UNIVERSITY "UNION - NIKOLA TESLA"

Nikola Tesla

THE FIFTH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENVIRONMENT AND TECHNOLOGIES

PROCEEDINGS

"Creating sustainable commUNITy"

INTERNATIONAL CONFERENCE ON SUSTAINABLE ENVIRONMENT AND TECHNOLOGIES

26 SEPTEMBER 2025
CARA DUŠANA 62-64, BELGRADE, SERBIA

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Ph.D Sanja Mrazovac Kurilić

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CONTENTS

THE URBAN REGENERATION OF A DETERIORATED HERAT THE CASE OF MSHEIREB, DOHA - QATAR

Ali A. Alraouf

HBK Hamad Bin Khalifa University: Doha, Ad Dawhah, Qatar

alialraouf@gmail.com

Abstract

Doha, the capital of Qatar, used to be a port town on the eastern part of the peninsula of Qatar. Historically, the town shared cultural commonalities with other Gulf cities particularly the relying on fishing and pearl diving as the main feature of its economy. The old town which was characterized by compacted urbanism, extended families living in courtyard houses and shaded allies, was totally abandoned after the oil discovery and the flow of unprecedented financial resources in late 70s and early 80s. This essay provides a critical narrative of the urban regeneration process that took place in the heart of Doha. It interrogates the new vision that was articulated to revitalize the old heart of the city and bring people back to such a valuable part of its urban fabric. The essay examines the Design Strategies used in the project to move from adaptive reuse to holistic urban regeneration. The essay analyses the using of oil and Gas revenues to help the city going beyond the western illusions and urban spectacle and argues that the project is a manifestation of a needed transformation from the urbanity of an image to the urbanity of meaning. Such city transformation is essential for constructing a more dynamic and vibrant identity for the city.

Introduction

Unlike plenty of architectural and urban projects in Qatar and Gulf cities, Msheireb project is creating a tangible impact. Interviews conducted with local people and expatriates living or visiting the project revealed interesting outcomes. Most of the urban projects in the Gulf are moving between the Western model particularly when designed by western architects and designers or the fake representation of traditional architecture. Yet, the results of the interviews illustrated a new category which can be best described as the authentic contemporary structured on the cultural localization. The interviewed local people's narratives were inspirational because they reasoned about different set of lessons learned from the project. Lessons which are relatively different from what architects and urban designers are interested in while analyzing or researching the project. An old Qatari man sitting at Sahat Al Wadi, said proudly: "This project shows how westerns can learn from us, instead of us imitating them all the time".

The Gulf Context

While each city on the Gulf has its own narrative, yet the similarities in main governing factors led to common issues and challenges particularly in the domain of urban development. A prime factor is the radical shift in all Gulf states' economy due to the discovery of oil. For the first time in their history, Gulf States begun to get regular ravenous from selling oil. A trade which was amplified during the first oil boom in the 70s. The availability of such unprecedented financial resources coupled with a desire to imitate the west and reject the old and traditional built environment resulted in a deliberate process of heritage destruction and erasing full chapters from the urban fabric of Gulf cities. The intimacy of the Gulf city is lost. More recently, Gulf cities, under the effect of the urban development model constructed by Dubai, were engaged in a regional competition to build the highest, the biggest and the tallest.

At present, Gulf cities are facing new urban complexities and challenges. Hence, envisioning the future is significate particularly considering two fundamental challenges: the post oil era and the post COVID era. The Post oil Era suggests providing an answer to the essential question: How to decarbonize cities? Multiple strategies emerge in Gulf cities and process of planning and adopting can be observed with relative concentration and determination. A prime factor is moving towards Transit-Oriented development (TOD). The move toward TOD facilitated the process of the decentralization of metropolitan urbanity (Wippel, 2014; Alraouf, 2019). The coherence of Gulf cities begun to be of a considerable focus to avoid urban fragmentation and city sprawl by restitching the urban fabric via public and green spaces. Revisiting the concept of streets in Gulf cities and how to consider streets as places for people not highways for cars, is another indication of city transformation. As for the post COVID era, a new urban condition was experienced during the COVID crisis particularly the imposed lockdown. Hence, emphasizing the humanization process of the urban settings in contemporary cities is essential. Public spaces are city saviors, a notion which was proved right during the COVID times. There were plenty of behavioral and functional changes observed during COVID including the increasing interest in walkability, green spaces, transforming roofs into family roof gardens and gathering spaces. In sum, Gulf cities are transforming on different levels and a new architectural and planning discourse is significantly needed.

Contextualizing Qatar Urbanity

The major transformation in Qatar's urbanity was the direct result from structuring Qatar Vision 2030, a document which is guiding all the development process in the state acknowledging the post oil challenges (QNV 2008; QNDF, 2016). The second major transformation was winning the bid for hosting the FIFA World Cup 2022 which was declared in 2010. Such accelerated transformations paved the way for a new identity for Qatar's emerging urbanity. A move from oil-based economy to knowledge-based economy facilitated the creation of a strong direction towards projects like universities, museums, research centers in addition to heritage preservation (Kamrava, 2013; Roberts, 2015; Alraouf, 2018; 2022). The new move replaced the old trend of build or more accurately imitate western cities in building skyscrapers and giant shopping malls.

The Narrative of Msheireb, the Heart of Doha

After the first oil boom in the 70s, Qatari Families moved rapidly from the old city center to the suburbs of Doha to areas where they can exhibit their wealth and enjoy modern lifestyle (Al-Buainain, 1999; Alraouf, 2012). With passing time, the area lost a lot of its affluent community to migration out into other regions, leaving much of the historic neighborhood neglected. In the beginning of the 21st century, crucial questions were formulated addressing such a unique part of Doha. Why was the heart abandoned and left to be deteriorated? How to restore, repair and re-weave the city? Msheireb as a case of urban regeneration was analyzed in different platforms (Gharib, 2014; Alraouf, 2021). Historically, Msheireb was the real heart of Doha and one of its more vibrant places. Yet, the active heart was abandoned because of a dominant dream for Qatari families to leave the old part of the city and move to the peripheries so new western villas can be built and replace their old, traditional houses.

The Heart of Doha (Msheireb) aims to bring Qataris back to the severely abended old center of Doha. "Bringing people back to the heart of Doha", was the initial slogan used to promote Msheireb mega mixed used development when first declared in 2008 by HH Sheikha Mozah Al Missned, The Qatari first lady at that time (Sh Moza, 2006). The aim of the project was to bring local people back to their roots to rediscover a sense of community and togetherness. As per the project slogan being the regeneration of an inner-city that will create a modern Qatari center imbedded in tradition, where global cultures will meet but not melt (Melhuish, Degan and Rose, 2016). A focus on challenges like social diversity and cultural relevance was considered in the evolution of the Masterplan (Law and Underwood, 2012). In doing so, the consultant and developers have incorporated traditional patterns of Gulf architecture and urbanism to create a contemporary Qatari architectural and urban language in a scheme that innovatively balances modernity with traditionalism (Jaidah and Bourennane, 2009; Alraouf, 2016; Jodido, 2014). Msheireb is a mixed used development project comprising office space, retail, leisure facilities, different housing types, hotels, museums, as well as cultural and recreational places. According to Msheireb properties, Msheireb is lying on 31 hectares, but the gross floor area (GFA) reaches 76 hectares (760000 m2). It is located in the Mohamed Bin Jassim District at the heart of Doha and adjacent to Amiri Diwan, Souq Waqif, and Al Koot Fort. The project consists of five main quarters comprising three extended governmental buildings including the National Archive. Msheireb project is designed as urban villages for future residents to be able to satisfy their needs in a walking distance. The layout is planned to allow a pedestrian friendly environment hence social interaction. As Gharib (2014) argues, the project is a step to move from locality to globalization as Qatar is consistent in balancing its local assets with global aspirations.

The project aspires to restore the lost shine to a location that is close to the hearts of all Qataris. Hence, it is crucial to bring it back to life. The project was also marketed as it aims to reduce the city's urban sprawl and revitalize the old center. The project, which was initially named "Heart of Doha", was described as a "city within a city" that merges the best characteristics of the past with the modern technologies. Most of the Gulf real-estate companies use slogans to emphasize the sustainable nature of their new projects. For example, Msheireb presents itself as the world's first sustainable downtown regeneration project, which uses traditional Qatari architectural language and aims to achieve one of the highest concentrations of LEED certified buildings in the world. The developers emphasize their commitment to using timeless techniques inherited from the traditional built environment.

The Alternative Development Process: A Research-based Architectural and Urban Strategy.

Unlike, most of the projects in Gulf cities where the element of time is almost irrelevant due to the overwhelming desire to build swiftly, Msheireb adopted another route. This route was characterized by extensive research journey to articulate planning, urban design, and architectural guidelines. How to deferral planning and design and focus on governing standards and guidelines and the production of the language of architecture and urbanism unique for the context and the project (Melhuish, 2014). A major factor in the success story of the project is the outcome of the significant decision to divide the development process into two stages. The first one is about conducting a holistic research journey to understand cultural, social, economic and architecture values and use it to formulate comprehensive architectural and planning guidelines (Gharib, 2014). The second is providing all architects and planners working in the project with these guidelines and hence guarantee a common understanding between all the participants in planning and designing the project in a harmonious manner.

The research process started with holistic resources compiling the different narratives about the architecture and urbanism in the Gulf and Qatar including anthropological, maritime, and social studies. It includes a search for a more contemporary language of architecture. This emerging language of architecture is new, contemporary, and bloomed from meticulous analysis of the Gulf and Qatari traditional architecture. Consequently, the research journey ended up with two set of integrated languages for the architecture and the urbanity of the project. Languages that will guarantee the harmony in spatial, social, formal, environmental aspects of the project without compromising the creativity and the individuality of every architect involved. The value of this research journey and its outcomes were not only reflected in the planning and design of Msheireb but open a wide spectrum of future research and practice.

The Mature Interpretation of Heritage in Msheireb

The project provides and on different levels, a matured understanding of the value of heritage. This can be seen on four main levels as illustrated below. Qatar`s heritage is represented in every traditional building in different eras and not limited to a specific timeframe. The conceptual approach of the project refrained from the classical way of copying the tradition. Rather, it invested in adhering to four levels of mature interpretation of the heritage. A four levels matrix of understanding of the value of Qatari heritage. Rather than a direct interpretation of what existed.

The First Level: Respect All History Chapters and Avoid Selecting

Doha transformed from its existence as small fishing village to the early days of oil exploration to Doha being an energetic capital city within six decades of development. Such a process of transformation and change was the first level of our understanding of the value of the heritage. The Msheireb project is concerned with the importance and the acknowledgement of each chapter of our history. So, it refrains from selecting a single timeframe or an era of the city's history. Rather, it adopted a more holistic understanding of heritage as the accumulation of the country history that continue to evolve.

The Second Level: Reestablishing Heritage Value

The project is calling for the positive manifestation of local heritage. It avoids conserving or preserving the heritage buildings and then left it as closed monuments within the city center. At Msheireb, the heritage buildings are telling the story, exhibit the value of their existence by having contemporary roles where it can serve the local community. For instance, four traditional houses were preserved and rehabilitated to contribute to the contemporary life of the city as well as tell the story of the history. The four heritage buildings which were transformed into museums, stand at Msheireb to exhibit not only their historical value but also the anatomy of the space, the beauty of using local materials, the courtyard, the harmony of the new and old, the respect of the history with the modern technology.

The Third Level: Heritage as a Source of Inspiration

The value of heritage as a creativity inspiration platform is of a paramount significance in the narrative of Msheireb. The project provides a model for how to use heritage as a platform for new creative chapter, a chapter of today that is a continuation of the past, yet it is modern. At Msheireb, the past was looked at as sources of inspiration, a reference book that is needed to learn from to create a new chapter in the ever-evolving history of the city.

The Fourth Level: Heritage Stimulating Creating a new Narrative for the Context of Msheireb

The integration and the coherence of the project was a great challenge. Hence, a research-based design and planning process were adopted to guarantee the harmonious and integrated outcome. Therefore, three-year process research with the support of researchers, academics, professionals, architects and urban planners local and international gather to come up with the guidelines and principles on what the project were build up on. The result was a unique creation of new architecture language, which formulates the guidelines for over one hundred architects and engineers working on the project. The new architecture language is as any spoken language every architect can use its vocabulary to create his or her poem, his or her words, his or her building, this what gave Msheireb this diversity with unity and the unity with diversity. A harmony that can`t be created without the new architecture language, was clearly achieved at Msheireb.

Cultural Continuity, Connectivity and Inclusivity in Msheireb

One of the strong aspects of the project is related to the urban and visual connectivity with the adjacent Souq Waqif, the most significant heritage area in Doha. The levels of connectivity can be seen in the architectural language extended from the facades of Souq Waqif and the Heritage quarters to the facades of Msheireb buildings but in a very abstracted and modernized way. Another level of connectivity is related to cultural amenities. From the galleries and cultural centers at the Souq, the connection is extended to the project via the presence of four museums occupying four traditional houses that were preserved and rehabilitated during the construction of the project. A third level of connectivity can be seen in the actual urban and movement relations between the Souq and the project. A major urban public space is connecting the two projects and allowing for an excellent visual adaptation and preparation for a better perception of the project. Hence, the project is providing an excellent case of a vibrant urban center characterized by mixed use development, urban diversity. The significance of the project is related to its ability to provide a successful example of the needed mixed-use development coupled with transit-oriented development and open to diversified community and users' groups. Such features are substantially needed for Qatar's future particularly the principle of moving towards post carbon paradigm and more reliance on sustainable and people friendly modes of development and urbanity.

The Architectural and Urban Significance of Msheireb

The project is characterized by authentic yet contemporary architecture. The language which is called contemporary Qatari architectural language resulted from analyzing the old traditional architecture of Doha and other Gulf cities to understand its concepts, principles and deep layers rather than the mere focus on visual vocabulary and copying the past. On the urban level and as opposed to plenty of projects in the Gulf, the project has no leftovers spaces that can be pointed out. The fact that the project has No leftovers is a result of a planning process to produce an integrated project, not a typical land division that produces fragmented and scattered urbanization. All the voids of the project are positive and encompass the qualities which Alexander (1979, 2012) discussed. The voids are integral part of the project's urban fabric where all of them are playing crucial rules in attaining the vibrancy of the public life. Therefore, the availability of small public spaces and pocket gardens, is one more positive feature of the project and its focus on people.

Conclusions and Final Thoughts

The Importance of the Project can be seen from different aspects

- Creating unprecedented sense of belonging to the previously abandoned heart of the city.
- Achieving a sense of pride. The project is not a group of skyscrapers as seen in different Gulf cities. A new level of pride emerged between local community members as they realized that the project is not the tallest tower, but a balanced approach between valuing the past and considering the future. Additionally, the project won heritage conservation and sustainability awards regionally and globally.
- Raising awareness about the available "Metro as a mode of urban movement and Walkability as a healthier way of life. A new level of social awareness regarding the vitality of public transportation (walking/public transport/connection to the metro network).
- Providing new architectural and urban esthetics: the new modern, the authentic, the creative vocabulary. A new level of aesthetics of construction and urbanism has changed the taste and mentality of society.

Influencing the rest of the city particularly the adjacent context and creating a model for local people to adopt. In this sense, I would argue that Msheireb constructs a precedent for the needed social paradigm shift from consumers to citizens. Advocating happier instead of stressed city dwellers by optimizing integration, socialization, slower city rhythm and nurturing the city is immensely important. The projects, as numbers illustrate, achieved density without high-rise which is the future of cities to be more human based, compacted, walkable and hence healthier. The project and for the first time since the official start of urban planning activities in Qatar moved beyond the typical process of subdivision and implement principles and concepts generated from the old traditional city fabric. Msheireb is a project of reinvented historic fabric rather than land subdivisions.

The project managed while preserving its own identity and character to avoid the extravaganza is clearly observed in most the rest of the Gulf urbanity. A real mixed-use development which is not a gated community but rather public heart accessible to all and adjacent to public transportation. A manifestation of a precedent in the built environment development in the Middle East and the Gulf where a real estate development company "Msheireb" is sponsoring such a profound research study. But more significantly, use its findings in an actual project to come up with a new paradigm in the notion of urban regeneration within the Middle East and the Gulf.

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THE COCHABAMBA VALLEY AND THE KEY ROLE OF A COMMUNITY-LED HINTERLAND FOR RESILIENCE PLANNING

Dipl. Ing. MA Rolf Schuett
Systemarchi, Kernen im Remstal, Germany

Email rolf.schuett@systemarchi.com

ABSTRACT

This paper describes the case of the Cochabamba valley (area: 1150 km², also called central valley) in Bolivia, in which several municipalities are located and where around two million people live. The largest one is Cochabamba city (700thousand inhabitants), followed by its fast growing neighbours of Quillacollo, Colcapirhua and Tiquipaya, which today can be considered as suburbs of Cochabamba city. The purpose of this paper is to analyze and raise attention on the urgent need to update and improve the way planning is implemented in the Central Valley, especially the hinterland that includes watersheds within the Tunari National Park, suburban areas, agriculture production and rural settlements. It also is aimed to stress the need to improve adaptation of watersheds, rural and urban communities to reduce vulnerability and improve conditions for living and food production.

Keywords: Water, resilience, indigenous participation, Community led NUA adaptation

1. INTRODUCTION AND METHODOLOGY

The Central Valley of Cochabamba and its hinterland planning challenges will be described here to display the current situation from the five named perspectives. The development process of the urban centres and their hinterland in the Central Valley and the challenges that they face summarize for several reasons the vulnerability on rural areas and urban settlements in Bolivia. The author of this paper considers essential to analyse them. Each lesson that can be learnt from them confirm that any plan for resilience must be integrally tailored to each individual case and site.

The author used a research methodology for qualitative data validation after Anselm Strauss' and Barney Glaser's Grounded Theory. This method uses coding and grouping of data, analysis and qualitative documentation (Strauss and Corbin 1997), and it is an ideal approach to combine inputs from different disciplines, which are necessary to support the paper's thesis.

2. FIVE ANALYSED ELEMENTS

The general thesis of this paper is that cities like the ones in the metropolitan region of Cochabamba need to cohesively pay more attention to parallel issues affecting their shared hinterland, rather than plan individually within their respective urban boundaries, when looking for strategies to contain the challenges of urban sprawl, pollution, gentrification or climate change. To sustenance this thesis, the author explores five background components: historical, social economical, geological, cultural and environmental perspectives, all specifically related to the site.

2.1 HISTORICAL ASPECTS

Historically speaking, the valley has been since centuries a food production centre, due to its fertile soil, its availability of fresh water and its mild climate. During the pre-Inca times and the Spanish colony, it would play a crucial role as agricultural base. Additionally, its central location between strategic settlements during Inca, colonial and early republican times turned it into a trade hub (Godillo Claure et al. 2005). Since the second half of the 20th century, the valley of Cochabamba is facing growing challenges due to population growth, demand for drinking water and sanitation and soil over-production with a subsequent pressure on its environment and resources (Alarcón et al. 2013). The municipality of Cochabamba had no control of the territorial planning outside the municipal boundaries but was granted the planning authority of a stripe of about 4 km width land along the main street corridor to the west of the valley. The migration movement promoted a rapid urbanization of this corridor and forced a reform of the old development plan (Plan Regulador) into a strategic metropolitan "Plan Director", eventually adopted in 1981 (López 2016).

However, neither of the programmes was successful in promoting an ordered growth of the urban space, mainly because of its jurisdictional limitations. Because of a missing territorial authority that would apply binding strategic measures, a sustainable regional balance between urban and rural zones never succeeded (López 2016).

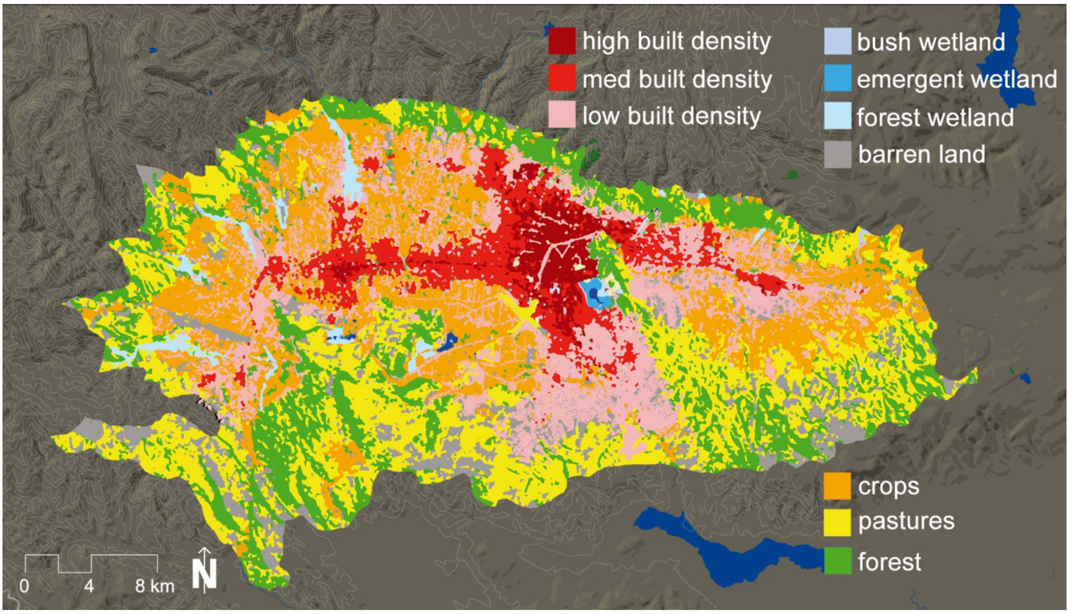

Fig 2.1.1 Land Use in the metropolitan region of Cochabamba (by Author, Data from Alarcón 2013 and López 2016)

2.2 CULTURAL ASPECTS

Water is perhaps the ideal element to describe one of the outstanding culture aspects of the valley community: their collective capability to get organized and successfully resist misuse of political power (Shultz 2008). Water is therefore not only crucial for life and productivity, but also a symbol of identity.

