Romanian legislation on the matter. ARACIS, the Romanian authority for quality assurance in higher education has specific performance criteria for support services. The attention paid to the Romanian context comes from the application of the methodological framework in a Romanian university [10]. The system approach to performance management is a strong argument in the favor of the necessity for designing a practical framework for their continuous improvement.

To fill this gap, the authors considered the possibility of assessing students' perception with support services and exploration of how the results of a questionnaire-based study and related statistical analysis could reveal key directions for improvement of support services. These directions should serve as support for the decision-making process in the university.

Collection of data for statistical analysis generally involves a multi-faceted approach for gathering of comprehensive information [11]. Common statistical analysis comprises a large variety of methods and tools, including software tools. Among the methods are descriptive analysis, correlations, regression analysis, Chi-square analysis, T-tests and ANOVA, chronological series analysis and others [12, 13].

Relevant information extracted from a statistical analysis can refer to resources' allocation, services improvement, specific informing activities, assessments, predictive modeling, comparative analyses, assessment of return on investment, and interdepartmental collaborations [14, 15].

Therefore, the next section presents the methodology and the results of its application in the case of a Romanian university.

III. STATISTICAL ANALYSIS OF STUDENTS' SATISFACTION WITH SUPPORT SERVICES – A CASE STUDY

A. *Methodology*

For the assessment of students' satisfaction with support services, the authors developed a questionnaire designed to capture users' perceptions, to observe the extent to which institutional reports can capture the central element of service delivery quality, that is user satisfaction.

The questionnaire comprised three categories of questions:

- Questions regarding demographic characteristics.
- Questions assessing the frequency of use of support services dedicated to students.
- Questions aimed at evaluating the support services.

The questionnaire also had a section dedicated to suggestions for improving support services.

The assessment of the support services was divided in sub-categories representing the characteristics of each service. Respondents were asked to assess each parameter using a Likert scale with five points, where 1 represents "unsatisfied" and 5 represents "excellent/very satisfied".

Further, to extract relevant information from the data collected from the questionnaire-based study, statistical analysis was performed using JASP, a dedicated software. Due to the specifics of the data collected, ANOVA and Turkey's HSD analyses were performed.

To ensure accuracy in data management and appropriate data processing, the results from the survey were coded, transforming text-based information into numerical codes. 64 variables were obtained. Moving forward, the data was processed, and the analyses were performed. The ANOVA tests were used to extract correlations between variables, thus highlighting the ones for which there are deviations from the average [12]. The significance level (p) was considered 0.05. The post-hoc analysis was performed for those variables that had a significance level $p<0,05$.

B. *Survey results*

The questionnaire was applied in a Romanian technical university counting approximately 15.000 students at all study levels. A total of 531 students from all the study levels participated in the study with complete responses that could be. However, the majority of them were undergraduates (91.3%), while 8.1% were master's students and 0.6% PhD students. Table 1 presents the demographic distribution of the respondents.

Table 1 Distribution of respondents by gender, age and current housing category

Variable	Frequency (%)	Number
Gender		
Male	51.4	273
Female	47.8	254
Other	0.8	4
Age (years)		
19-22	81.2	431
23-25	12.6	67
26-35	2.8	15
36-45	1.9	10
>45	1.5	8
Housing arrangement		
Student dormitory	48.6	258
Private dormitory	0.4	2
Alone - own dwelling	9.0	48
With family/parents	23.4	124
Rented dwelling	18.6	99

As presented in Table 1, most respondents are below 25 years of age and present an approximately even gender distribution (51.4% male and 47.8% female). With regards to housing arrangements, half of respondents live in university dormitories. In the case of those who live in other housing arrangements, the predominant reasons stated by students were:

- Not soliciting a place in the dormitory (36%)
- Unsatisfied with dormitory conditions (18%)
- Not accomplishing admission conditions (3%).

Regarding the other support services provided by the university analyzed, below are the main takeaways from students' responses:

1. 16.8% of students use cafeterias or fast food on the university campus, 62.7% cook at home and the rest opt for private locations or other dining arrangements.

2. Few students use frequently the library services, with 38.4% of the respondents using these services only a few times per semester.

3. The sports facilities are one of the most frequently used support services, with 73.1% of students reporting to use them.

4. Other services reported to be used are the medical services (students' clinic), with 21.7% of respondents using these services, and counselling and career orientation services (10.5% of respondents).

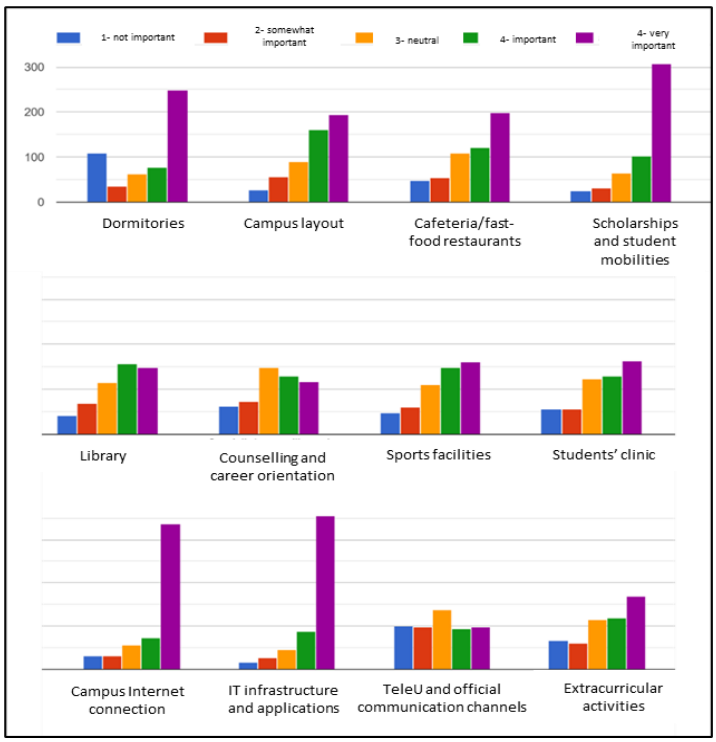


Fig. 1. Distribution of respondents' rated importance of support services for their academic performance (Source: the authors' own conception)

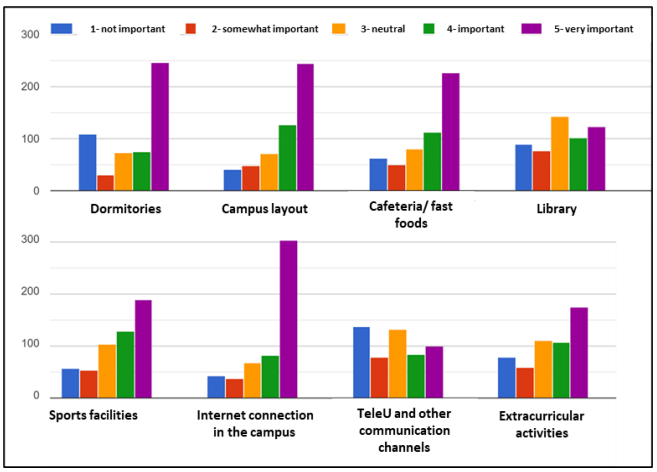


Fig. 2. Distribution of respondents' rated importance of support services for leisure time (Source: the authors' own conception)

As per Fig. 1, students perceive that dormitories, scholarships and students mobilities, Internet connection in the campus and the IT infrastructure and applications are the most important support services for their academic performance. A 'neutral' rating was predominant in the case of the university's proprietary television channel (TeleU) and other official communication channels, as well as with regards to counselling and career orientation services. Nonetheless, the campus layout and the cafeteria and the fast-food restaurants are also considered important for students' academic performance, but at a lower level as compared to dormitories, scholarships and students mobilities, Internet connection in the campus and the IT infrastructure and applications.

Similar results were obtained regarding the importance of these services for leisure time.

An interesting observation is that students predominantly rated support services as 'neutral', indicating that these services do not meet their quality expectations and there is room for improvement.