All water provision systems in the micro watersheds of the valley are used for crops irrigation. Water for human consumption is obtained from deep wells. Outside the urban areas, there is an important community involvement in water management for irrigation and domestic use (Bustamante et al., 2004). One example is called "Machu Mit'a": a system of community river water distribution. River Khora is the only one with perennial flow. "Machu Mit'a" is also used to manage lagoons, dams, small reservoirs and distribution trenches. Indigenous communities distribute water as equally as possible, however using superficial irrigation, which is considered less efficient. They strictly use ancient, pre-Columbian practices to manage their resources (Boillat 2008).

However, due to a steady growing population and urban sprawl, the provision of water for domestic consumption is becoming harder to fulfill as time passes. The sadly remembered 'Cochabamba Water War' in February 2000 in

Cochabamba city, the largest municipality and capital city in the valley, is a dramatic example.

Cochabamba's water war is today a symbol of Bolivia's government traditional anti globalization rhetoric, supported by most of the population, representative of the claim to sovereign access to Bolivia's natural resources and a revindication of national pride (Assies, 2003).

On 28 of July 2010, the General Assembly of the United Nations declared the privatization of water unethical and water and sanitation a human right (Hall et al., 2014). Certainly, the events in Cochabamba motivated the international discussion about this matter, and even though previous inter-governmental agreements had already named water and sanitation a basic entitlement, this was the first declaration that committed all UN member nations to fully implement this right.

2.3 GEOLOGICAL CONTEXT

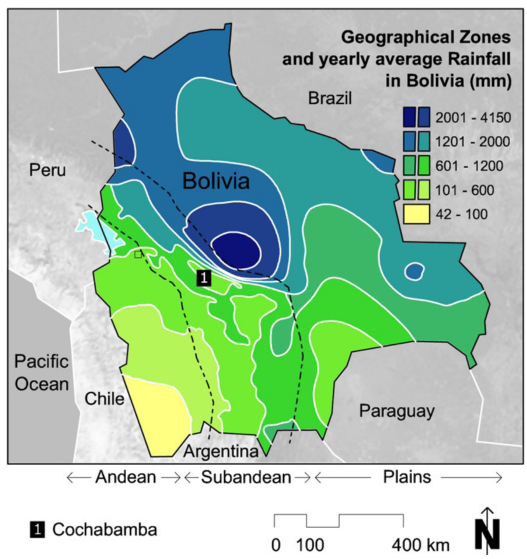

Fig 2.3.1 Main River Basins in Bolivia	Fig 2.3.2 Geogr. Division and Rain Zones

Bolivia can be divided into three topographical regions: The Andean, Subandean and Plains regions (Fig. 2.3.2). They feature different average precipitation rates: Andean 500 mm, Sub Andean 950 mm and Plains 1870 mm per year. The national availability of fresh water per capita and year is 160 m³ (year 2000), comparable to the one in Norway, one of the highest in the world. Therefore Bolivia is considered a world fresh water reservoir.

Regarding its geomorphology, the central valley can be divided into three zones: (1) a mountainous zone, with high peaks and deep slopes that are prone to cause landslides, where rock material gets carried down to the valley; (2) a zone of slope and piedmont, with mostly coarse grained material with high hydraulic permeability, coarser in the higher areas at the mountain edge and finer in the lower areas down the valley; and (3) a plain zone with older sedimentation, fluvial lacustrine deposits, fine materials where most populated areas are located. These areas are swampy and contain salt efflorescences.

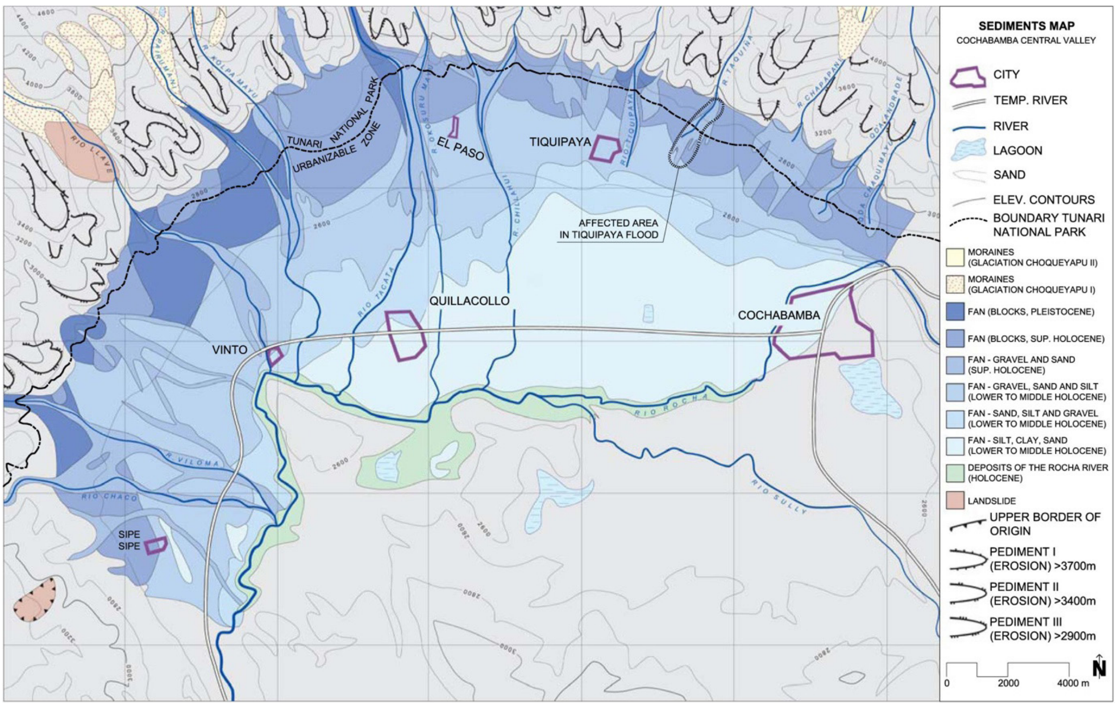

Fig. 2.3.3 Map of Sediments in the Central Valley of Cochabamba (Source: Renner & Velasco, 2000)

The zones of slope and piedmont and some central parts in the basin are important host formations for ground-water. They contain complex multilayered aquifers with confined and semi-confined characteristics. However, not all these reserves are favourable for the exploitation of fresh water. There is also a growing number of private wells in the valley area and overall water scarcity.

In summary, the piedmont areas play a critical role for the human activities in the valley. They are partially prone to flash floods and need special care, because of their importance for the recharge of ground water.

2.4 SOCIO-ECONOMIC (AND STRUCTURAL) ASPECTS

Cochabamba and its surrounding valleys are a visible example of how rural poverty and poor watershed management are correlated. The geology of the valley of Cochabamba has been described above, but the effects of increased pressure on available resources include intermitent water availability in reservoirs, overexploitation of key sources, in sufficient infrastructure, reduced recharge due to urban sprawl.

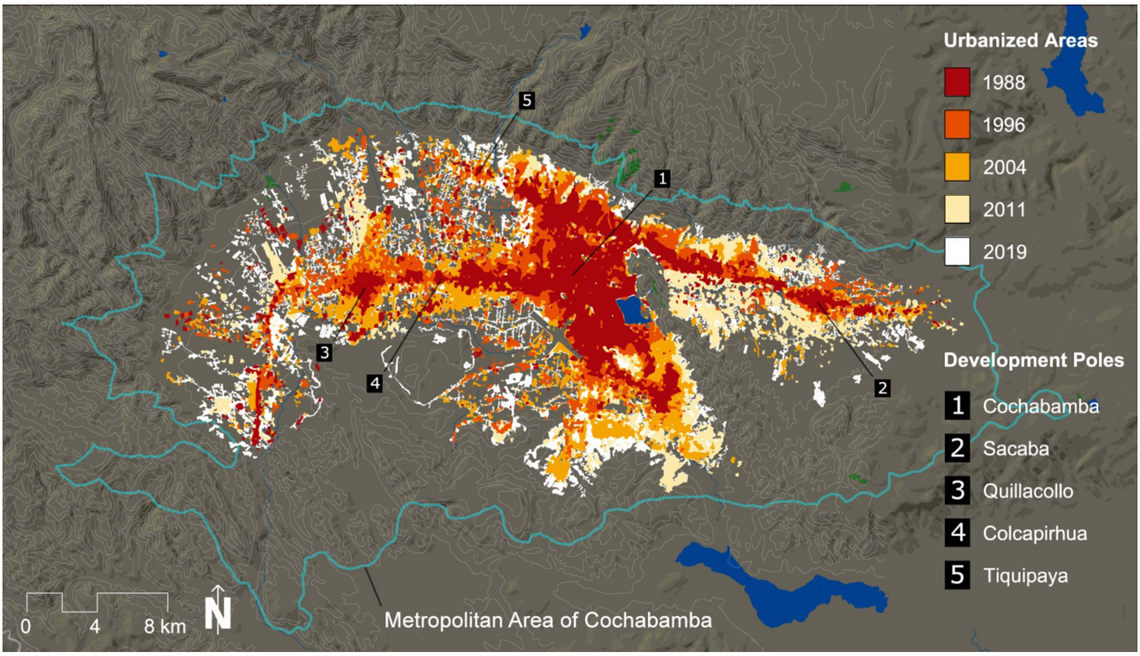

Fig. 2.4.1 Urban growth of the central Valley of Cochabamba (by Author, Data from Alarcón 2013 and López 2016)

2.5 ENVIRONMENTAL CHALLENGES

Land cover degradation and natural disasters are described here as the major challenges.

The Tiquipaya flash floods of sixth of February 2018 occurred after a sequence of days of rainy weather that saturated the soil in the upper areas of the Tiquipaya Cordillera, which eventually collapsed as landslides. Because of the awareness about the fragile geology of the Tiquipaya Cordillera, as described in the previous section of this paper, and the ongoing deforestation, the reduction of permeability and indolence of local authorities towards settlements in vulnerable areas, the Tiquipaya flash flooding occurred not without previous warning signals.

3. DISCUSSION

The New Urban Agenda focuses on sustainable urbanization and is structured in five pillars of implementation: (1) Improving existing urban policies, (2) designing and applying a solid urban legislation with rules and regulations, (3) Urban Planning and Design, (4) Urban Economy and Municipal Finance and (5) local physical implementation (United Nations, 2017). Climate change adaptation is especially necessary in developing countries, which concentrate the most vulnerable people in the planet (Bicknell et al. 2009).

The author suggests applying these principles to improve the urban design, promote adaptation and reduce vulnerability, adapting it to meet the particular issues of the site in each of the five categories previously analyzed in this paper.

3.1 HISTORICAL ASPECTS: WHAT TO LEARN FROM THE PAST?

The first NUA pillar, namely improving existing urban policies, should aim to reduce vulnerability with integral strategies. In developing countries the boundary traced on paper between urban and rural zones is seldom visible on site (see Fig 2.1.1). In 1991 in Tiquipaya the authorities set the elevation contour 2750 as limit between Tunari National Park and the urban zone. But this limit has not been respected. And along the course of rivers, the washland boundaries have not been successfully implemented, as already mentioned.

Interdisciplinary work for sustainable planning is challenging, because it forces the participants to think out of the box (Romero-Lankao 2018). The author of this paper considers that the solution should incorporate strong community participation: Rural and urban communities need to understand that they have the right to settle as much as authorities have the obligation to make sure their ground is safe, but this can only happen when both sides cooperate. This approach has worked out before in other negotiations, especially the ones concerning water provision.

3.2 HOW TO INCORPORATE THE CULTURAL ASPECTS?

The fifth pillar of the NUA addresses local physical implementation, which groups all the NUA principles into a proper preventive and smart planning, which is an investment towards a resilient and inclusive city.

The author underlines the need for a change of paradigms in the traditional agenda of regional planning in Cochabamba. It suggests the shift from a vertical process based on programmes to a discussion process based on consensus with affected communities, as it is traditionally done on the country side, for instance using a binding decision-making assembly called cabildo.

Past studies and technical cooperation experiences describe how locals have succeeded in the past to adapt to adverse climatic conditions (Mendez Torrico and MacKinnon 2002, Boillat and Berkes 2013). This attitude is part of the cultural background of indigenous communities, all of which are used to work the land despite the difficult climatic and topographic conditions in the Andes (Boillat and Berkes 2013, Sherwood and Bentley 2009). And this has a tradition that has lasted for centuries (Ensor and Berger 2009). Many experts coincide in that it may not be necessarily productive to impose alternative ways that radically change the way they manage their resources, but to apply adaptive management and improve community networking (Tompkins & Adger 2004, Chu et al. 2018, Caprotti et al. 2017). The complex indigenous identities have shaped the way politics are run in Bolivia in the last 25 years (Gustafson 2009). So far they have been able to build resilience with own holistic strategies (Boillat and Berkes 2013). Once again, the author of this paper is convinced that to be effective, new planning approaches, including the New Urban Agenda, should rather gradually be introduced and adapted to the local uses and not vice versa.

3.3 WHAT TO CONSIDER IN RESPECT TO GEOLOGY?

Local planners urge persuading settlers to move away from vulnerable sites or give up areas of their properties that intersect with the buffer zones. Authorities announced instead that settlers will otherwise have to assume responsibility for any personal or material damage to their private property in the event of flooding. Proper landscape design and community collaboration can help to persuade more social responsibility in this issue. This point is addressed by the third pillar of the NUA: Urban Planning and Design with which locals can identify. Here especially guaranteeing a sustainable use of public space is crucial. The ancient community water distribution management Machu Mit'a (see point 2.2 Cultural Aspects) is a perfect example of shared responsibility.

The geophysical background behind the vulnerability of many new urban settlements in the piedmont areas of the Cochabamba valley has been explained in this paper. The map of sediments developed by Renner and Velasco (Fig. 2.3.2) shows as well that this phenomenon is not recent and that these areas are elementary for the recharge of aquifers. Both aspects have extreme importance both for ensuring the resilience of the human settlements in Cochabamba and for the protection of fresh water sources for the future, especially if the extreme weather events will continue to happen or increase in frequency.

3.4 HOW TO IMPROVE AND STRENGTHEN THE STRUCTURAL POTENTIALS?

Local farmers apply a "traditional ecological knowledge" to protect their fragile natural resources (soil, water, crop varieties) by means of shared water management and a cyclic cultivation system. To increase agricultural yield, they combine rotation of crops and rest years, and they base their rotation on location (altitude), soil fertility, slope and availability of water (Boillat and Berkes 2013).

The author considers that if the conditions for farmers are improved (fertile soil and water availability, fair trade, access to local markets, inclusive regional development, and flexible legislation), farmers will not be forced to give up agriculture, and cities will not have to accommodate domestic migrants in their periphery, with the effect of more urban sprawl and soil compactation.

The extraordinary challenge is now how to increase the domestic production of food in a sustainable fashion, e.g. without increasing GHG emissions, without depleting freshwater reserves and sacrificing forests as natural carbon capture resource. According to Timothy J. Killeen, an environment scientist specialized in the Andes and Amazon regions, it is possible to at least double the food production in Bolivia without sacrificing its forests and biodiversity. The key may be to improve the water use efficiency and the use of underutilized farmland (Mander, 2015).

In this sense, the inter-disciplinary discussion should contribute to working out integral strategies for improvement in at least three different levels: Agricultural areas, Tunari national park and urban setting.

Perhaps the lack of proper training and information is the main reason why climate change variables are incorporated so slowly in decision-making processes in developing countries. Latin America is not an exception (Hardoy and Pandiella 2009).

The fourth NUA pillar: Urban Economy and Municipal Finance should be applied to tackle the absence of reliable information, inventories, digital cadastres (which is also a consequence of the lack of proper data acquisition and management) and human capacity development. Risk reduction implies a combination between development planning and risk management (Hardoy and Pandiella 2009, Rudd et al. 2018).

3.5 HOW TO TACKLE THE ENVIRONMENTAL ISSUES?

Current statutory implementation problems are addressed by the second NUA pillar: designing and applying a solid urban legislation with rules and regulations. Environmental issues should be addressed in this context. Because of the slow contribution of the few recharge sites for aquifers, diverse studies estimate a deficit in seasonal recharge of 8,5M m^3/year in the Tiquipaya watershed area (Sáenz 2005).

During the research for this paper, the author interviewed Prof. Ramiro Iriarte Ardaya, head of CISTEL, a research Institute for Remote Sensing of the University of San Simon in Cochabamba. His department has been monitoring bush and forest fires of the last 10 years in the park. The number of fires has doubled in the last five years to about two hundred per year on average. Prof. Iriarte states that among the reasons are lack of control, slash and burn clearing techniques and negligence. Forest fires on the edge of urban areas have resulted in an increased number of informal settlements that can barely be controlled with reduced budget of local authorities. Improved landscape design at the urban periphery would provide clearer boundaries. It could also motivate more involvement of the population in reporting fire events. The loss of vegetation also contributed to erosion and landslides, as mentioned before.

Prof. Iriarte recommends a stepwise renewed afforestation, exploiting the adaptability of native species at increased altitude. Exhaustive records of resources, like a detailed study of existing species and extensive inventories, also for living fauna in the National Park Tunari, are necessary to evaluate biodiversity issues and proper decision-making. There is awareness on the unstable topography of the 39 micro watersheds of the Tunari National Park and a constant monitoring is mandatory for the prevention of disasters.

As described before, the fragile ecosystems of the Tunari national park have been affected the uncontrolled change of land use above the 2750m contour. The restoration of the natural micro-watersheds of the Tunari cordillera is the best way to reduce vulnerability of the communities in the lower valley (Méndez Torrico and MacKinnon 2002, author's interview with Prof. Iriarte), but also it will ensure the natural recharge of aquifers in the valley, which are vital for the future availability of fresh water. The preservation of green and agricultural fields in the metropolitan area will also contribute to CO2 reduction, absorption of micro particles and as buffer zones between urban areas, the park and vulnerable zones. Compatible buffer zones between urban areas and the Tunari National Park would also strengthen the enforcement of clear limits and boundaries of fragile zones, something all consulted experts agree on.

4. CONCLUSIONS

Habitat III, connected to the SDG11, calls for a reformulation of the discussion on best methods for sustainably managing human settlements. It supports the application of the NUA as a guide, which introduces the 'right to the city' and promotes urban planning, the smart city approach and the cooperation between public and private investment, to name some keys.

So far, outstanding progress has been achieved following the urban related commitments adopted by UN member countries, such as the Millennium Development Goals, the Sustainable Development Goals or the UN Habitat declarations. But the achieved progress has not been extensive. Today, not only developing countries struggle to meet the goals set in the Vancouver Declaration in 1976.

The way we deal with unsustainable cities will continue evolving. We should look at human settlements within and outside city boundaries. Universal principles neither can be translated into universal recipes, especially wherever the structural conditions are not prepared to implement them.

The author is convinced that the combination of efforts to incorporate a multiple scope regional development strategy for the hinterland of the urban areas in the metropolitan region of Cochabamba would provide the best likelihood for a sustainable and resilient valley. The environmental measures will contribute to a better air, soil and water quality; cultural protection will make the community more inclusive and may even contribute to social and political stability; the consideration of the geomorphology and geophysical aspects will help to reduce vulnerability and to better synchronize landscape and urban design; the socio-economic aspects will contribute to guarantee the right to safe settlement areas under fair conditions and learning from experience, incorporate alternative planning tools that involve more horizontal discussion will contribute to a more cohesive planning, perhaps even to a better reflection of the identity of its people and cultural heritage.

This paper introduced an alternative way to develop integrated strategic planning using qualitative observation of available scientific data, historic happenings and local expertise. It is oriented by approaches applied by expert colleagues and the author's professional experience. The approaches used for qualitative analysis may be universally applicable, but the multiple scopes for regional development, based on the development of the hinterland of the metropolitan area of Cochabamba, form a unique strategy.

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DIFFUSION MODELS OF DRUG RELEASED IN POLY (VINYL ALCOHOL)/CHITOSAN/GENTAMICIN HYDROGELS

Ana Janković[1], Milena Stevanović[1], Marija Djošić[2], Teodor M. Atanackovic[3], Vesna Mišković-Stanković[4]

[1] Innovation Center of the Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

[2]Institute for Technology of Nuclear and Other Mineral Raw Materials, Bulevar Franš d'Eperea 86, 11000 Belgrade, Serbia

[3]Faculty of Technical Sciences, University of Novi Sad, 21000 Novi Sad, Serbia

[4]Faculty of Ecology and Environmental Protection, University Union - Nikola Tesla, Cara Dušana 62-64, 11158 Belgrade, Serbia

E-mail: vesna.miskovicstankovic@unionnikolatesla.edu.rs

Abstract

The aim of this work was to synthesize and characterize the poly(vinyl alcohol)/chitosan/gentamicin (PVA/CHI/Gent) hydrogel aimed for wound dressing and to predict diffusion behaviour using novel General fractional derivative model (GFD). The PVA/CHI/Gent hydrogel was prepared by physical cross linking of poly(vinyl alcohol)/chitosan dispersion using freezing-thawing method, then swollen for 48 h in gentamicin solution at 37°C, and characterized by FE-SEM and FTIR. The concentration of released gentamicin was determined using a high-performance liquid chromatography (HPLC) coupled with mass spectrometry (MS). The experimental gentamicin release profile verified the initial burst release effect, i.e. 60 % loaded antibiotic was released within first 48 h which could be very useful in preventing biofilm formation, followed by slow release of gentamicin in a later time period. Diffusion mechanism of gentamicin release was studied by comparison of novel GFD and Korsmeyer-Peppas, Makoid-Banakar and Kopcha diffusion models. It was proven that our novel diffusion GFD model better fitted with experimental data, and enabled the determination of diffusion coefficient precisely for the entire time period.

Keywords: hydrogels, poly(vinyl alcohol), chitosan, gentamicin, diffusion.

1. INTRODUCTION

Biomaterials for soft tissue implants (heart valves, urinary tract, cornea, blood vessels, liver, cartilage) and wound dressings are polymer hydrogels with required properties: biocompatibility, bioinertness, non-toxicity, antimicrobial activity, hydrofility, ability for swelling. Advantages of polymer hydrogels with embedded antimicrobial agens are efficient drug concentration at the targeted place, minimum adverse effects and avoid of systemic antibiotics administration. The concentration of released antimicrobial agens should not be too high to cause toxic effects on the human cells and should exhibit initial burst release followed by later slow and sustained release with time. Biocompatible polymers chitosan (CHI) and poly(vinyl alcohol) (PVA) are often used for soft tissues reparation, as drug carriers, or as the wound dressings. Gentamicin is the one of the most often used antibiotic having broad-spectrum activity, rapid and dose-dependent activity and minimal host tissue toxicity. Generally, profiles of drug release from hydrogel matrices usually exhibit quick initial release - the so-called "burst release" effect, followed by a longer period of gradual release (Nesovic, 2021). There are several diffusion models used for evaluating the drug release profiles from hydrogel carriers, among which the most widespread are Korsmeyer-Peppas (Korsmeyer, 1983), Makoid-Banakar (Makoid, 1993) and Kopcha (Kopcha, 1991) models.

The aim of this work was to synthesize and characterize the poly(vinyl alcohol)/chitosan/gentamicin (PVA/CHI/Gent) hydrogel aimed for wound dressing and to investigate the mechanism of gentamicin release using novel two compartmental General fractional diffusion (GFD) model (Miskovic-Stankovic, 2023) in comparison with Korsmeyer-Peppas, Makoid-Banakar and Kopcha diffusion models.

2. MATERIALS AND METHODS

2.1. Materials

The following chemicals were utilized for preparation of PVA/CHI/Gent hydrogel: poly(vinyl alcohol) powder (fully hydrolysed, Mw = 70-100 kDa), chitosan powder (Mw = 190-310 kDa, deacetylation degree 75-85 %,) and gentamicin sulfate solution (50 mg/ml in dH_2O). For antibacterial properties evaluation, monobasic and dibasic potassium phosphates were used. Cell culture suspensions for cytotoxicity tests were prepared using MTT tetrazolium salt, EDTA, fetal calf serum and antibiotic-antimycotic solution.

2.2. Synthesis of PVA/CHI/Gent hydrogel

PVA colloid dispersion was prepared by dissolving PVA powder in hot distilled water at 90 ºC for 2 h, under magnetic stirring. Chitosan was dissolved in 2 vol% CH_3COOH under constant stirring at room temperature. After cooling of PVA, the CHI dispersion was added dropwise and the final dispersions (containing 10 wt% PVA and 0.5 wt% CHI) were homogenized by mixing at room temperature for 2-3 h. Further, the PVA/CHI hydrogels were prepared by physical cross linking of PVA/CHI dispersion using freezing-thawing method in 5 cycles. One cycle consisted of 16 h freezing at -18 °C followed by 8 h thawing at 4 °C. Finally, the PVA/CHI hydrogels were swollen in 5.0 mg/ml gentamicin solution at 37oC during 48 h to obtain the PVA/CHI/Gent hydrogel.

2.3. Characterization

Field-emission scanning electron microscopy (FESEM) was carried out on Mira3 XMU FEG-SEM (Tescan, Czech), operated at 7 kV, with SE detector. Fourier-transform infrared spectroscopy (FTIR) was carried out using the Nicolet iS10 FTIR Spectrometer (Thermo Fisher Scientific, USA) between 4000 cm^{-1} and 400 cm^{-1}.Tensile test of PVA, PVA/CHI and PVA/CHI/Gent hydrogels was performed at Texture Analyzer (Shimadzu, Japan) with load cell of 5 kN and test speed of 1 mm/min.

For the drug release assay, PVA/CHI/Gent hydrogel was immersed in deionized water and kept at 37 °C. High-performance liquid chromatography (HPLC) (Thermo Fisher Scientific, USA) was utilized for gentamicin components separation and the detection and quantitative analysis was done in an ion trap mass spectrometer (MS) (LCQ Advantage, Thermo Fisher Scientific).

Antibacterial properties of PVA/CHI/Gent hydrogels were evaluated by quantitatively monitoring changes in the viable number of bacterial cells. Two bacterial strains were used, *Staphylococcus aureus* TL (culture collection FTM, University of Belgrade, Serbia) and *Escherichia coli* ATCC 25922 (American Type Culture Collection).

The 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) test was employed to evaluate the toxicity of hydrogels against human (MRC-5) and a mice (L929) fibroblast cell lines.

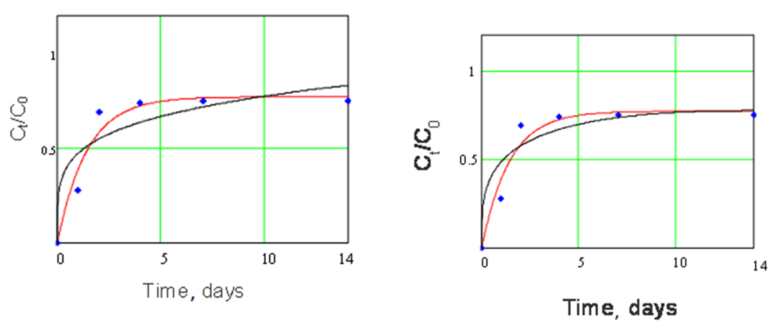
3. RESULTS AND DISCUSSION

3.1. Physicochemical and mechanical characterization

FESEM revealed three-dimensional network structures of PVA/CHI/Gent hydrogel with interconnected micropores evenly distributed through the hydrogel, while FTIR spectra showed characteristic functional groups for PVA, CHI and Gent. Tensile strength (σ_{TS}), Young's modulus of elasticity (E) and tensile strain for maximum of tensile curves (ε_m) have been determined from stress-strain curves obtained by tensile test. It was shown that chitosan and gentamicin in PVA/CHI/Gent hydrogel significantly affects its mechanical properties: tensile strength of PVA/CHI increased by 13.1%, Young's modulus by 18.0% and tensile strain, ε_m, by 83.1% compared to pure PVA, while tensile strength of PVA/CHI/Gent decreased by 31.7%, Young's modulus of elasticity by 11.4%, and tensile strain, $\varepsilon_{m,}$ is five times smaller compared to PVA/CHI (Miskovic-Stankovic, 2024).

3.2. Diffusion models

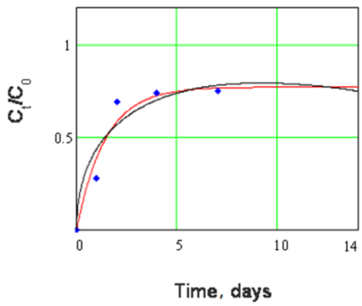
Diffusion mechanism of gentamicin release from PVA/CHI/Gent hydrogel was studied by comparison of novel two compartmental models with General fractional derivative (GFD) and Korsmeyer-Peppas, Makoid-Banakar and Kopcha diffusion models (Fig. 1), where c_t is the concentration of gentamicin released from hydrogel at time, t; and c_o is the initial concentration of gentamicin inside the hydrogel, obtained by HPLC measurements. It can be seen the GFD model fitted the experimental gentamicin release profile better than other models and enabled the determination of the diffusion coefficient of gentamicin in entire time period.



(a)

(b)

Figure 1. Comparison between (a) Korsmeyer-Peppas (black line) and GFD model (red line) (b) Makoid-Banakar (black line) and GFD model (red line).



(c) Kopcha (black line) and GFD model (red line), ◆ experimental points. Reprinted from (Miskovic-Stankovic, 2024). Copyright 2024 by Serbian Chemical Society.

(c)

3.3. Cytotoxicity and antibacterial activity

Both PVA/Gent and PVA/CHI/Gent hydrogels proved as non-cytotoxic against two fibroblast cell lines – human MRC-5 and mouse L929 (Fig. 2) and exhibited strong antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* bacterial strains (Fig. 3a and b).

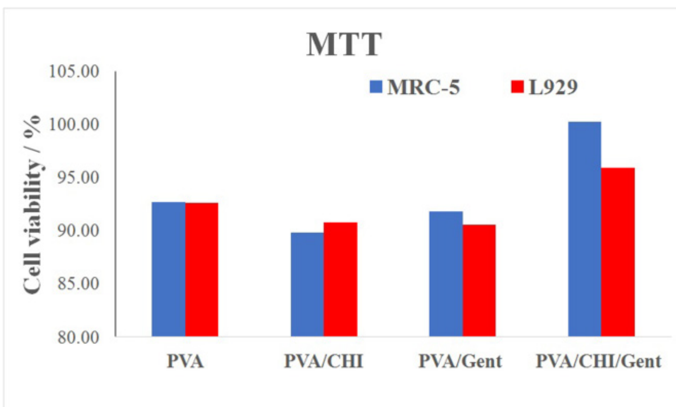
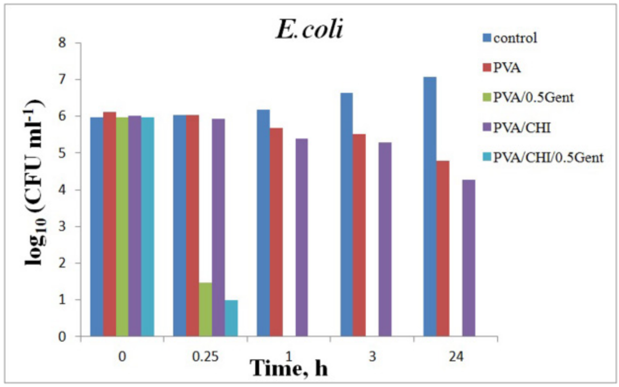
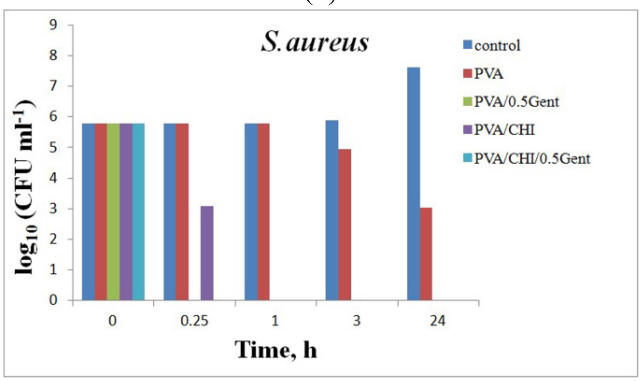


Figure 2. MRC-5 and L929 cells viability in the presence of PVA/Gent and PVA/CHI/Gent hydrogels. Reprinted from (Miskovic-Stankovic, 2024). Copyright 2024 by Serbian Chemical Society.



(a)



(b)

Figure 3. Antibacterial activity of PVA/Gent and PVA/CHI/Gent hydrogels against E. coli (a) and S. aureus (b). Reprinted from (Miskovic-Stankovic, 2024). Copyright 2024 by Serbian Chemical Society

4. CONCLUSION

Synthesized poly(vinyl alcohol)/chitosan/gentamicin (PVA/CHI/Gent) hydrogel is non-toxic towards human MRC-5 and mouse L929 fibroblast cell lines and exhibits strong antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*. Novel General fractional derivative (GFD) model better described the experimental data of gentamicin release than Korsmeyer-Peppas, Makoid-Banakar and Kopcha diffusion models, and enabled the determination of the gentamicin diffusion coefficient more precise. Presence of chitosan and

gentamicin in PVA/CHI/Gent hydrogel significantly affects its mechanical properties.

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PM EFFECTS FROM DEMOLITION OF THE OLD PAPER FACTORY IN NOVI SAD

Miljan Šunjević[1], Boris Obrovski[1], Vladimir Rajs[1], Sanja Dubljević[1], Aleksandra Čavić[2]

[1]Faculty of Technical Sciences, University of Novi Sad

[2]Faculty of Economics and Engineering Management, University Business Academy in Novi Sad

msunjevic@uns.ac.rs

Abstract:

The demolition of industrial buildings in urban environments presents a significant environmental and public health concern due to high generation and emission of particulate matter (PM). The research investigates the expected emissions of PM10 and PM2.5 during the demolition of the former paper factory in Novi Sad, Serbia, covering 3,353 m² of constructed area. Emission factors recommended by the EMEP/EEA Tier 1 methodology were applied to estimate pollutant loads. The results indicate augmented emissions of PM10 and PM2.5 under uncontrolled conditions. The demolition was structured as a six-month phased activity, allowing a lower daily distribution of emissions. Risk assessment was calculated for two exposure groups: workers directly engaged in demolition activities and the nearby residential population. Findings reveal that workers experience exposures exceeding occupational exposure limits (OELs) without adequate protective measures, while local residents in surrounding could be subjected to ambient concentrations surpassing WHO guidelines.

Key words: Demolition, Particulate Matter, PM10, PM2.5, Health Risk Assessment.

INTRODUCTION

Demolition of old industrial facilities is an integral part of urban transformation and land reuse in post-industrial cities. In Novi Sad, Serbia's second largest city, the urban fabric has undergone substantial transformation over the past decades, with many obsolete factories being replaced by residential or commercial developments. One such facility is the old paper factory, a once vital industrial complex now demolition (figure 1.).

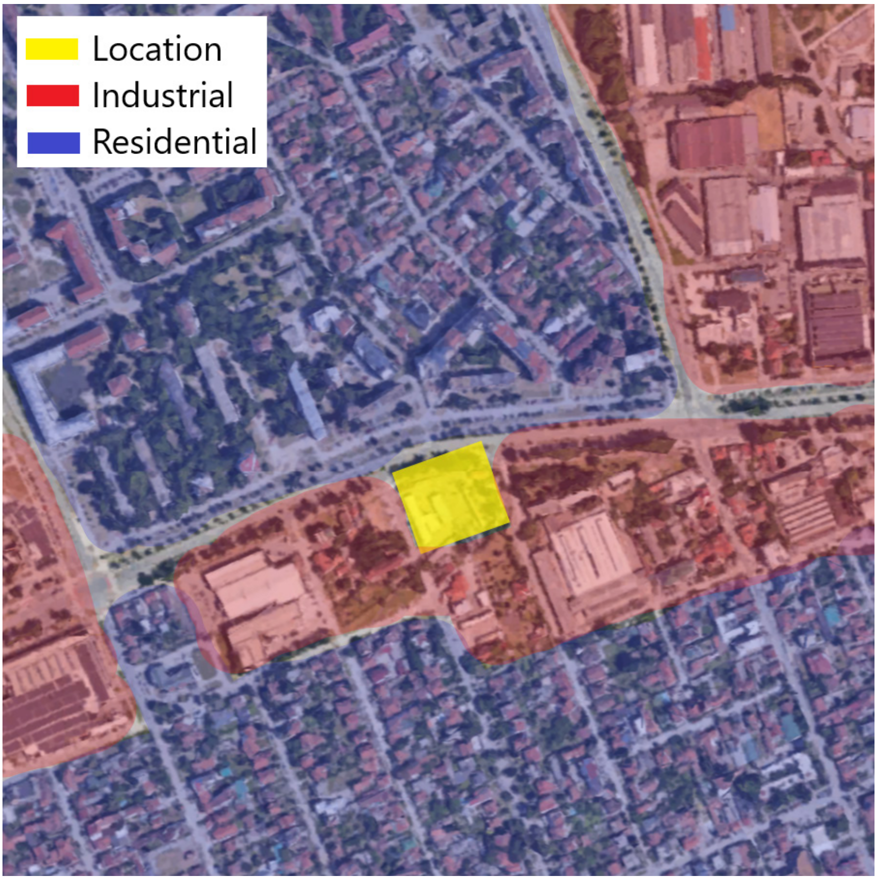
Figure 1. Old paper factory location – pre and post demolition satellite images.

Demolition is not only a technical and economic process but also an environmental challenge (Li et al., 2019; Yan et al., 2020). Dust and particulate matter (PM) emissions are among the most significant pollutants generated during demolition. PM10 (particles with diameter <10 µm) and PM2.5 (<2.5 µm) are particularly concerning, as they penetrate the human respiratory system, causing adverse cardiovascular, pulmonary, and systemic effects (Hime et al., 2018; Ukaogo et al., 2020)coal-fired power stations, diesel exhaust, domestic wood combustion heaters, and crustal dust. The principal purpose of this review is to compare the evidence of health effects associated with these different sources with a view to answering the question: Is exposure to PM from some emission sources associated with worse health outcomes than exposure to PM from other sources? Answering this question will help inform development of air pollution regulations and environmental policy that maximises health benefits. Understanding the health effects of exposure to components of PM and source-specific PM are active fields of investigation. However, the different methods that have been used in epidemiological studies, along with the differences in populations, emission sources, and ambient air pollution mixtures between studies, make the comparison of results between studies problematic. While there is some evidence that PM from traffic and coal-fired power station emissions may elicit greater health effects compared to PM from other sources, overall the evidence to date does not indicate a clear 'hierarchy' of harmfulness for PM from different emission sources. Further investigations of the health effects of source-specific PM with more advanced approaches to exposure modeling, measurement, and statistics, are required before changing the current public health protection approach of minimising exposure to total PM mass.","container-title":"International Journal of Environmental Research and Public Health","DOI":"10.3390/ijerph15061206","ISSN":"1660-4601","issue":"6","journalAbbreviation":"IJERPH","language":"en","license":"https://creativecommons.org/licenses/by/4.0/","page":"1206","source":"DOI.org (Crossref. Epidemiological studies have consistently linked short- and long-term PM exposure with hospital admissions, asthma exacerbations, and increased mortality (Southerland et al., 2022). In densely populated environments, the potential for acute exposure episodes necessitates systematic environmental assessment prior to demolition activities.

MATHERIALS AND METHODS

Location

The research focuses on the demolition of the old paper factory in Novi Sad. The factory covers a footprint of 3,353 m^2, composed primarily of reinforced concrete, masonry walls, and tin roofing. The demolition site is situated in a mixed-use zone with residential and industrial buildings situated in the vicinity (Figure 2.). The demolition of this site poses a direct risk to workers and an indirect risk to nearby residents due to airborne dust dispersion. The primary surrounding zone is made of residential buildings and industrial with low height (up to 12m) which allows easier PM10 and PM2.5 dispersion in the surrounding. The good local meteorological conditions, high silt content and prevailing winds from the northwest play a key role in particle dispersion.



Emission modeling

The PM emission modeling was conducted using the EMEP/EEA Air Pollutant Emission Inventory Guidebook, Tier 1 methodology, which provides standardized emission factors for construction and demolition activities. This framework was selected because it is widely applied across Europe, ensures comparability with similar studies, and is suitable for screening-level assessments where site-specific measurements are not yet available.