Figure 2 presents the perceived importance of support services for leisure time. Dormitories, campus layout, food serving facilities and the Internet connection in the campus were the services with the highest frequency of 'very important' rankings from students.

C. *Statistical analysis*

The statistical analysis of the perceived students' satisfaction with the university's support services provides relevant information regarding efficacy, use rate and impact on students' academic performance.

As stated in section II, statistical analysis enables extraction of valuable conclusions based on the analysis of large data volumes.

Table 2 presents the results of the ANOVA test highlighting the variables for which $p<0.05$. These are the key improvement areas to be considered as more urgent than the rest, as satisfaction with them is proven to be less.

With regards to the post-hoc analysis, Table 3 presents significant comparisons for support services.

Table 2 ANOVA test results – variables with $p<0.05$

Variable	**p value**
Preferred food facility	0.047
Importance of dormitories for academic performance	0.002
Importance of extracurricular activities for academic performance	0.015
Importance of dormitories for leisure time	0.040
Satisfaction with access to information on availability and criteria for granting places and dormitory allocation	0.045
Satisfaction with the Library and online information resources (available book collection)	0.010
Satisfaction regarding the degree of topicality of bibliographic resources	0.022
Satisfaction with access to magazines and other categories of periodicals	0.016
Satisfaction with access to standards and other collections	0.031
Satisfaction with the degree of digitalization of the book borrowing and returning process	0.009
Satisfaction with the library program	0.003

Table 3 Significant comparisons of post-hoc analysis for university support services.

Variable	**Mean diff**	**p-adj**
Library and online resources	0.4291	0.0116
Access to magazines and other categories of periodicals	0.4035	0.0242
Access to standards and other collections	0.4118	0.0216
Available book collection	0.4828	0.0079
Degree of digitalization of the book borrowing and returning process	0.3955	0.0233
Degree of topicality of bibliographic resources	0.4829	0.0085
Library program	2.2821	0.0422
Extracurricular activities	0.6424	0.0128
Importance of dormitories for academic performance	3.1538	0.0026
Preferred food facility	-0.3118	0.0465

Based on the statistical analysis and the correlations performed, the main observations are as follows:

1. In the case of multiple dimensions of library services, master's degree students present a higher level of satisfaction as compared to bachelor's degree students.

2. PhD students perceive dormitories as less important both for their academic performance and leisure time as compared to other study level students.

3. Master's students perceive extracurricular activities as more important for their academic performance as compared to undergraduate students.

4. Library services, dormitory conditions, IT infrastructure and applications, food serving facilities should represent key improvement areas to be considered by the university's management team.

V. CONCLUSIONS

Continuous improvement management is a systematic approach that can address these challenges by implementing the principles of continuous optimization of the services offered. This methodology, adapted to the specifics of higher education institutions, can contribute to the

development of an efficient economic model for optimizing university support services, in accordance with the needs and expectations of students.

The questionnaire-based research is a central component of the study, with application of a structured questionnaire to students in a Romanian university to assess their satisfaction with support services.

The main results of the questionnaire included the identification of services with the lowest degree of satisfaction, and the analysis of statistical differences between groups of students in different study cycles. These results provided a solid basis for developing recommendations for improvement and validating the proposed model.

The statistical analysis carried out using the JASP software tool allowed for rigorous processing of the data collected through the questionnaire. The use of ANOVA tests for the analysis of students' perception of university support services identified significant differences between groups, while the post-hoc analysis using the HSD Tukey test allowed the identification of variables with significant statistical differences.

Key findings of the statistical analysis included identifying significant differences in service perception between study cycles, determining variables with a major impact on student satisfaction, and establishing correlations between demographic characteristics and degree of satisfaction. These results helped to understand the factors that influence students' perception of support services and guided the development of improvement strategies.

Through this case study, the authors managed to validate the theoretical model that reveals the importance of the users' perception for continuous improvement of services. In the case of universities, the users are the students and the services referred to are university support services. Hence, the questionnaire-based study contributes to the collection of quantitative data, predominantly, while the statistical analysis enables generation of qualitative data for supporting the decision-making process.