For demolition processes, the Tier 1 method expresses particulate matter emissions as an emission factor (EF) per unit of demolished surface area. In the selected case, the following factors were applied:

- PM10 = 0.20 kg/m² demolished
- PM2.5 = 0.035 kg/m² demolished

Multiplying EF by the demolition surface area of 3,353 m² generated baseline emissions of 670.6 kg PM10 and 117.4 kg PM2.5 under uncontrolled conditions. These values represent the total load expected from mechanical demolition without mitigation measures such as water spraying or enclosure.

Demolition Scheme

Realistic project dynamics included demolition activities that were distributed across six months, following an S-curve of intensity: 10%, 15%, 25%, 25%, 15%, 10% (Table 1.). The phasing allows for progressive buildup, peak, and reduction of emissions. Each phase corresponds to specific demolition tasks and environmental control priorities:

1. Month 1 (10%) – Pre-demolition, soft stripping, fencing, hazard removal.
2. Month 2 (15%) – Roof removal, small annexes, scaffolding.
3. Month 3 (25%) – Peak demolition I: half of primary structures.
4. Month 4 (25%) – Peak demolition II: remaining structures.
5. Month 5 (15%) – Slab breakout, foundation removal, crushing.
6. Month 6 (10%) – Backfilling, grading, stabilization.

Table 1. Monthly distribution of PM emission from demolition

Month	Share	PM_{10} (kg)	$PM_{2.5}$ (kg)
1	10%	67.1	11.7
2	15%	100.6	17.6
3	25%	167.7	29.3
4	25%	167.7	29.3
5	15%	100.6	17.6
6	10%	67.1	11.7
Total	100%	670.6	117.4

Risk assessment

Risk assessment was carried out separately for demolition workers and the nearby residential population, using established occupational and public health guidelines as benchmarks. For workers, exposure estimates were compared against Occupational Exposure Limits (OELs) defined under European regulations, where the 8-hour time-weighted average (TWA) for PM10 is 3 mg/m³ and proposed values for PM2.5 are around 1.5 mg/m³. Worker exposure scenarios considered peak concentrations at the breathing zone during dust-intensive tasks, incorporating the potential effectiveness of personal protective equipment (PPE) such as FFP2/FFP3 respirators. For the general population, health risks were evaluated against the World Health Organization Air Quality Guidelines, which set short-term thresholds of 50 µg/m³ for PM10 and 25 µg/m³ for PM2.5.

Worker exposure

Assumed peak-month task mix (representative):

- 3 h high-dust mechanical demolition at 5 mg/m³ PM10
- 3 h general handling/loading at 2 mg/m³ PM10
- 2 h low-dust activities at 0.5 mg/m³ PM10

Calculation:

CTWA= ∑iCi×ti/8h

CTWA=((5×3)+(2×3)+(0.5×2))/8=2.75 mg/m³

Nearby population

For calculation peak month value was selected: 1-h PM10 - 150 µg/m³ during active work, and background emission as 30 µg/m³ when there are no works.

C24=(Cwork×t+Cbg×(24−twork))/24

C24=(150×8+30× (24-8))/24=70 µg/m³

RESULTS AND DISCUSSION

Using the EMEP/EEA Tier 1 methodology, total uncontrolled particulate matter emissions from the demolition of the Novi Sad old paper factory were calculated at 670.6 kg PM10 and 117.4 kg PM2.5 for the 3,353 m² site. When distributed over the planned six-month phased schedule, average daily loads were estimated at approximately 5 kg/day PM10 and 0.9 kg/day PM2.5, with highest monthly emissions during peak structural demolition in months 3 and 4 (≈168 kg PM_{10} each).

Field-representative modeling of occupational exposure without protective equipment indicated an 8-hour time-weighted average of 70 µg/m³ PM10 in the worker breathing zone. This value is well below the European Occupational Exposure Limit (OEL) for inhalable dust of 3,000 µg/m³ (3 mg/m³), suggesting that in this particular demolition scenario, direct worker exposure remains within regulatory thresholds. Although the calculated 70 µg/m³ TWA for workers is below occupational thresholds, it represents a substantial elevation over typical ambient urban PM_{10} concentrations (20–30 µg/m³ in Novi Sad). Epidemiological literature indicates that chronic exposure, even below OELs, can contribute to reduced lung function and respiratory symptoms. Therefore, while regulatory compliance is technically met, best practice still supports the use of engineering controls and PPE to minimize unnecessary cumulative exposure.

At the site boundary and within 200 m of the demolition area, modeled concentrations during peak months reached 150 µg/m³ PM10. This level exceeds the WHO Air Quality Guideline (50 µg/m³, 24-h mean), confirming a risk of short-term exceedances for nearby populations. For nearby residents, the exceedance of WHO short-term guidelines is a critical finding. Obtained concentrations during active work are associated with increased hospital admissions for asthma and cardiovascular conditions. Sensitive groups, such as children, the elderly, and individuals with pre-existing respiratory disease, face elevated risk even during temporary exceedances.

CONCLUSION

The research assessed the environmental and health implications of demolishing the 3,353 m² paper factory in Novi Sad, with a focus on particulate matter emissions and their impacts on workers and the surrounding community. Using the EMEP/EEA Tier 1 methodology, total uncontrolled emissions were estimated at 670.6 kg of PM_{10} and 117.4 kg of $PM_{2.5}$. Under the planned six-month phased demolition, average daily emissions are moderate; however, peak months generate levels that can temporarily elevate ambient concentrations above international health guidelines.

Worker exposure resents a significant increase over urban background levels and contributes to cumulative respiratory risk, underscoring the need for preventive measures. For nearby residents, modeled daily averages exceed the

WHO guideline of 50 µg/m³, indicating a potential for short-term health impacts, particularly among vulnerable groups.

The results demonstrate that, although extended demolition schedules reduce acute exposure, mitigation measures remain essential. Water spraying, dust suppression, debris management, protective equipment, and real-time monitoring can collectively reduce emissions keeping exposures within safer thresholds.

ACKNOWLEDGEMENTS

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CONSTRUCTION MACHINERY PM EMISSION ANALISYS AND HEALTH RISK ASSESSMENT

Miljan Šunjević[1], Boris Obrovski[1], Vladimir Rajs[1], Sanja Dubljević[1], Aleksandra Čavić[2]

[1]Faculty of Technical Sciences, University of Novi Sad

[2]Faculty of Economics and Engineering Management, University Business Academy in Novi Sad

msunjevic@uns.ac.rs

Abstract:

Construction machinery represents one of the largest localized sources of particulate matter (PM) emissions on urban construction sites, posing both environmental and occupational health concerns. The research quantified emissions from five representative machine types—excavators, bulldozers, wheel loaders, dump trucks, and concrete mixers—using the U.S. EPA AP-42 unit/phase method. Daily activity rates were estimated in horsepower-hours and converted into particulate emissions (PM10 and PM2.5). Results showed that bulldozers, concrete mixers, and excavators were the dominant emitters, each generating up to 400 g/day of PM10 and 200 g/day of PM2.5. Exposure concentrations, modeled within a 50 m radius breathing zone, were compared against World Health Organization (WHO) guidelines. All machinery exceeded the 2021 WHO thresholds, confirming severe occupational risks. The findings highlight the urgent need for dust suppression, adoption of cleaner engine technologies, administrative controls, and personal protective equipment (PPE). Beyond direct worker impacts, the study emphasizes the broader role of construction activities in urban air quality degradation, underscoring the importance of integrating emission reduction strategies into sustainable construction practices.

Key words: Construction machinery, Particulate Matter, Health Risk Assessment

INTRODUCTION

Construction activities are essential urban development factors, and simultaneously major contributors to local air pollution. Globally, the construction sector accounts for a significant share of energy use and polluting substances emissions, particularly in rapidly urbanizing regions. Among the various pollutants released, particulate matter (PM), especially PM10 and PM2.5, has been identified as a critical environmental and occupational health concern due to its strong association with respiratory and cardiovascular diseases (*WHO*, 2021). PM10 refers to particles with an aerodynamic diameter less than 10 micrometers, which are capable of reaching the lower respiratory tract, while PM2.5, with diameters less than 2.5 micrometers, can penetrate even deeper into the alveolar region of the lungs, posing more severe health risks (Hime et al., 2018)coal-fired power stations, diesel exhaust, domestic wood combustion heaters, and crustal dust. The principal purpose of this review is to compare the evidence of health effects associated with these different sources with a view to answering the question: Is exposure to PM from some emission sources associated with worse health outcomes than exposure to PM from other sources? Answering this question will help inform development of air pollution regulations and environmental policy that maximises health benefits. Understanding the health effects of exposure to components of PM and source-specific PM are active fields of investigation. However, the different methods that have been used in epidemiological studies, along with the differences in populations, emission sources, and ambient air pollution mixtures between studies, make the comparison of results between studies problematic. While there is some evidence that PM from traffic and coal-fired power station emissions may elicit greater health effects compared to PM from other sources, overall the evidence to date does not indicate a clear 'hierarchy' of harmfulness for PM from different emission sources. Further investigations of the health effects of source-specific PM with more advanced approaches to exposure modeling, measurement, and statistics, are required before changing the current public health protection approach of minimising exposure to total PM mass.","container-title":"International Journal of Environmental Research and Public Health","DOI":"10.3390/ijerph15061206","ISSN":"1660-4601","issue":"6","journalAbbreviation":"IJERPH","language":"en","license":"https://creativecommons.org/licenses/by/4.0/","page":"1206","source":"DOI.org (Crossref.

The generation of particulate matter on construction sites arises from two dominant sources:

- combustion-related emissions from diesel-powered construction machinery,
- fugitive dust emissions caused by mechanical disturbance of soil, loading and unloading of materials, and vehicular movement on unpaved surfaces.

Diesel combustion is particularly problematic, as it produces not only fine particles but also black carbon, a short-lived climate pollutant with significant radiative forcing potential. As construction machinery often operates in close proximity to workers and within densely populated urban environments, the resulting air quality degradation affects both occupational safety and public health.

Quantification of emissions from construction machinery is challenging due to the diversity of equipment, variability of operational cycles, and site-specific conditions. The U.S. Environmental Protection Agency (EPA) developed the AP-42 Compilation of Air Pollutant Emission Factors, which provides standardized methodologies for estimating emissions from a wide range of anthropogenic sources, including construction activities. The "unit or phase method" in AP-42 is widely applied in environmental impact assessments and air quality modeling, as it allows for the calculation of emissions based on machine power rating, activity hours, and fuel consumption. The main advantage is in its adaptability to project-specific parameters, making it suitable for both preliminary planning and regulatory reporting.

Previous studies have documented that construction activities can contribute between 10–25% of total PM10 emissions in urban areas (Li et al., 2019, 2019; Southerland et al., 2022; Sunjevic et al., 2023). Field measurements conducted near large-scale building and roadworks have shown localized PM10 concentrations exceeding 500 µg/m³, significantly higher than ambient air quality standards (Sunjevic et al., 2023, 2024). In addition to environmental impacts, such high exposures pose direct health risks to workers, who may spend 6–10 hours daily in dust-intensive environments without adequate protective equipment. Occupational exposure to particulate matter has been linked not only to chronic obstructive pulmonary disease, but also to increased prevalence of lung cancer among long-term workers in the construction sector (Hime et al., 2018; Ukaogo et al., 2020)coal-fired power stations, diesel exhaust, domestic wood combustion heaters, and crustal dust. The principal purpose of this review is to compare the evidence of health effects associated with these different sources with a view to answering the question: Is exposure to PM from some emission sources associated with worse health outcomes than exposure to PM from other sources? Answering this question will help inform development of air pollution regulations and environmental policy that maximises health benefits. Understanding the health effects of exposure to components of PM and source-specific PM are active fields of investigation. However, the different methods that have been used in epidemiological studies, along with the differences in populations, emission sources, and ambient air pollution mixtures between studies, make the comparison of results between studies problematic. While there is some evidence that PM from traffic and coal-fired power station emissions may elicit greater health effects compared to PM from other sources, overall the evidence to date does not indicate a clear 'hierarchy' of harmfulness for PM from different emission sources. Further investigations of the health effects of source-specific PM with more advanced approaches to exposure modeling, measurement, and statistics, are required before changing the current public health protection approach of minimising exposure to total PM mass.","container-title":"International Journal of Environmental Research and Public Health","DOI":"10.3390/ijerph15061206","ISSN":"1660-4601","issue":"6","journalAbbreviation":"IJERPH","language":"en","license":"https://creativecommons.org/licenses/by/4.0/","page":"1206","source":"DOI.org (Crossref.

Quantitative occupational risk assessments of construction machinery emissions despite the known hazards remain limited, particularly in the context of site-specific operations. The main literature mostly focuses on traffic-related emissions or fugitive dust from demolition and earthworks, whereas fewer studies explicitly evaluate the combined contributions of heavy-duty machinery. Given the rapid urban expansion in many regions, including Southeast Europe, there is a growing need for more rigorous quantification of emissions from typical construction fleets and for their integration into health risk assessment frameworks.

MATHERIALS AND METHODS

Machinery selection

The selection of construction machinery for the research was guided by both literature review and field observations of medium-sized urban construction projects, which typically involve earthworks, foundation excavation, grading, and material handling. Heavy machinery is the dominant source of emissions on such sites because of its reliance on diesel engines, high horsepower ratings, and extended daily operation times. Five categories of equipment were chosen as representative of core construction processes: Excavators, Bulldozers, Wheel Loaders, Dump Truck and Concrete Mixer Trucks.

Excavators are indispensable for soil excavation, trenching, and loading materials into trucks. They are among the most frequently used machines during the initial phases of construction and demolition. Modern hydraulic excavators typically range from 100 to 300 horsepower (hp). For the purposes of the research, a mid-200 hp model was selected as representative of medium-sized projects. Excavators are significant contributors to emissions not only due to their engine size but also because of long duty cycles (5–8 hours daily) and frequent high-load operation.

Bulldozers are employed for grading, pushing soil, and clearing debris. They are characterized by high horsepower (200–350 hp) and substantial fuel consumption during heavy pushing operations. Bulldozers often operate continuously during land preparation and are identified as some of the largest PM emitters on construction sites. A 250 hp machine with 5 h/day of activity was selected to represent average bulldozer use.

Wheel loaders are versatile machines used for lifting, transporting, and loading soil, gravel, and other bulk materials. Although smaller than bulldozers, their frequent short-cycle operation makes them an important emission source. Loaders typically fall in the 150–250 hp range, with 180 hp selected as representative for the analysis. They are often deployed in combination with excavators and trucks, forming critical links in construction material flows.

Dump trucks are necessary for hauling excavated materials to disposal sites or bringing aggregates and other raw materials to the construction site. Unlike stationary or semi-stationary equipment, dump trucks contribute both on-site emissions (from idling, loading/unloading) and off-site emissions (from transport on urban road networks). Their emissions are typically quantified per kilometer traveled rather than per unit horsepower. For the research purposes, a truck fleet with an average of 300 hp engines and a 20 km/day hauling distance was assumed, reflecting the short to medium transport distances typical of urban projects.

Concrete mixers ensure the delivery and mixing of fresh concrete at construction sites. They typically range from 200–300 hp, with 250 hp chosen as middle value. While the direct emissions are lower than those of excavators or bulldozers, mixer trucks are important to include due to their frequent presence on sites and repeated engine load fluctuations during mixing operations. Their emissions are compounded by extended idling during pouring activities, which can significantly elevate local PM concentrations.

The selected machines reflect a balance between earthmoving (excavators, bulldozers, loaders), material transport (dump trucks), and construction support (concrete mixers). Additional equipment such as cranes, graders, and compactors also contribute, their share of total emissions is comparatively lower or more site-specific.

Prediction Model

The emission modeling in the research is based on the methodology described in the *AP-42*, developed and maintained by the U.S. Environmental Protection Agency (EPA). AP-42 is widely recognized as the standard reference for emission factor development and has been applied in environmental impact assessments, air quality modeling, and regulatory compliance studies for more than three decades. It is very effective for construction activities, as it allows emissions to be calculated based on measurable activity rates and standardized emission factors.

The core principle of the AP-42 methodology is to link pollutant emissions to activity levels through empirically derived emission factors. The generic equation can be expressed as:

$$E = A \times EF \times (1 - C)$$

Where:

E = pollutant emission (g/day or g/event),

A = activity level (e.g., horsepower-hours, liters of fuel consumed, or kilometers traveled),

EF = emission factor (g/unit of activity),

C = control efficiency (fraction, dimensionless).

This flexible formulation allows for application across a variety of machinery types and operational conditions. In the research, horsepower-hours were used as the basis for off-road construction machinery, while kilometers traveled were used for on-road trucks. Control efficiency was assumed to be zero (C = 0), representing a worst-case scenario and most common in the Eastern Europe where no dust suppression or emission control devices are applied.

To model worker exposure concentrations, a simplified dispersion model was applied. Emissions from each machine were assumed to disperse within a cylindrical volume of air representing the immediate work zone:

$$V = \pi \times r \times 2 \times h \times V$$

Where:

r = 50 m (radius of effective exposure zone),

h = 2 m (average human breathing height).

For each machine, the concentration (mg/m^3) was estimated as:

$C=E\times V\times C$

Where E is the daily emission converted to milligrams, and V is the mixing volume (15,700 m^3).

Emission and Activity Rate Factors

Emission factors were derived from the most recent AP-42 updates for non-road and on-road diesel engines:

- Non-road construction equipment (diesel):
  - PM10 = 0.20 g/hp×h
  - PM2.5 = 0.10 g/hp×h
- On-road heavy-duty diesel trucks:
  - PM10 = 2.5 g/km
  - PM2.5 = 1.25 g/km

These factors represent average uncontrolled emissions for Tier 0–Tier 2 diesel engines, which are still widely in use in many regions, including Southeast Europe. While newer Tier 4 equipment achieves significantly lower emissions due to advanced after-treatment systems, the selected values reflect realistic site conditions where mixed-age fleets are employed.

Activity rates were estimated based on machine horsepower and daily operating time:

$A=HP\times OT$

Where:

HP= Machine horse power

OP= Machine operational time

Health Risk Assessment

Occupational exposure was assessed using an **8-hour time-weighted average (TWA)** approach, reflecting the standard working shift on construction sites. Daily emissions from each machine, calculated in grams and converted to micrograms, were divided by the fixed exposure volume of **15,700 m³** (cylindrical zone with 50 m radius and 2 m breathing height). This provided worst-case estimates of particulate matter concentrations (µg/m³) in the worker breathing zone, assuming continuous operation and no atmospheric dispersion beyond the defined volume.

The modeled TWA concentrations were then compared exclusively with the **World Health Organization** (*WHO Global Air Quality Guidelines*, 2021), which remain the most authoritative global benchmark for health protection:

- PM10: 45 µg/m³ (24 h mean)
- PM2.5: 15 µg/m³ (24 h mean)

Although WHO values are set for the general population and ambient exposure, their adoption in occupational assessment provides a **precautionary baseline** for evaluating risks in environments where workers may face much higher concentrations.

RESULTS AND DISCUSSION

Daily emissions of PM10 and PM2.5 were calculated using the AP-42 method, with all machinery standardized to 8 hours/day of operation. The activity rate was expressed as horsepower-hours (hp×h/day), while dump truck emissions were calculated based on distance traveled (20 km/day). Excavators, bulldozers, and concrete mixers showed the highest activity rates and, correspondingly, the largest emissions (Table 1.).

The results show that bulldozers and concrete mixers generate the highest daily emissions (400 g PM10 and 200 g PM2.5), followed closely by excavators. Wheel loaders produced moderate values, while dump trucks contributed the least. However, even the lowest emitter (dump truck) still exceeded WHO thresholds when concentrations were modeled in the worker exposure zone.

Table 1. Modeled values

Machinery	Power (hp)	Activity Rate (hp×h/day)	PM10 (g/day)	PM2.5 (g/day)
Excavator	200	1,600	320	160
Bulldozer	250	2,000	400	200
Wheel Loader	180	1,440	288	144
Concrete Mixer	250	2,000	400	200
Dump Truck	300	— (20 km/day)	50	25

When compared with the **WHO 2021 air quality guidelines** (45 μg/m³ for PM10, 15 μg/m³ for PM2.5), the modeled concentrations for all machinery were found to highly exceed permissible levels.

In terms of risk classification Bulldozers, Concrete Mixers, and Excavators are defined as High-Risk Machinery. Wheel Loaders located them self in **Medium-to-High Risk Machinery, while Dump Trucks are considered to pose Signiant Risk.** The results confirm that **every category of construction machinery poses a severe occupational health hazard**, with exposures far beyond WHO health-based standards.

CONCLUSION

The research demonstrated that particulate matter emissions from the most common construction machinery—excavators, bulldozers, wheel loaders, dump trucks, and concrete mixers—generate exposure concentrations far above health-based standards. The results confirm that workers in close proximity to active machinery face severe occupational risks, particularly from bulldozers, concrete mixers, and excavators, which emerged as the dominant sources. To mitigate these hazards, construction sites must prioritize dust suppression, adoption of cleaner engine technologies, administrative controls such as task rotation and zoning, and the consistent use of respiratory protective equipment. Beyond worker health, these findings also highlight the broader environmental burden of construction activities on ambiental air quality, underscoring the need for stricter regulatory oversight and the integration of emission reduction strategies into sustainable construction practices.

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MONITORING: A KEY FACTOR IN ENVIRONMENTAL PROTECTION IN CERAMIC PRODUCTION

Novica Staletović[1*], Violeta Nikolić[2], Vladanka Presburger-Ulniković[3], Robert Rekecki [4]

[1,2,3] Faculty of Ecology and Environmental Protection, University "Union-Nikola Tesla" Belgrade, Serbia
[4]Wienerberger d.o.o Kanjiža

[*]*corresponding author:* nstaletovic@unionnikolatesla.edu.rs

ABSTRACT

This paper provides a brief overview of the ceramic tile manufacturing process and analyzes its environmental impact. Keramika Kanjiža d.o.o. is a facility operating under an integrated permit. The analysis identified potential risks of environmental pollution resulting from inadequate waste management, uncontrolled air emissions, and wastewater discharge in ceramic tile manufacturing. This paper analyzes key monitoring findings and presents compliance with best available techniques, BREF documents, SRPS ISO 14001:2015, and legal regulations.

Keywords: ceramic manufacturing, environmental impact, monitoring, IPPC

INTRODUCTION

Every manufacturing process has or can have a significant impact on the environment, especially if it involves activities and facilities for which an integrated permit is required, as is the case with ceramic tile production. To minimize the environmental impact, it is necessary to monitor (track and measure) environmental parameters and apply the best available techniques (BAT) to achieve environmental quality and meet the requirements of standards and legislation. Monitoring is an integral part of the environmental protection management system and involves the systematic assessment of the chemical or physical properties of pollutants that are emitted into the air, discharged into water, or disposed of as waste. Monitoring is carried out through the systematic tracking of indicator metrics, specifically by monitoring negative environmental impacts, the state of the environment, and measures and actions taken to reduce these impacts and improve environmental quality.

Compliance with internationally recognized standards such as SRPS ISO 9001:2015, SRPS ISO 14001:2015, SRPS ISO 45001:2018, and SRPS EN ISO 50001:2018, as well as legal requirements, is crucial for the sustainable development of any company (Staletović et al., 2025). The legal framework for monitoring is defined by the Law on Environmental Protection ("Official Gazette of RS" No. 135/2004, 36/2009, 72/2009, 43/2011, 14/2016, 76/2018, 95/2018 and 94/2024), as well as the obligation to develop a Monitoring Plan in accordance with the Law on Integrated Prevention and Control of Environmental Pollution ("Official Gazette of RS", No. 135/2004, 25/2015, and 109/2021).

The "Keramika Kanjiža" d.o.o. factory manufactures wall and floor glazed ceramic tiles. The factory is located in the area designated for industrial and commercial buildings in the urban plan of the city of Kanjiža. To implement the environmental protection policy for monitoring, it is necessary to adhere to the SRPS ISO 14001:2015 standard, which is based on the process approach and the PDCA methodology (Plan - Do - Check – Act (Improve)). To plan measures for the efficient and effective management and measurement (monitoring) at the "Keramika Kanjiža" d.o.o. factory, an approach compatible with the integrated quality and environmental management model has been defined, as shown in Figure 1.

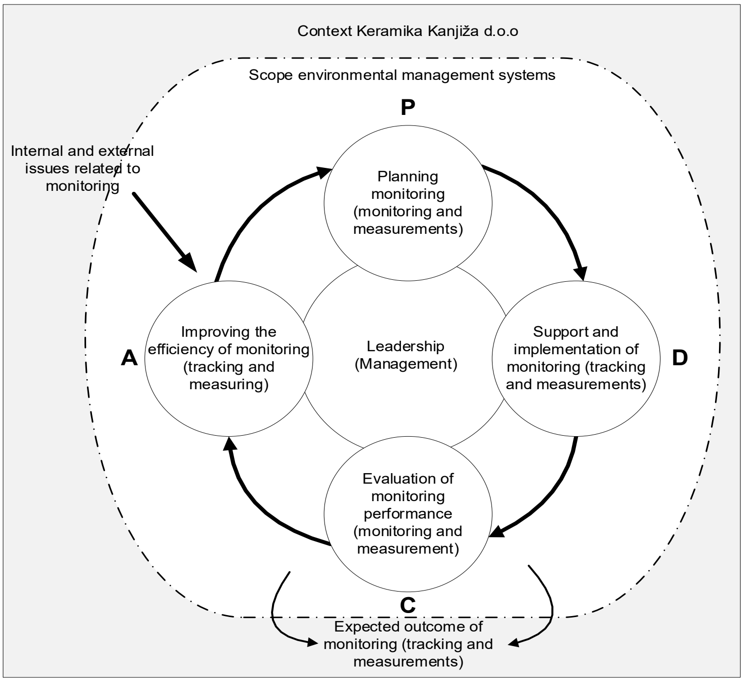

Figure 1 Monitoring management approach compatible with SRPS ISO 14001:2015

DESCRIPTION OF MACROLOCATION AND MICROLOCATION

The municipality of Kanjiža is located on the right bank of the Tisa River, in the northernmost part of Serbia. It covers 399 square kilometers and has 10,000 inhabitants. **Figure 2 shows an orthophoto of Kanjiža, with the location of the "Keramika Kanjiža" d.o.o. factory indicated.**

Figure 2 Orthophoto of Kanjiža

The "Keramika Kanjiža" d.o.o. complex is located in the northern part of Kanjiža, 2 km from the city center. **The distance from the manufacturing plant "Keramika Kanjiža" d.o.o. to the first residential buildings is about 300 m.** The factory is located at 46° 04' 10" north latitude and 20° 02' 26" east longitude, at an altitude of 81 m.

DESCRIPTION OF THE MANUFACTURING PROCESS

The "Keramika Kanjiža" d.o.o. factory uses clay and feldspar as the main raw materials in the production of glazed ceramic wall and floor tiles. For the glazes, it uses frits (insoluble bases), kaolin, and ceramic paints and inks for digital printing. The factory employs a single-firing technology, and the process sequence follows the scheme (Figure 3).

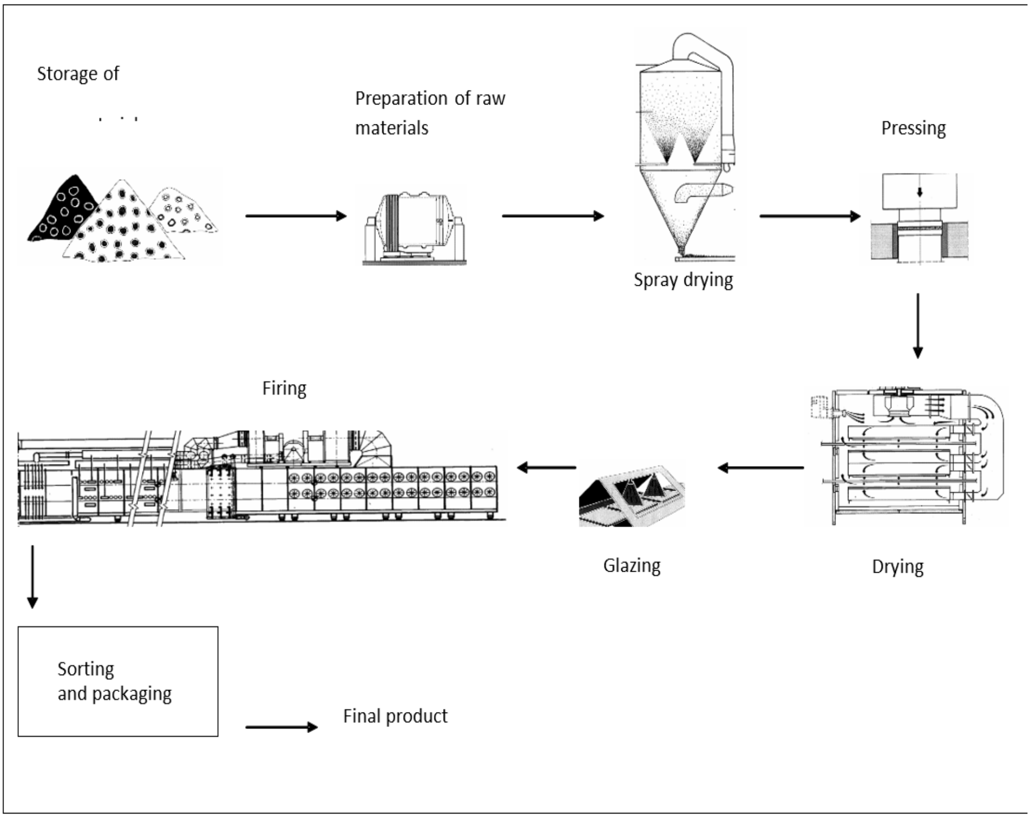

Figure 3 Simplified scheme of the manufacturing process

MONITORING PLAN

The environmental impact of the “Keramika Kanjiža” d.o.o. plant is assessed by monitoring the quality of the following: air (emissions of pollutants and greenhouse gases -GHG), water (process waste, sanitary, underground, and atmospheric), land, noise, and industrial waste. There is a potential risk of environmental pollution caused by the “Keramika Kanjiža” d.o.o. plant. Therefore, it is essential to conduct continuous monitoring, improve environmental protection measures, apply the best available techniques (BAT), and align with the relevant reference documents (BREF).

DISCUSSION

Analysis of air emission results

The processing of clay and other raw materials for ceramic tile production inevitably leads to the creation of dust, particularly during dry periods. The stages of raw material preparation and material transport result in the release of fine dust. A smaller amount of dust is also released during other stages of the process, such as atomization, drying, glazing, firing, and sorting/packing of ceramic tiles. In the ceramic industry, dust is one of the most significant pollutants in terms of quantity. In addition to particulate matter, the emission of gaseous compounds occurs as a result of the combustion of natural gas during the atomization, drying, and firing stages. The emissions of the following compounds are characteristic in the ceramic industry: particulate matter; sulfur dioxide (SO_2) and other sulfur compounds; nitrogen oxides (NO_2) and other nitrogen compounds; volatile organic compounds (VOCs); metals and their compounds; chlorine, fluorine, and their compounds. Long-term monitoring of air emission measurements at the "Keramika Kanjiža" d.o.o. factory has shown that, in a significant number of cases, there were no exceedances of the permitted emission limits, either in terms of BREF documents or current legal regulations.

Analysis of wastewater test results

In ceramic tile manufacturing, water is a very important resource. The water that is directly used for preparing the ceramic mixture, engobes, and glazes does not cause problems with wastewater discharge, because this water evaporates during the later stages of the process, such as drying and firing the ceramic tiles, and there is also a recirculation system in place. Wastewater is primarily generated during the washing and cleaning of the equipment, glaze leakage onto the floor, etc. At this stage, clay materials and components of the glaze that enter the water flow become suspended. However, emissions into the water also occur during the operation of the wet scrubbers on the atomizer. Therefore, wastewater is typically loaded with the same raw materials and auxiliary materials used in the production process. As a rule, these compounds are insoluble in water. Wastewater is characterized by turbidity and coloration due to the very fine suspended particles of glaze and clay. From a chemical perspective, wastewater is characterized by the presence of: suspended solids (clay, frits, and insoluble silicates); dissolved anions (sulfates); suspended and dissolved heavy metals (lead, zinc); boron in small quantities; and traces of organic materials (screen printing medium).

By installing a decanter for wastewater treatment, the resulting technological wastewater is purified and returned to the production process. This allows the entire amount of wastewater to be returned to the production cycle after purification, without being discharged into the recipient. The separated sludge is also recycled, added to the ceramic mixture, and reused. The quality of processed waste water at the exit from the device is < 0.1% of colloidal and suspended matter. With the introduction of the purifier and technological improvements in the process, water consumption per unit of finished product has been significantly reduced compared to earlier years.

Analysis of soil and groundwater test results

According to the available results of soil and groundwater quality testing, no contaminants exceeding the permitted levels were identified, either in terms of metal content or traces of fuel or lubricants.

The Rulebook on the list of activities that may cause soil pollution and degradation, procedures, data requirements, deadlines, and other conditions for soil monitoring ("Official Gazette of RS", No. 102/2020), defines a list of activities that may cause soil pollution and degradation. According to this List of activities, "Keramika Kanjiža" d.o.o. is classified under group 3 (Mineral industry), subgroup 3.5. Facilities for the manufacture of ceramic products by firing — particularly roof tiles, bricks, refractory bricks, tiles, ceramic tableware, or porcelain — with a production capacity exceeding 75 t per day and/or a kiln capacity exceeding 4 m^3, with a loading density per kiln exceeding 300 kg/m^3.

Analysis of waste material testing results in the production process

The production of ceramic tiles generates the following types of waste materials:

- Various types of sludge originating from wastewater treatment, cleaning during clay preparation, glaze preparation and application equipment, as well as from wet grinding;

- Broken or damaged products, such as raw tiles from the pressing and glazing stages, or scrap tiles after the firing and sorting stages;

- Dust generated during the dedusting of exhaust gases;

- Used absorbent materials (limestone) from the flue gas purification system;

- Waste (plastic, wood, metal, paper, etc.)

Some of the waste materials listed above can be recycled and reused in the production process. For example, sludge, dust from dedusting, and waste raw tiles are returned to the clay preparation stage. Materials that cannot be reused internally are processed either in facilities from other industrial sectors or in external plants for treatment, recycling, or disposal.

Compliance with BAT requirements and the plant adaptation measures program

Monitoring is organized, controlled, and systematized by the person in charge of environmental protection management. Their duty is to plan and organize monitoring and measurements, as well as to propose measures to eliminate the causes of poor results and/or improve the monitoring and measurement processes.

Table 1 presents the compliance with BAT requirements and the reference BREF documents, demonstrating that the "Keramika Kanjiža" d.o.o. plant exhibits a high level of compliance. This is ultimately reflected in the issuance of the IPPC (*Integrated Pollution Prevention and Control*) permit by the competent environmental authority.

Table 1: Compliance with BAT requirements at "Keramika Kanjiža" d.o.o., (BREF EU CER, August 2007)

BAT and requirements established by reference documents	**Compliance with BAT (YES/NO)**
5.1. Environmental management	
Environmental Management System (ISO 14001)	YES
5.2 Dust emissions	
5.2.1. Diffuse dust emission	YES
5.2.2. Dust emission from dry dusters	YES

5.2.3. Dust emission from dryers	YES
5.2.4. Dust emission from the firing kiln	YES
5.3 Emissions of gaseous components	
5.3.1. Primary measures/techniques	YES
5.3.2. Secondary measures/techniques	YES
5.4 Technological Wastewater	
a) Reduce water consumption by optimizing processes	YES
b) Pre-treat technological wastewater	YES
c) Reduce the load level of treated wastewater	YES
5.5 Sludge from Wastewater Treatment	
a) Recycle sludge back into the process (adding to ceramic mixture)	YES
5.6 Solid Waste / Process Waste	
a) Return unmixed raw materials/materials to the process	YES
b) Return broken product (rejects) to the process – wall tiles	YES
c) Use broken product in other industries – floor tiles	YES

CONCLUSION

This paper analyzes the ceramic tile manufacturing process at the "Keramika Kanjiža" d.o.o. plant and its environmental impact based on monitoring results. The purpose of the monitoring was to review all production process activities that have or may have an impact on key environmental factors (air, water, soil). The obtained results were used to assess the compliance of emissions from the "Keramika Kanjiža" d.o.o. plant with the values prescribed by legal regulations and bylaws; for the application of the best available techniques (BAT) for preventive measures and alignment with BREF documents.

A multi-year analysis of monitoring reports from the "Keramika Kanjiža" d.o.o. facility indicates that there have been no exceedances of environmental pollution limits across all monitored environmental aspects. This positive outcome can be attributed to the effective implementation of the best available techniques (BAT). Furthermore, the consistent application and ongoing enhancement of integrated management systems, in accordance with the SRPS ISO 9001:2015 and SRPS ISO 14001:2015 standards, have played a crucial role in maintaining compliance. The "Keramika Kanjiža" d.o.o. plant adheres to all legal requirements and possesses a valid integrated permit, as confirmed by the monitoring reports.

"Keramika Kanjiža" d.o.o. plant not only meets current legal and environmental requirements but also demonstrates a proactive approach to environmental management through continuous monitoring and improvement. Maintaining compliance over multiple years confirms the effectiveness of applied BAT measures and integrated management systems.

Looking ahead, ongoing investment in technological innovation, resource efficiency, and circular economy principles could further strengthen environmental performance and resilience to future regulatory changes. These practices not only protect the environment but also enhance the company's competitiveness and reputation in both domestic and international markets.

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SRPS ISO 14001: 2015 – Environmental management systems – Requirements with guidance for use

COMPARATIVE ANALYSIS OF AMBIENT AND INDOOR AIR QUALITY AT UNIVERSITY UNION - NIKOLA TESLA: FOCUS ON $PM_{2.5}$, PM_{10} AND CO_2

Violeta Nikolić[1*], Aleksandra Milošević[2], Vladanka Presburger-Ulniković[3], Novica Staletović[4]

[1,3,4]Faculty of Ecology and Environmental Protection, University "Union-Nikola Tesla", Belgrade, Serbia

[2]Faculty of Construction Management, University "Union-Nikola Tesla", Belgrade, Serbia

[*]*corresponding author: violetanikolic22@unionnikolatesla.edu.rs*

ABSTRACT

The paper provides a comparative analysis of ambient air quality parameters and indoor air quality in the classrooms of the University of Union–Nikola Tesla, with a particular focus on the concentrations of CO_2 and PM particles. Changes in the concentrations of CO_2, $PM_{2.5}$ and PM_{10} particles in the ambient air were monitored over a 24-hour period and displayed according to air quality criteria. These parameters were then compared with the concentrations of the same parameters of indoor air, measured in the working environment (classroom) while students were present. Indoor air quality parameters were measured at different time intervals and under varying conditions (e.g., with the classroom door open or closed). The results of the measurements indicated that, regardless of whether the classroom door was open or closed, the concentration of $PM_{2.5}$ particles increased over time. Additionally, a significantly higher concentration of CO_2 was in the indoor air than in the ambient air, clearly indicating the need for improved ventilation of the working environment in the presence of a larger number of students.

Keywords: air quality, PM particles, CO_2

INTRODUCTION

Poor indoor air quality in the workplace directly affects both cognitive performance and health. Recent research indicates that the perception of air quality is not an isolated parameter but is closely linked to thermal conditions. Fanger (2006) found that even when objective parameters, such as low CO_2 concentration, fall within acceptable levels, warmer and more humid environments significantly worsen subjective air quality perceptions. This suggests that people are more likely to perceive the air as "stuffy" in warmer conditions, even if ventilation is adequate.

Thermal comfort also plays a crucial role in shaping perception and productivity. In classroom environments, elevated temperatures not only reduce thermal comfort but also increase students' sensitivity to minor air quality deficiencies, directly impacting concentration (Wargocki and Wyon, 2007). These findings are supported by professional standards such as ASHRAE Standard 55-2020, which emphasizes the need to integrate thermal and air quality parameters in indoor space design, recognizing the importance of individual tolerance to heat.

The aim of this research is to determine the levels of pollutants (CO_2, $PM_{2.5}$, PM_{10}) in classrooms and their relationship with environmental factors, such as temperature and humidity. Based on the obtained results, measures will be proposed to improve air quality, thereby enhancing student concentration, learning abilities, and overall health.

MATERIALS AND METHODS

To measure ambient air parameters, the EkoNET-AIR application was used in conjunction with the automatic IoT measuring station AQ10x, installed on the facade of the "Union - Nikola Tesla" University building (Cara Dušana 62–64, Belgrade). Measurements were conducted on january 23-24th, 2025., during typical winter conditions. Measurements of CO_2 and particulate matter (PM) concentrations in indoor air were conducted using portable digital sensors:

- Extech CO240 – a handheld indoor air quality meter equipped with a non-dispersive infrared (NDIR) sensor for CO_2, as well as sensors for temperature and relative humidity. The device allows real-time monitoring via a connected computer.
- Bosch BME680 (Bosch Sensortec) – a miniature sensor with high linearity and accuracy for detecting gases, temperature, pressure, and humidity.
- Sharp GP2Y1030AU0F – a sensor featuring a built-in infrared diode and photodiode, capable of discriminative detection of $PM_{2.5}$ and larger particles.