The study is not without faults. One of the main limitations of the study is the necessity of treating the data with caution. Any extrapolation of the data should be done with consideration to the particularities of the population referred to. Also, questionnaire-based studies are subject to bias, as students' perceptions is subjective information. This was reduced through statistical analysis, but there is no guarantee that it is eliminated. Thirdly, geographic and institutional extension of the study should be performed to increase reliability of the proposed methodology. Nonetheless, the perception on support services should be investigated from the perspective of multiple stakeholders to ensure comprehensiveness of collected data.

REFERENCES

[1] Businessmap (2023). What Is Continuous Improvement? The Complete Guide. Available online: https://businessmap.io/lean-management/improvement/what-is-continuous-improvement (accessed 6.07.2025)

[2] Martins, M., Varela, M. L. R., Putnik, G., Machado, J., & Manupati, V. K. (2019). Tools implementation in management of continuous improvement processes. In Advances in Manufacturing II: Volume 2-Production Engineering and Management (pp. 348-357). Springer International Publishing.

[3] Dağgöl, E. (2024). Project managers' understanding of continuous improvement in project management. Revista de Gestão e Projetos, 15(1), 36-68.

[4] Bârsan, M.R., Kifor, Ş. (2020). Continuous improvement challenges: implementing PBL in one university in Romania. Studies in Business & Economics, 15(2).

[5] Carvalho, J. D. (2023). Continuous improvement in organizations. River Publishers. https://doi.org/10.1201/9781003374114

[6] Erinle, O. G., Akpe, A. T., Nuan, S. I., Solanke, B.; Iriogbe, H. O. (2024). Implementing continuous improvement processes in oil and gas operations: A model for enhancing product service line performance. Global Journal of Research in Multidisciplinary Studies, 2(01), 068–079. https://doi.org/10.58175/gjrms.2024.2.1.0040

[7] Stimec, A., & Grima, F. (2019). The impact of implementing continuous improvement upon stress within a Lean production framework. International Journal of Production Research, 57(5), 1590-1605.

[8] ISO 21001:2025. Educational organizations — Management systems for educational organizations — Requirements with guidance for use.

[9] Dicker, R., Garcia, M., Kelly, A., Mulrooney, H., 2019. What does 'quality' in higher education mean? Perceptions of staff, students and employers. Studies in Higher Education 44, 1425–1441. https://doi.org/10.1080/03075079.2018.1445987

[10] Boatca, M. E., Costa, I. M., & Tamasila, M. (2023). Analysis of Support Services in A Romanian University: Prospects for Continuous Improvement. Acta Technica Napocensis-Series: Applied Mathematics, Mechanics, and Engineering, 65(3S).

[11] Aklimawati, L., & Hartatri, F. S. (2019). Assessment of Service Quality Using Weighted SERVPERF Approach. Pelita Perkebunan: A Coffee and Cocoa Research Journal, 35(1), 70–84. https://doi.org/10.22302/ICCRI.JUR.PELITAPERKEBUNAN.V35I1.352

[12] Urcádiz Cázares, F. J., & Monroy Ceseña, M. A. (2022). Nominal scale as alternative of service quality evaluation : study case from Hacienda Bugambilias Hotel, Mexico. Visión de Futuro, 26, No 2-2022, 168–187. https://doi.org/10.36995/j.visiondefuturo.2022.26.02.005.en

[13] Dogra, T. (2023). A comparative analysis of service quality in public and private sector hotels. Journal of Tourism Management Research, 10(1), 47–61. https://doi.org/10.18488/31.v10i1.3369.

[14] 70. Sandi A, A., Triwibowo, D. N., Sumantri, R. B. bambang, & Haryono, R. C. S. (2023). Pelatihan penggunaan aplikasi spss untuk menunjang tugas akhir mahasiswa. https://doi.org/10.46880/methabdi.vol3no2.pp195-199

[15] Vieira, V., & Cavalcanti, E. P. (2020). Análise dos serviços de um restaurante universitário na perspectiva dos usuários. Research, Society and Development, 9(10). https://doi.org/10.33448/RSD-V9I10.8715.