Before each measurement, the devices were calibrated in accordance with the manufacturer's technical specifications.

RESULTS AND DISCUSSION

Special attention during investigation was paid to changes in the concentrations of $PM_{2.5}$ and PM_{10} particles, and CO_2. The daily ambient air pollution parameters (Figure 1) indicate typical variation – an increase in urban air pollution during the day, especially in the afternoon hours due to traffic and heating system activity.

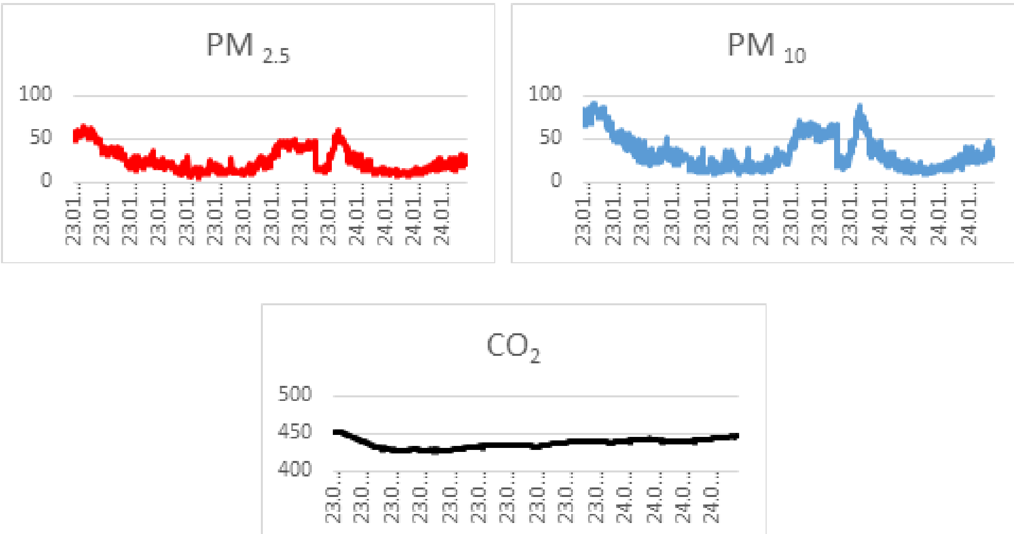

Figure 1 Concentrations of $PM_{2.5}$, PM_{10} particles and CO_2 in the ambient air over a 24-hour period

The statistical analysis of the results of ambient air quality measurements, which include meteorological parameters (temperature, pressure and relative humidity) and concentrations of certain parameters, such as CO_2, $PM_{2.5}$ and PM_{10} monitored over a 24-hour period, is shown in Table 1.

Table 1 Statistical analysis of measured ambient air parameters (over a 24-hour period)

Parameter	Temperature	Humidity	Pressure	CO_2	$PM_{2.5}$	PM_{10}
MIN	3.3	71	1023.7	426.4	7	10
MAX	12.9	99.9	1031.9	452.8	65	92
AVERAGE	8.51	91.57	1027.4	437.36	25.39	34.9
MEDIAN	8.5	99.9	1027.3	438.2	21	28

STDEV	2.74	11	2.3599	6.0417	14.022	19.6
CV	0.32	0.12	0.0023	0.0138	0.5523	0.562
CV*100	32.2	12.01	0.2297	1.3814	55.228	56.16

Meteorological parameters registered a range typical for a winter day (min/max temperature 3.3/12.9 °C). The maximum concentrations of detected pollutants, reaching: CO_2 452.8 µg/m³; $PM_{2.5}$ 65 µg/m³ and PM_{10} 92 µg/m³, due to urban pollution. These max values significantly exceed safe limits – for example, the highest measured value of PM_{10} is almost twice the permitted daily limit according to EU air quality standards of 50 µg/m³, and $PM_{2.5}$ exceeds the WHO daily criterion of 15 µg/m³ by four times.

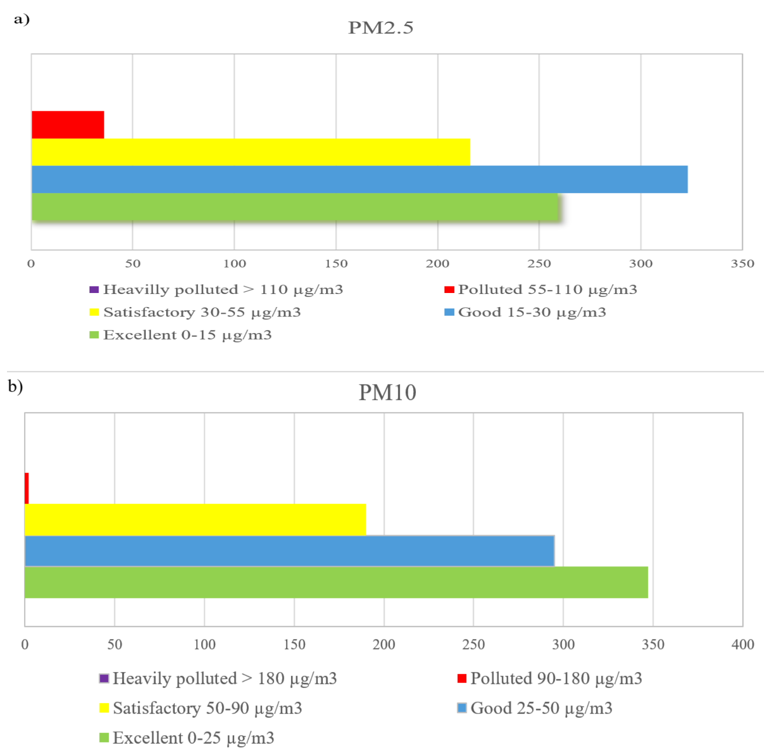

Figure 2 Values of $PM_{2.5}$ and PM_{10} parameters according to the air quality criteria

Air quality categorization is based on the concentration of individual pollutants, expressed in micrograms per cubic meter (µg/m³), with each pollutant having a separate categorization. The concentrations of $PM_{2.5}$ and PM_{10} particles in ambient air, in accordance with the air quality criteria, are shown in Figure 2. The results indicate that air quality, based on PM particle levels, is generally good to satisfactory, but occasionally reaches polluted levels. Notably, $PM_{2.5}$ concentrations exceed the permissible limit more frequently than PM_{10} concentrations.

By comparing the temperature and relative humidity of ambient and indoor air (Table 2), the following conclusions can be drawn:

- Relative humidity in the classroom is significantly lower than in ambient conditions.
- Over time, the relative humidity of indoor air (in the classroom) increases slightly.
- The temperatures of both ambient and indoor air increase slightly, regardless of whether the classroom door is open or closed. This is due to both atmospheric conditions, i.e. the increase of ambient temperature, and, and the presence of a larger number of students in the classroom in the case of indoor air.

Table 2 Comparison of ambient and *indoor air parameters*

Parameter	**Temperature (°C)**	**Relative humidity (%)**
Closed door		
Ambient	7.2	96
Indoor	21	39.59
Ambient	9.8	81
Indoor	21.8	40.98
Open door		
Ambient	10.3	82
Indoor	22.5	34.28
Ambient	11	78
Indoor	23.9	39.35

The research involved a comparative analysis of $PM_{2.5}$ and PM_{10} particle concentrations, as well as CO_2 levels, in ambient and indoor air over the same time intervals, designated as t_1 to t_4, where $t_1 < t_2 < t_3 < t_4$. Based on the diagram shown in Figure 3, the following conclusions were drawn:

- Regardless of whether the classroom door is open or closed, the concentration of $PM_{2.5}$ particles increases over time.
- When the door is closed, the concentrations of both $PM_{2.5}$ and PM_{10} are lower in the indoor air than in the ambient air, however, $PM_{2.5}$ levels indoors still increase over time.
- When the door is open, indoor concentrations of both $PM_{2.5}$ and PM_{10} also remain lower than ambient values, but both increase as time progresses.
- Therefore, even if frequent door opening reduces pollutant buildup, prolonged stay in classrooms always leads to elevated concentrations of dust and PM particles and CO_2.
- $PM_{2.5}$ concentrations reached 21 µg/m³, exceeding the WHO's recommended daily limit of 15 µg/m³, but remaining below the limits defined in national legislation (25 µg/m³ for 24 h). According to these results, indoor air quality falls into Category II for $PM_{2.5}$.
- PM_{10} concentrations were significantly lower, with maximum values around 12 µg/m³. This complies with all applicable regulations and recommendations, classifying this parameter within Category I.

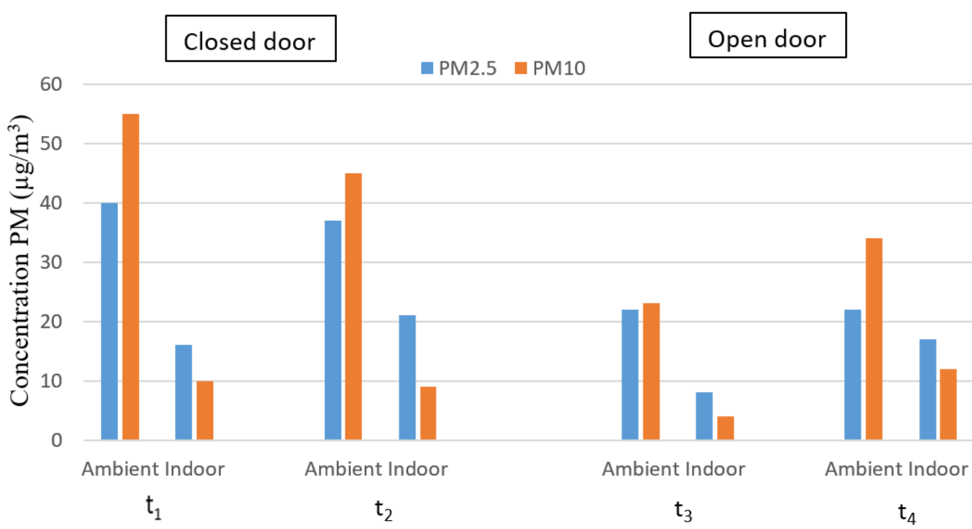

Figure 3 Concentration of PM particles in ambient and indoor air during different time intervals and ventilation conditions

When it comes to the concentration of CO_2, a significantly higher concentration of CO_2 can be observed in the indoor air than in the ambient air (Figure 4), which is a consequence of the present students' respiration.

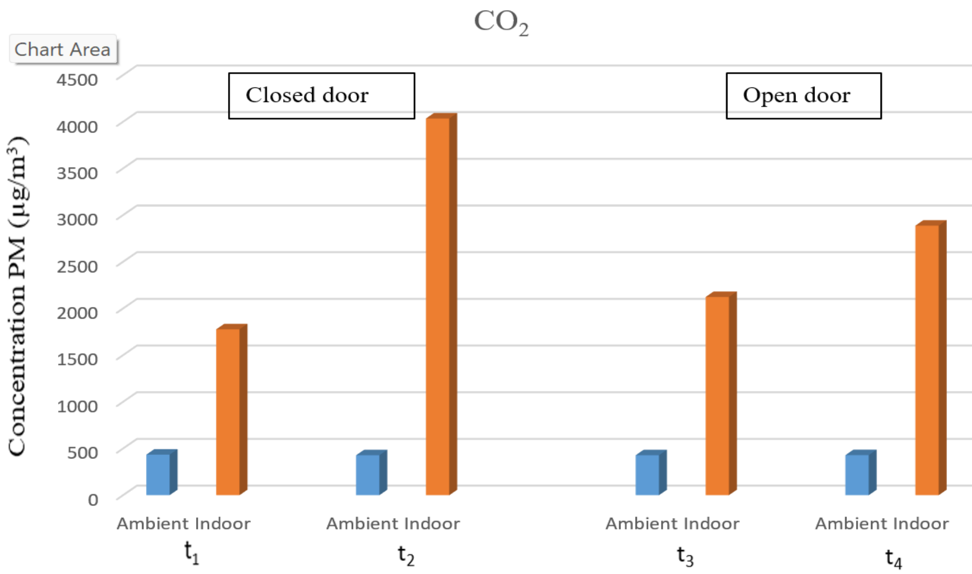

Figure 4 Comparative concentrations of CO_2 in ambient and indoor air with an analysis of the influence of ventilation

CO_2 concentrations in indoor air exceeded the 1000 ppm limit prescribed by the EN 13779 standard, indicating exposure to elevated levels of accumulated CO_2. The data also show that opening the classroom door contributes to the reduction of CO_2 concentrations, clearly indicating the need for additional ventilation, especially in the presence of a large number of students.

CONCLUSION

The research conducted a comparative analysis of $PM_{2.5}$, PM_{10}, and CO_2 concentrations in ambient and indoor air at the same time intervals in the classrooms at the University of Union–Nikola Tesla. Currently, the most significant challenge identified is classroom overcrowding, which leads to a rapid decline in air quality and negatively affects students' cognitive performance. To address this issue, the following immediate measures are recommended: limiting the number of students per classroom, as well as introducing automated window systems or mechanical ventilation, depending on the available spatial and technical capabilities.

Integrating strategies for managing both thermal comfort and air quality—such as improving ventilation, using air purifiers, and regulating indoor temperatures—can substantially improve student well-being and academic performance. The health, cognitive, and productivity benefits of improved indoor air quality (IAQ) in educational settings are significant. Implementing cleaner air solutions through automated ventilation and filtration systems, along with educating users about air quality, represents a recommended practice for the future. By prioritizing these measures, educational facilities can create healthier, more supportive learning environments for students. Future research could include long-term monitoring and the impact of implemented ventilation systems on student performance.

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OPEN RESPONSIBLE RESEARCH AND INNOVATION: OPPORTUNITIES AND CHALLENGES

Ljiljana Nikolić-Bujanović[1] , Sanja Mrazovac Kurilić[1] , Predrag Ilić[2]

[1]University "Union - Nikola Tesla", Faculty of Ecologi and Evironmental Protection, Belgrade, Serbia, [2]PSRI Institute for Protection and Ecology of the Republic of Srpska, Banja Luka, Vidovdanska 43, Banja Luka, Republic of Srpska, Bosnia and Herzegovina,

ljnikolicbujanovic@unionnikolatesla.edu.rs

Abstract:

In the context of rapid technological advancement and global connectivity, the concepts of Open Science and Open Responsible Research and Innovation (ORRI) are key elements for sustainable social and economic development. ORRI integrates principles of anticipation, inclusiveness, transparency, and ethics into research processes, enabling greater community engagement and socially beneficial outcomes. This paper explores the core principles of the ORRI approach, challenges in its implementation, and ethical dilemmas associated with open science in contemporary settings. Special attention is given to the application of ORRI principles in Serbia and Bosnia and Herzegovina through best practice examples from the University Union – Nikola Tesla (UUNT), including projects in the fields of environmental protection, education, and green technologies. The aim of the paper is to encourage broader implementation of open and responsible science, as well as knowledge exchange between academia, industry, and society.

Keywords: open science, responsible research and innovation, ORRI, scientific ethics, sustainable development, community engagement, University Union Nikola Tesla

INTRODUCTION

In a world of rapid technological change and increasing global connectivity, the concept of open science and innovation and community engagement is becoming crucial for the development of economies, businesses, and societies as a whole. Open science and innovation is an approach to scientific results and innovations in which organizations and individuals expand their activities, collaborating with partners beyond the traditional boundaries of organizations. This approach enables a faster flow of ideas and technologies, which can significantly enhance creativity, product development, and problem solving. Community engagement, on the other hand, involves the active involvement of members of local or wider communities in the innovation process, contributing to greater democratic inclusion and social progress.

Open Responsible Research and Innovation (ORRI) Open Responsible Research and Innovation (ORRI) is a process that considers the broader impacts of research and innovation, marking a paradigm shift in their conduct. Its goal is to ensure that the positive societal and economic benefits of research and innovation are fully realized, while minimizing unintended negative impacts. However, implementing ORRI often encounters significant challenges and barriers. Achieving the necessary shift in research and innovation systems is difficult, particularly when ORRI goals and principles appear to conflict with objectives deemed of higher value, importance, or urgency. Consequently, numerous resources and tools for ORRI have been developed over the past decade.

ORRI principles at a glance

The set of twelve principles is grounded in the wide array of ORRI research and practice to provide well-established ways of 'how' to do ORRI, to suggest 'what' to do, i.e. ORRI content and to illustrate 'why' to do ORRI, i.e. ORRI rationale and motivation. They have been developed into a holistic guide for addressing concrete challenges and needs of ORRI practitioners to support ORRI practices in a variety of settings: (https://www.reinforcing.eu/project-resources)

1. ORRI requires the anticipatory, adaptive, and inclusive governance of research and innovation to steer them towards socially desirable ends.

2. ORRI ensures that societal goals such as equality, diversity & inclusion, safety & security, social cohesion & sustainability are pursued and practised in R&I organisations and processes.

3. ORRI recognises the importance of innovation ecosystems and requires a multi- stakeholder commitment by all actors in the quadruple helix (academia, government, business/industry, society) to ensure that all relevant perspectives as well as types and levels of expertise and experience are represented and considered in innovation processes.

4. ORRI involves the anticipation of future trends, developments and challenges and the strategic adaptation of current activities, thereby fostering reflexivity and mutual responsiveness between society, policy, research, and development.

5. ORRI aims to overcome market deficits by fostering transformative change required by the SDGs and reflecting the fact that developed and developing countries are unequally benefitting from scientific-technological advancements.

6. ORRI makes a distinct effort to broaden representation and participation, thus seeking to integrate and address the needs and views of vulnerable or marginalized groups in innovation processes.

7. ORRI needs indicators and procedures towards transformative change which strengthen individual & organisational agency (the ability to act), legitimacy and accountability to become institutionalized, i.e., integrated in organisational structures.

8. ORRI takes an experimental approach to innovation based on organizational learning, cocreation, and co-design (e.g., in Living Labs) and to the adaptation of social norms and needs, rules and regulation as well as institutions and infrastructures.

9. ORRI follows a holistic approach taking into account the interconnected factors influencing the development, use and impact of innovations (including unintended negative effects).

10. ORRI is based on the values of openness to and mutual responsiveness among all parties involved and, therefore, calls for open science, open innovation, and transparency.

11. ORRI requires institutional structures for the ethical conduct of all activities, the integrity of all parties involved and adherence to fundamental ethical standards, such as human rights and the precautionary principle.

12. ORRI relies on an informed, open-minded, and engaged citizenry, which requires quality science education from an early age on and across all social and professional groups, fostering curiosity and science literacy as enablers of public engagement and active science citizenship.

Open Science in Serbija end word

In Serbia, open science has been in focus in recent years, especially through alignment with European initiatives. Key activities and regulations include:

1. National strategy of open science (http://www.open.ac.rs/)

Serbia adopted the Open Science Policy in 2018, which requires the results of publicly funded research to be publicly available. In 2023, the Action Plan for the Implementation of Open Science was launched, which sets guidelines for the development of infrastructure and the education of researchers.

2. Digital repositories and archives exist such as NaRDuS - National Repository of Doctoral Dissertations and Scientific Papers (https://nardus.mpn.gov.rs/) as well as Phaidon - Digital Platform for Archiving and Access to Scientific Data. Also, University Repositories - University of Belgrade, Novi Sad and Niš have developed their own archives for storing scientific works.

3. Cooperation with European projects - OpenAIRE – Serbia is part of this pan-European network for open access to scientific works and data (https://www.openaire.eu/). EOSC (European Open Science Cloud) also includes Serbia in the European cloud of open science (European Open Science Cloud (EOSC) https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/our-digital-future/open-science/european-open-science-cloud-eosc_en). New EU research projects - Horizon Europe, in which Serbian researchers participate, require open access to research results.

The EU otherwise strongly supports open science through initiatives such as:

-Plan S – A policy that requires all publicly funded scientific work to be immediately and openly available.

-Open Research Europe - Free platform for publishing scientific papers with open access.

-FAIR principles - Standards for open data (Findable, Accessible, Interoperable, Reusable).

In the United States NIH (National Institutes of Health) - Requires open access to data and publications while OSTP Memorandum (2022) - American federal agencies must ensure free access to publicly funded scientific publications.

China and other countries are investing in open databases and cooperation with international initiatives. India is developing national repositories. Africa and Latin America are working to advance digital archives and open scholarly networks.

The goal of this paper is to draw attention to the principles of open science, which brings numerous advantages - it accelerates research, increases the visibility of scientists and reduces unnecessary costs, but also numerous challenges. In addition, the goal is to show examples of good practice of University Union-Nikola Tesla (UUNT), as the holder of the project "Sustainable Development through Responsible Research: Strengthening ORRI in Serbia and Bosnia and Herzegovina" (SuDe2Re) within the REINFORCING Grantee, through the application of ORRI principles in examples of implemented projects.

CHALLENGES AND ETHICAL PRINCIPLES IN THE APPLICATION OF OPEN SCIENCE

The ORRI (Open, Reproducible, Responsible, Inclusive) principles in science require that research be open, reproducible, accountable, and inclusive. Although these principles have the potential to improve scientific practice and its social impact, their implementation in the natural sciences faces a number of challenges:

1. Open Science and access to data

✅ Challenges:

- Financial and infrastructural barriers to establishing open data repositories.
- Protection of intellectual property and patent rights.
- Balance between open access and security of sensitive data (e.g. biomedical research).

✅ Ways to achieve compliance:

- Establishment of open scientific platforms and datasets (e.g. Zenodo, OpenAIRE).
- •Encouraging journals to embrace open access.
- Development of policies that regulate data sharing while protecting privacy.

2. Reproducible Science and the reliability of results

✅ Challenges:

- Low reproducibility rates in some disciplines.

- Pressure on researchers to publish new results rather than confirm existing ones.
- Lack of detailed documentation of research methodology.

✅ Ways to align:

- Promotion of pre-registration of research.
- Mandatory sharing of codes and methods in research publications.
- Financial incentives for replication studies.

3. Responsible Science and ethical dilemmas

✅ Challenges:

- Dealing with the bioethical and environmental consequences of research.
- Manipulation of data to obtain "desired" results.
- Political and corporate influence on research agendas.

✅ Ways to align:

- Establish independent ethics committees to oversee research.
- Transparent funding of projects without conflicts of interest.
- Promotion of responsible communication of science to the public.

4. Inclusive Science and social impact

✅ Challenges:

- Unequal access to research funding between developed and underdeveloped countries.
- Gender and cultural barriers in the scientific community.
- Limited collaboration with local communities that are directly affected by scientific results.

✅ Ways to align:

- Policies that encourage equal opportunities for researchers of all backgrounds.
- Collaboration with local communities in developing sustainable solutions.
- Public discussions and scientific literacy as part of university programs.

THE ROLE OF UNIVERSITIES IN PROMOTING RESPONSIBLE SCIENCE

Universities play a key role in promoting responsible science through education, research and social engagement. Responsible science involves ethical research, transparency, inclusiveness and sustainability, and universities can contribute to its development in several ways:

1. Ethical education and academic integrity

Universities should promote academic integrity through curricula that incorporate ethical principles in science.

Students and researchers must be trained to recognize and avoid scientific fraud, plagiarism and data manipulation.

2. Supporting open and reproducible science

Universities can promote open access to research, including free access to scientific publications (open access).

Encouraging the reproducibility of research ensures that scientific results are verifiable and reliable.

3. Interdisciplinary approach and collaboration

Connecting different scientific fields enables a holistic approach to solving global challenges such as climate change, health crises and technological ethics.

Collaboration with industry, government and the civil sector contributes to the application of scientific results for socially beneficial purposes.

4. Social responsibility and sustainability

Universities should encourage the development of research that has a positive impact on society, taking into account economic, social and environmental aspects.

Promotion of sustainable technologies and environmentally friendly practices in scientific research.

5. Scientific integrity policies and regulations

Establishment of ethics committees and mechanisms for monitoring scientific research.

Combating bias in research and corruption in the financing of science.

Universities, as centers of knowledge, have a duty to shape science in a responsible manner, contributing to both the academic community and the wider society.

The relationship between academia and industry also plays a key role in fostering sustainable development, as both parties contribute to innovations, technologies and policy strategies that impact the economy, society and the environment. Their cooperation can lead to sustainable solutions that are both scientifically sound and commercially viable. Academia emerges as a source of knowledge and innovation, and industry as a catalyst for the implementation and acceleration of change. Key areas of cooperation are:

✅ Green energy and technologies - development of renewable energy sources, efficient batteries and smart grids.

✅ Circular economy - waste reduction, recycling and resource optimization.

✅ Sustainable agriculture - biotechnology, ecological breeding models and biodiversity conservation.

✅ Green construction and urban development - energy-efficient materials and smart cities.

While there are challenges and ethical dilemmas in this collaboration:

Conflict of interest – the danger of subordinating academic research to industry profits.

Transparency and open science – it is important to ensure that research remains independent and accessible to the wider community.

Long-term focus – industry often strives for quick profits, while scientific research requires time for development.

As models of successful collaboration so far, the following can be mentioned:

- Public and private partnership initiatives.
- Incubators and technology parks linked to universities.
- Joint research projects and knowledge exchange programs.
- University laboratories in cooperation with industrial companies.

EXAMPLES OF OPEN SCIENCE AT UUNT

As part of the scientific research work at UUNT, through several projects, the principles of open science and innovation were applied and promoted.

The project "*Monitoring of the impact of works on the construction site on air quality using IoT technologies, in the territory of the City of Novi Sad*", of the City Administration for Zhs Novi Sad with the participation of UUNT, is an example of cooperation between administration, business and science through the application of scientific results in the improvement of work in this case at the construction site of the city of Novi Sad. Using IoT technology, the concentration of polluting gases and particles during various activities on the construction site was monitored, including meteorological conditions as an important parameter. In this way, on the basis of our scientific results, it was possible to plan works on the construction site with a minimal impact of pollution on the construction site workers.

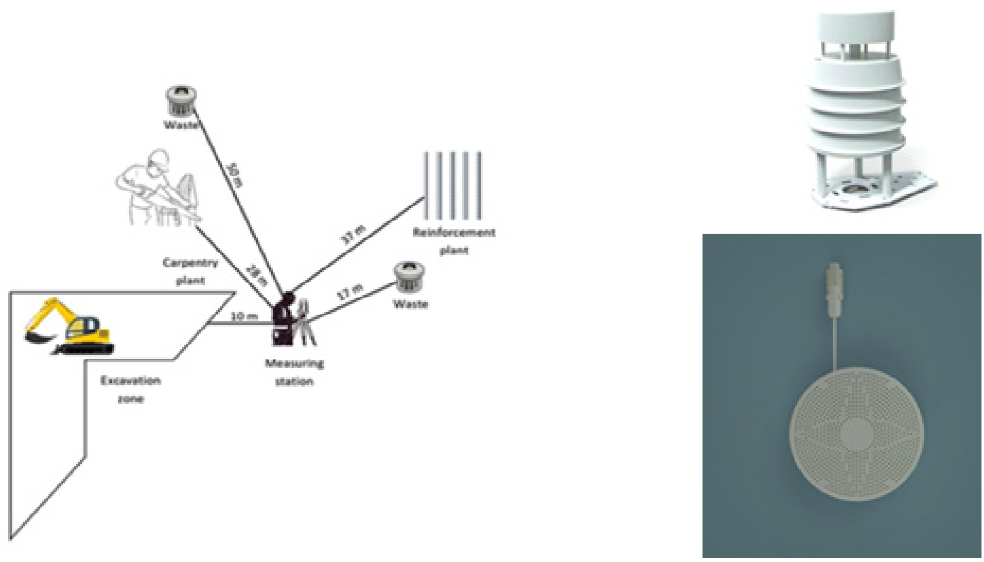

Fig1. *Scheme of pollution measurement at the construction site with IoT technology*

The DeepGreenInno, Horizon Europe, EIT Raw Materials project with the participation of over eight research and higher education institutions (UNIBL, ICBL, UUNT, IUS, POLIS, CNR, InnoGreece, UNIRuse) and two associated members (University of NS and Science and Technology Park NS) had the main task of strengthening the consortium's expert network, in order to provide an opportunity for the most promising students to come together with large businessmen and entrepreneurs from small and medium-sized enterprises for the exchange of knowledge. The project supported the development of high-quality training through workshops in the field of environmentally friendly industrial materials innovations, as well as the introduction of the principles of "green" innovations with an increasing role of "deep technology". In parallel with understanding the deep technological dimension of "green materials technologies", the innovative potential in this area was promoted among young people through training and mentoring and encouraged them to seek self-employment in startups or to consider seeking green solutions in companies where they are already employed.

The RisBriefcase project, Horizon Europe, EIT RMTask, in which UUNT was a participant, aimed to transfer knowledge to the youngest population, elementary school students, about the wealth of mineral resources on the territory of Serbia, as well as how technological processes from raw materials to finished products that we all use.

Fig2. Workshop "KNOWLEDGE CASE"

The project "*Long-term and seasonal variations in the concentrations of major pollutants in the air at selected air quality monitoring stations in Serbia"* funded by UUNT, provided insight into air quality through web and mobile applications, using the AK10k device. Recording of changes in meteorological parameters (P, T, RH), changes in the concentration of gases in the atmosphere (CO, CO_2, SO_2, NO, NO_2, O_3), as well as changes in the concentration of PM particles (PM1, PM2.5 and PM10) in real time, enabling data visualization (map, list, graph), notifications/alarms when values are outside the defined range, data processing algorithms, export to CSV file (RAV, calibrated values, time, GPS...). Through the SuDe2Re ORRI project within the REINFORCING Grantee, these data will be open to the general public.

Fig 3. Device AK10k

CONCLUSION

Open innovation and community engagement are powerful tools for achieving a more inclusive and dynamic innovation process. Although they bring numerous opportunities, such as faster development, cost reduction and greater social responsibility, they also pose numerous challenges, especially in the areas of intellectual property protection, coordination, and maintaining motivation. The successful implementation of open innovation depends on the willingness of organizations to embrace new collaboration models and develop effective management strategies, which will ultimately enable sustainable progress and a positive impact on the wider society.

Otvorena nauka donosi brojne prednosti – ubrzava istraživanja, povećava vidljivost naučnika i smanjuje nepotrebne troškove. Iako postoje izazovi, trend otvorene nauke postaje standard u globalnom istraživačkom prostoru. Srbija ide u korak sa ovim trendovima, ali su potrebni dodatni napori kako bi se osiguralo potpuno usvajanje otvorene nauke u svim naučnim disciplinama. Etika otvorene nauke osigurava da naučna istraživanja budu poštena, dostupna i korisna za celo društvo. Primena ovih principa omogućava veće poverenje u nauku, efikasniju razmenu znanja i brži napredak u svim naučnim disciplinama.

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https://www.reinforcing.eu/

https://www.reinforcing.eu/project-resources

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National Repository of Dissertations in Serbia https://nardus.mpn.gov.rs/

CHEMICALLY ACTIVATED BIOCHAR FROM IQOS RESIDUES AS AN EFFICIENT ADSORBENT FOR DICLOFENAC REMOVAL FROM WATER

Hadi Waisi [1, 4*], Miloš Marinković [1], **Zoran Sekulić[2], Marko Milojković[3], Sanja Krstić[1], Martina Waisi[4], Aleksandar Janićijević[1]**

[1]Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[2] Institute of Public Health of Belgrade, Bulevar Despota Stefana 54a, 11108 Belgrade, Serbia

[3]Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade

[4]Faculty of Ecology and Environmental Protection, University UNION-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

*hadiwaisi@yahoo.com

ABSTRACT

This study investigates the preparation of activated carbons from IQOS electronic cigarette residues, through carbonization and subsequent chemical activation with KOH, H_3PO_4 and H_2SO_4. The obtained adsorbents were characterized by BET and BJH analyses to determine surface area and pore distribution. Adsorption experiments were conducted using diclofenac sodium as a model pharmaceutical pollutant in water. Results demonstrated that KOH-activated carbon achieved the highest surface area (1420 m²/g) and adsorption efficiency (98.7%), followed by H_3PO_4-activated (92.4%) and H_2SO_4-activated (78.6%) carbons. The study highlights the potential of IQOS residues as a sustainable precursor for the production of activated carbon, offering a circular economy solution for waste valorization and effective removal of emerging contaminants from water.

Keywords: Activated carbon; Biochar; Diclofenac; Adsorption; IQOS waste; Water treatment

INTRODUCTION

Over the past decade, the issue of emerging contaminants in aquatic environments has gained major attention due to their persistence, bioaccumulation, and adverse impacts on ecosystems and human health (aus der Beek et al., 2016). Pharmaceuticals are particularly critical because they are continuously released, incompletely removed in wastewater treatment, and may promote antimicrobial resistance (Kümmerer, 2009). Diclofenac, a widely used NSAID, is among the most frequently detected pharmaceuticals in waters, occurring at ng/L–µg/L levels (Vieno et al., 2005). Owing to its recalcitrant structure, it resists biological degradation and causes ecotoxicological effects such as kidney impairment in fish, reduced survival of invertebrates, and possible endocrine disruption (Triebskorn et al., 2004; Schwaiger et al., 2004). In recognition of these risks, the European Union placed diclofenac on its watch list of priority substances in 2013 (European Commission, 2013).

Conventional removal technologies, including advanced oxidation processes like ozonation, photocatalysis, and Fenton reactions, achieve high efficiency but demand significant energy, costly reagents, and may generate harmful by-products (Poyatos et al., 2010). In contrast, adsorption offers simplicity and scalability of adsorbents (Crini & Lichtfouse, 2019). Activated carbon remains the most widely used adsorbent due to its large surface area and stability, but traditional production from coal or wood biomass raises sustainability concerns, stimulating research into waste-derived precursors (Lua & Yang, 2004).

Cigarette butts have recently been studied as precursors for activated carbon because of their cellulose acetate content, nicotine residues, and abundance (Moerman & Potts, 2011; Parker & Raynor, 2017). Yet the environmental burden of electronic cigarette products like IQOS has been overlooked, despite their polymeric and organic-rich residues (Auer et al., 2017). Controlled thermal treatment of IQOS sticks yields porous carbon with high surface area and microporosity, representing a circular economy strategy for waste valorization (Waisi et al., 2023).

This study investigates the conversion of IQOS residues into activated carbon through optimized carbonization and activation. The resulting carbon exhibited high surface area, developed microporosity, and abundant functional groups, all favorable for adsorbing organic pollutants (Marsh & Reinoso, 2006; Bandosz, 2006). Diclofenac was chosen as a model pollutant due to its persistence, ecological relevance, and regulatory importance (Ratola et al., 2012). The research aims to demonstrate both the feasibility of valorizing IQOS residues and their potential for diclofenac removal, contributing to sustainable waste management and advanced materials for environmental remediation in line with green chemistry and circular economy principles (Crini et al., 2019).

MATERIALS AND METHODS

Preparation of biochar from IQOS residues

Residues from IQOS electronic cigarettes were collected, dried at 105 °C for 24 h, and carbonized in a tubular furnace (Carbolite, UK) under nitrogen atmosphere. The heating rate was set to 10 $°C \cdot min^{-1}$, with a final temperature of 600 °C maintained for 2 h. The obtained carbonaceous solid, hereafter referred to as biochar, was ground and sieved to <200 µm for further treatment (Waisi et al., 2023).

Chemical activation procedures

Three activation strategies were applied in order to enhance the porosity and surface chemistry of the biochar:

1. KOH activation: modified Biochar was mixed with KOH solution (1:3, w/w), dried at 110 °C, and calcined at 750 °C for 1 h under N_2. The product was repeatedly washed with 0.1 M HCl and deionized water until neutral pH, then dried (Lua & Yang, 2004).
2. H_3PO_4 modified activation: Biochar was impregnated with 85 wt.% H_3PO_4 (1:2, w/w) at 60 °C for 6 h, dried at 105 °C, and subsequently heated to 500 °C under N_2 atmosphere for 2 h. Samples were washed until neutral and dried (Ngamcharussrivichai et al., 2008).
3. H_2SO_4 modified activation: Biochar was treated with concentrated H_2SO_4 (98 wt.%, 1:1, w/w) at room temperature for 4 h, dried, and calcined at 450 °C under N_2. After repeated washing with deionized water, the sample was dried at 110 °C (Yang & Xie, 2007).

The resulting activated carbons were labeled AC–KOH, AC–H_3PO_4, and AC–H_2SO_4.

Characterization

N_2 adsorption–desorption isotherms were obtained at –196 °C on a Micromeritics ASAP 2020 analyzer. Samples were degassed at 200 °C for 12 h prior to analysis. Specific surface area was determined by the Brunauer–Emmett–Teller (BET) method (Brunauer et al., 1938), while pore size distribution was obtained using the Barrett–Joyner–Halenda (BJH) model (Barrett et al., 1951).

Adsorption experiments for diclofenac removal

Diclofenac sodium salt (≥99%, Sigma–Aldrich) was selected as a model contaminant. A stock solution (1000 mg·L^{-1}) was prepared in deionized water, and working solutions of 10–50 mg·L^{-1} were freshly diluted before experiments. Batch adsorption tests were conducted in 250 mL Erlenmeyer flasks with 100 mL diclofenac solution and 0.1 g of adsorbent (biochar, AC–KOH, AC–H_3PO_4, AC–H_2SO_4). Suspensions were shaken at 150 rpm at 25 ± 1 °C. At predetermined intervals (0–300 min), samples were withdrawn, filtered (0.45 µm), and analyzed.

Residual diclofenac concentrations were measured using UV–Vis spectrophotometer (Shimadzu UV-1800) at λmax = 276 nm (Crini & Lichtfouse, 2019). Adsorption capacity was calculated according to the standard equation.

RESULTS AND DISCUSSION

Textural properties of biochar and activated carbons

The BET analysis revealed pronounced differences in surface area and porosity between raw biochar and chemically activated carbons (Table 1). The specific surface area of untreated biochar was only 185 m²/g, while KOH activation increased it more than sevenfold (1420 m²/g), confirming the efficiency of alkaline activation in pore generation. Phosphoric acid activation also resulted in a high surface area (980 m²/g), while sulfuric acid was less effective (610 m²/g). These results are consistent with previous reports indicating that KOH generates abundant micropores through redox reactions with the carbon matrix (Lua & Yang, 2004), whereas H_3PO_4 promotes cross-linking and partial mesoporosity development (Ngamcharussrivichai et al., 2008).

Table 1. BET surface area and pore characteristics

Sample	BET surface area (m²/g)	Total pore volume (cm³/g)	Average pore diameter (nm)
Biochar	185	0.12	2.6
AC–KOH	1420	0.92	2.4
AC–H_3PO_4	980	0.68	2.8
AC–H_2SO_4	610	0.41	2.7

Pore size distribution

The BJH analysis (Table 2) showed that the contribution of micropores and mesopores varied depending on the activating agent. KOH-activated carbon displayed the highest micropore fraction (78.3%), which is favorable for adsorption of small organic molecules such as diclofenac. In contrast, H_3PO_4 activation yielded a balanced distribution of micropores (64.7%) and mesopores, improving accessibility for larger molecules. The H_2SO_4-activated sample exhibited the lowest micropore fraction, reflecting partial pore blockage due to surface sulfonation reactions (Yang & Xie, 2007).

Table 2. Micropore vs. mesopore distribution

Sample	Micropore volume (cm^3/g)	Mesopore volume (cm^3/g)	Micropore fraction (%)
Biochar	0.06	0.06	50.0
AC–KOH	0.72	0.20	78.3
AC–H_3PO_4	0.44	0.24	64.7
AC–H_2SO_4	0.25	0.16	60.9

Diclofenac adsorption

Adsorption experiments demonstrated a clear correlation between surface characteristics and pollutant removal efficiency. As shown in Table 3, raw biochar exhibited limited adsorption of diclofenac (46.2%, q_e = 9.2 mg/g), reflecting its low surface area. In contrast, AC–KOH achieved almost complete removal (98.7%, q_e = 19.7 mg/g), while AC–H_3PO_4 also showed high efficiency (92.4%, q_e = 18.5 mg/g). AC–H_2SO_4 was less effective (78.6%, q_e = 15.7 mg/g), consistent with its lower surface area and partial pore blockage. The superior performance of AC–KOH is attributed to its high microporosity and surface basicity, which enhance π–π interactions and electrostatic adsorption of diclofenac molecules (Bandosz, 2006).

Table 3. Diclofenac removal efficiency

Sample	Removal efficiency (%)	Adsorption capacity q_e ($mg \cdot g^{-1}$)
Biochar	46.2	9.2
AC–KOH	98.7	19.7

Sample	**Removal efficiency (%)**	**Adsorption capacity q_e ($mg \cdot g^{-1}$)**
AC–H_3PO_4	92.4	18.5
AC–H_2SO_4	78.6	15.7

CONCLUSION

In this study, waste residues from IQOS electronic cigarettes were successfully transformed into biochar and subsequently activated using three different chemical methods (KOH, H_3PO_4 and H_2SO_4). The obtained activated carbons exhibited markedly improved textural properties compared to raw biochar, as evidenced by BET and BJH analyses. Among the tested samples, KOH activation provided the highest surface area (1420 m^2/g) and micropore fraction (78.3%), which directly correlated with superior adsorption performance.

Adsorption experiments using diclofenac as a model pharmaceutical pollutant confirmed the significant advantage of chemically activated carbons over untreated biochar. The AC–KOH achieved almost complete diclofenac removal (98.7%) under relatively mild batch conditions, while AC–H_3PO_4 and AC–H_2SO_4 also showed promising activity (92.4% and 78.6%, respectively).

The results indicate that IQOS residues represent a valuable precursor for the production of sustainable activated carbons within the circular economy framework. The high adsorption efficiency toward diclofenac, combined with good regeneration potential, suggests that AC–KOH and AC–H_3PO_4 are particularly promising candidates for application in water treatment technologies. This approach not only mitigates the environmental burden of electronic cigarette waste but also provides an innovative solution for addressing pharmaceutical pollution in aquatic ecosystems.

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FECAL BACTERIA AS INDICATORS OF SOIL SANITARY STATUS

Hadi Waisi [1, 4*], Miloš Marinković [1], **Zoran Sekulić[2], Marko Milojković[3], Stevan Blagojević[1], Martina Waisi[4], Aleksandar Janaćković[1]**

[1]Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[2] Institute of Public Health of Belgrade, Bulevar Despota Stefana 54a, 11108 Belgrade, Serbia

[3]Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade

[4]Faculty of Ecology and Environmental Protection, University UNION-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

*hadiwaisi@yahoo.com

ABSTRACT

The presence of fecal bacteria in soils is a critical indicator of sanitary conditions and potential public health risks, particularly in areas impacted by human activity. This study aimed to quantify the abundance of *Escherichia coli* and *Enterococcus spp.* in soils from urban parks, conventionally managed agricultural fields with manure, organically managed agricultural fields without manure, rural untouched areas, and sites near illegal dumps. Soil samples were collected from 0–10 cm depth and analyzed using standard microbiological methods, including serial dilutions and selective media. Results showed significantly higher bacterial concentrations in urban and manure-amended soils, as well as in soils near dumpsites, compared to control rural soils. The findings demonstrate a clear link between anthropogenic impact, waste management practices, and microbial soil contamination. Moreover, the persistence of *E. coli* in certain soils suggests its limited reliability as an indicator of recent fecal input, highlighting the importance of combining multiple indicators. This study emphasizes the necessity of regular soil microbiological monitoring to protect both environmental quality and public health.

Keywords: Fecal indicator bacteria, *Escherichia coli*, *Enterococcus spp.*, Soil contamination, Microbiological monitoring

INTRODUCTION

Soil is a complex ecosystem that plays a key role in maintaining ecological balance, agricultural productivity, and human health. Although often perceived as inert, it is a dynamic medium rich in microorganisms that directly or indirectly influence plants, animals, water, and air quality. The presence of pathogenic and indicator bacteria, especially of fecal origin, is increasingly used as a relevant parameter for assessing sanitary soil quality (Gerba & Smith, 2005; Davis et al., 2022).

Fecal bacteria such as *Escherichia coli* and *Enterococcus spp*. are traditionally used as indicators of water and food contamination. Their application in soil quality assessment is gaining importance, particularly in urban/peri-urban environments and intensively farmed soils where manure or inadequately treated waste is frequently applied (Stević et al., 2014; López-Gálvez et al., 2023). High concentrations may point to the presence of pathogens as well as poor management of wastewater, fertilizers, or septic systems (Rahman et al., 2018).

Although *E. coli* is often regarded as an indicator of recent fecal pollution, growing evidence shows that some strains can persist for extended periods in soil and even become part of the indigenous microflora (Ishii & Sadowsky, 2008; Park et al., 2016). This raises questions about its reliability as a sole indicator and highlights the value of combining different indicator organisms for more accurate sanitary risk assessment.

MATERIALS AND METHODS

Sampling locations

Soil samples were collected from five locations in the wider area of Belgrade (Serbia), representing different types of land use and anthropogenic impact:

- L1 (Urban soil): Tašmajdan park (44.812°N, 20.470°E), located in the city center and characterized by intensive human activity and potential sewage impact.
- L2 (Conventional agricultural soil with manure): Agricultural fields near Obrenovac (44.654°N, 20.209°E), regularly fertilized with livestock manure.
- L3 (Organic agricultural soil without manure): Fields in the vicinity of Barajevo (44.608°N, 20.418°E), managed under organic farming practices without manure application.

- L4 (Rural control soil): Forested area on Avala mountain (44.678°N, 20.517°E), representing minimally impacted soil with negligible anthropogenic influence.
- L5 (Soil near an illegal dumpsite): Peri-urban area in Krnjača (44.862°N, 20.467°E), located in the vicinity of an unmanaged waste disposal site.

At each site, five composite soil samples were collected from a depth of 0–10 cm using sterile tools, stored in sterile containers, and transported to the laboratory at 4 °C for analysis within 6 h.

Sample preparation and dilutions

From each sample, 10 g of soil were suspended in 90 mL sterile saline (0.85 % NaCl, pH 7.0 ± 0.1) and homogenized for 5 min. Serial 10-fold dilutions (10^{-1}–10^{-6}) were prepared, and 1 mL aliquots were used for plating.

Plating and selective media

- MacConkey agar: for coliforms including *E. coli* (incubation 37 °C, 24–48 h).
- Slanetz–Bartley agar: for *Enterococcus* spp. (37 °C, 48 h).

Spread-plate technique was applied in duplicate.

Identification and confirmation

Colonies were enumerated and expressed as CFU/g dry soil. Confirmation included:

- *E. coli*: β-glucuronidase (MUG) fluorescence, indole test, IMViC profile; additional reference incubation on mFC agar (44.5 °C).
- *Enterococcus* spp.: bile-esculin hydrolysis at 44 °C and growth in 6.5 % NaCl.

Only plates with 30–300 colonies were used for calculations.

Soil physico-chemical parameters

- pH (electrometric)
- Moisture (105 °C drying to constant weight)
- Organic matter (loss-on-ignition at 550 °C)

Statistical analysis

Data were expressed as mean ± SD (n=5). Counts were log10(CFU+1)-transformed. Normality (Shapiro–Wilk) and homogeneity (Levene) were confirmed. One-way ANOVA followed by Tukey HSD was used ($p<0.05$). Pearson correlation tested associations between bacteria counts and soil parameters.

RESULTS AND DISCUSSION

The results of microbiological analyses are summarized in Table 1, showing the abundance of *E. coli* and *Enterococcus spp.* across the investigated soils. The highest contamination was observed at the conventional agricultural soil treated with manure (L2: 2.8×10^4 CFU/g *E. coli*, 2.1×10^4 CFU/g enterococci) and at the site near the dumpsite (L5: 3.1×10^4 CFU/g *E. coli*, 2.9×10^4 CFU/g enterococci). In contrast, the rural control site (L4) exhibited very low values (1.1×10^2 CFU/g and 9.0×10^1 CFU/g), which confirms the absence of anthropogenic impact. Urban soil (L1) showed intermediate contamination, reflecting the influence of human activities in public areas, while organically managed soil (L3) contained fewer bacteria than the conventionally fertilized soil, highlighting the effect of manure application on microbial contamination levels.

Table 1. Abundance of fecal indicator bacteria in soils (log10 CFU/g, mean ± SD, n=5)

Location	*E. coli*	*Enterococcus spp.*
L1 Urban	4.08 ± 0.25	3.98 ± 0.21
L2 Conventional (manure)	4.45 ± 0.31	4.32 ± 0.29
L3 Organic	3.54 ± 0.19	3.46 ± 0.17
L4 Rural (control)	2.04 ± 0.08	1.95 ± 0.07
L5 Dumpsite	4.49 ± 0.27	4.46 ± 0.30

The observed trends correspond closely with the physical–chemical properties presented in Table 2. Soils with higher moisture and organic matter, particularly L2 and L5, supported the largest bacterial populations. Statistical analysis confirmed a significant positive correlation between organic matter and bacterial abundance (r = 0.78 for *E. coli*; r = 0.83 for *Enterococcus spp.*, $p < 0.05$). These findings are in line with earlier studies that identified organic matter and humidity as key factors in supporting bacterial persistence (Park & LaPara, 2010; Rahman et al., 2018).

Table 2. Soil physico-chemical parameters

Location	**pH**	**Moisture (%)**	**Organic matter (%)**
L1 Urban	6.7	22.5	5.3
L2 Conventional	6.4	25.0	6.1
L3 Organic	7.1	18.7	4.5
L4 Rural	7.3	15.0	3.2
L5 Dumpsite	6.1	28.4	7.0

It is noteworthy that *E. coli*, traditionally considered a marker of fresh fecal contamination, was also present at elevated levels in soils with older organic deposits, such as L5. This suggests its capacity for prolonged survival and adaptation to soil conditions, as previously reported (Ishii & Sadowsky, 2008; Thompson et al., 2009). Consequently, relying solely on *E. coli* as an indicator could underestimate the complexity of contamination sources. The combined use of *E. coli* and *Enterococcus spp.* provides a more accurate reflection of sanitary risks, as enterococci have demonstrated higher persistence in diverse soil environments (Byappanahalli et al., 2012).

CONCLUSION

This research confirmed that fecal bacteria, particularly *E. coli* and *Enterococcus spp.*, are effective indicators of soil sanitary status. Their abundance closely correlated with anthropogenic pressures, including manure application and waste disposal, as well as with soil physico-chemical properties such as moisture and organic matter. The highest contamination levels were observed at conventionally fertilized fields and dumpsites, while rural control soils exhibited minimal bacterial presence. The results underline the need for systematic microbiological monitoring of soils, especially in agricultural and urban environments, to mitigate potential health risks and to ensure safer environmental management practices.

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PREPARATION AND CHARACTERIZATION OF ACTIVATED CARBON DERIVED FROM VINEYARD PEACH STONES

Hadi Waisi [1, 4*], Miloš Marinković [1], Zoran Sekulić[2], Marko Milojković[3], Aleksandra Radulović[1], Martina Waisi[4], Aleksandar Janićijević[1]

[1]Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[2] Institute of Public Health of Belgrade, Bulevar Despota Stefana 54a, 11108 Belgrade, Serbia

[3]Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade

[4]Faculty of Ecology and Environmental Protection, University UNION-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

*hadiwaisi@yahoo.com

ABSTRACT

This study explores the valorization of vineyard peach (Prunus persica var. *vinogradarska*) stones as a renewable precursor for the production of high-performance activated carbon. The raw stones were subjected to controlled carbonization, followed by chemical activation using potassium hydroxide (KOH). The resulting materials were characterized by Brunauer–Emmett–Teller (BET) surface area analysis, Barrett–Joyner–Halenda (BJH) pore size distribution, and Scanning Electron Microscopy (SEM). The biochar obtained after carbonization exhibited a specific surface area of 420 m^2/g, which increased significantly to 2380 m^2/g after KOH activation, accompanied by the development of a predominantly microporous structure. SEM micrographs revealed a marked transformation of the surface morphology, with the emergence of a highly porous network characteristic of chemically activated carbons. These findings highlight the suitability of vineyard peach stones as an agro-industrial residue that can be effectively transformed into advanced porous materials. The prepared activated carbon shows promising potential for adsorption-based applications in environmental remediation, thereby contributing to sustainable waste management and circular economy strategies.

Keywords: Peach stone; Activated carbon; Biochar; Adsorption; Waste valorization

INTRODUCTION

In recent years, the valorization of agro-industrial residues for the production of advanced functional materials such as activated carbons has gained increasing scientific and technological relevance. Agricultural by-products are generated in large quantities worldwide and, if not properly managed, pose disposal and environmental challenges (Ioannidou & Zabaniotou, 2007). Lignocellulosic wastes—including fruit stones, nutshells, and seed shells—are particularly promising due to their high carbon content and rigid structure, which can be efficiently transformed into porous carbons through carbonization and activation (Demirbas, 2008; Ahiduzzaman & Sadrul Islam, 2016). Their conversion into high-value adsorbents provides a sustainable alternative aligned with circular economy principles (González-García, 2018).

Fruit stones such as those from peach, apricot, and olive have already been identified as suitable precursors for activated carbon (Yang et al., 2007; Jeguirim & Limousy, 2018). However, the specific variety known as "vineyard peach" (*vinogradarska breskva*), (*Prunus persica* (L.) Batsch), has received little scientific attention, despite its promising characteristics as a potential precursor. These stones are often discarded in large volumes by the fruit-processing industry, despite their high fixed carbon content and mechanical stability, making them attractive raw material for porous adsorbents (Demirbas, 2004; Fu et al., 2017). Activated carbon remains the most widely applied sorbent in environmental remediation due to its high surface area, chemical stability, and tunable porosity (Marsh & Reinoso, 2006; Bandosz, 2006). Nevertheless, conventional routes relying on coal or petroleum precursors raise sustainability concerns, stimulating interest in renewable biomass-based alternatives (Lua & Yang, 2004).

Among chemical activation techniques, potassium hydroxide (KOH) activation is regarded as one of the most effective, producing ultrahigh surface areas and dominant microporosity. The mechanism involves redox reactions between KOH and the carbon matrix, formation of metallic potassium, and gas evolution that generates a highly porous network (Otowa et al., 1993; Wu et al., 2005). Surface areas above 3000 m^2/g, and in some cases exceeding 5000–6000 m^2/g, have been reported for fruit-stone-derived carbons (Zhu et al., 2018; Xu et al., 2018). Characterization of such materials typically combines nitrogen adsorption–desorption isotherms to determine Brunauer–Emmett–Teller (BET) surface area and Barrett–Joyner–Halenda (BJH) pore size distribution (Brunauer et al., 1938; Barrett et al., 1951), together with Scanning Electron Microscopy (SEM) for direct visualization of morphology (Jeguirim & Limousy, 2018). This integrated approach provides insight into the relationship between activation conditions, pore development, and potential performance in adsorption-based applications.

The present study investigates the preparation and characterization of activated carbons from vineyard peach stones through carbonization and KOH activation, with emphasis on SEM and BET analyses as key indicators of textural properties and material performance.

MATERIALS AND METHODS

Sample preparation and carbonization

Fruit stones of vineyard peach (*Prunus persica* (L.) Batsch, var. vinogradarska breskva) were first washed thoroughly with deionized water to remove residual pulp and other impurities, and then dried at 105 °C for 24 h. The dried stones were crushed, ground, and sieved to obtain particles below 2 mm. Carbonization was carried out in a tubular furnace (Carbolite, UK) under a continuous nitrogen flow (100 $mL·min^{-1}$). The heating rate was 10 $°C·min^{-1}$ up to 600 °C, which was maintained for 2 h. The obtained biochar was labeled as biochar and used as precursor for chemical activation.

KOH activation

Chemical activation was performed using potassium hydroxide (KOH, p.a., Merck). Biochar was impregnated with KOH at a weight ratio of 1:3 (biochar:KOH) in deionized water and mixed until a homogeneous paste was formed. The mixture was dried at 110 °C overnight and subsequently calcined at 750 °C for 1 h under N_2 atmosphere. After cooling, the product was repeatedly washed with 0.1 M HCl and deionized water until neutral pH was reached. The activated material was dried at 110 °C for 12 h and labeled as AC–KOH.

Textural characterization (BET and BJH analysis)

Nitrogen adsorption–desorption isotherms were obtained at –196 °C using a Micromeritics ASAP 2020 analyzer. Prior to measurement, samples were degassed under vacuum at 200 °C for 12 h. The specific surface area was determined using the Brunauer–Emmett–Teller (BET) method (Brunauer et al., 1938), while pore size distribution and pore volumes were derived from the Barrett–Joyner–Halenda (BJH) model (Barrett et al., 1951).

Morphological analysis (SEM)

Surface morphology of both the raw biochar and the activated carbon was observed using a scanning electron microscope (JEOL JSM series, Japan). Samples were sputter-coated with a thin layer of gold prior to analysis. Micrographs were taken at different magnifications (×100 and ×250), including secondary electron images (SEI) and backscattered electron composition images (BEC).

RESULTS AND DISCUSSION

Textural properties

The BET analysis showed that the raw biochar had a relatively low surface area (420 m²/g) with limited porosity. After KOH activation, the specific surface area increased drastically to 2380 m²/g, accompanied by a significant rise in total pore volume and micropore fraction. This improvement is attributed to the chemical reactions between carbon and KOH, which generated micropores and widened existing pores.

Table 1. BET surface area and pore characteristics

Sample	**BET surface area (m²/g)**	**Total pore volume (cm³/g)**	**Average pore diameter (nm)**
Biochar	420	0.21	2.8
AC–KOH	2380	1.18	2.4

These values fall within the range reported for fruit-stone-derived activated carbons (Zhu et al., 2018; Xu et al., 2018), confirming that vineyard peach stones are an effective precursor for high-surface-area carbons.

Pore size distribution

BJH analysis revealed that raw biochar had a nearly balanced micropore/mesopore ratio, whereas KOH activation strongly enhanced microporosity (up to 76%). This is consistent with SEM observations of densely distributed micropores and microchannels.

Table 2. Micropore vs. mesopore distribution

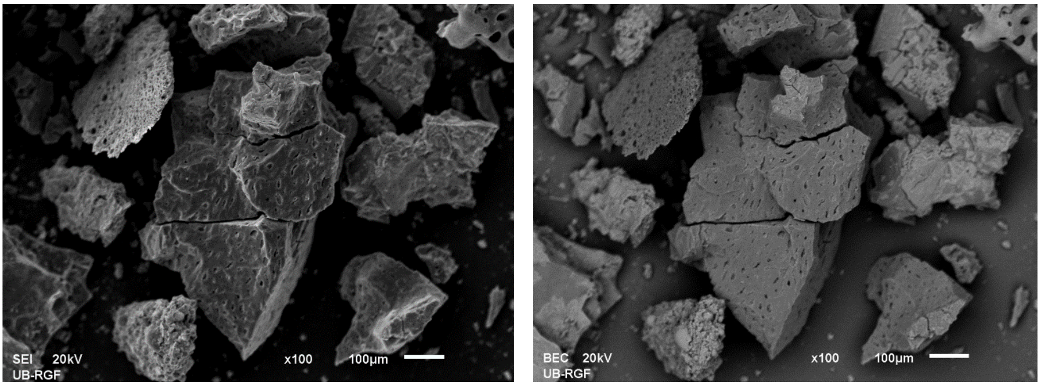
Sample	Micropore volume (cm³/g)	Mesopore volume (cm³/g)	Micropore fraction (%)
Biochar	0.10	0.11	47.6
AC–KOH	0.90	0.28	76.3

The predominance of micropores suggests that the obtained carbon is well-suited for adsorption of small organic molecules, while the presence of mesopores improves accessibility and diffusion.

Scanning Electron Microscopy (SEM)

Surface morphology was studied with a JEOL JSM series scanning electron microscope. Samples were sputter-coated with gold before imaging. Micrographs were obtained at magnifications of ×100 and ×250 in both secondary electron imaging (SEI) and backscattered electron composition (BEC) modes.

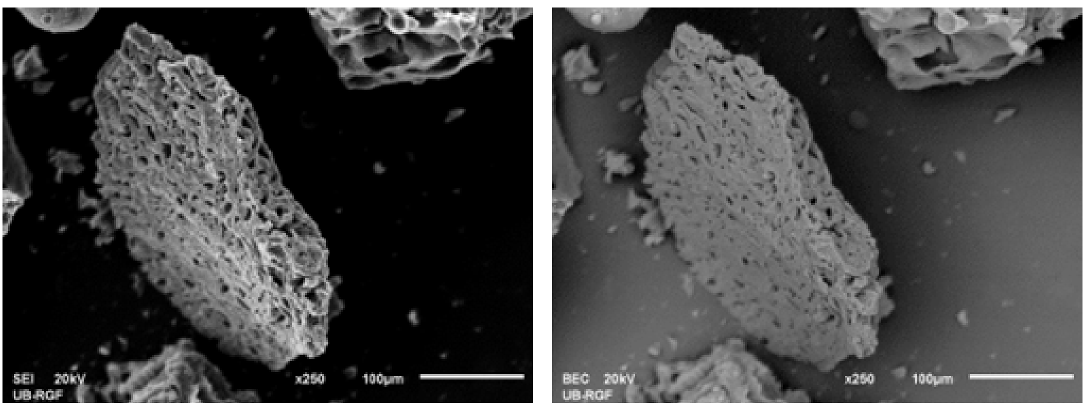
- Figure 1 (×100) illustrates the overall morphology of the vineyard peach stone–derived carbon. Large fragments with clearly visible cracks and surface pores are observed, indicating the effect of KOH activation in developing porosity.
    - *SEI (a)* highlights surface relief and topology, revealing micropores and the early stages of mesopore network formation.
    - *BEC (b)* shows a relatively homogeneous chemical composition, with no major mineral inclusions, typical of low-ash agricultural residues.
- Figure 2 (×250) provides a more detailed view of the fine pore structure. Activation generated a network of microchannels and cavities spatially distributed throughout the carbon matrix.
    - *SEI (a)* emphasizes the roughness and irregularity of the surface, with a dense network of micropores contributing to the increased specific surface area and adsorption potential.
    - *BEC (b)* confirms the absence of large inorganic agglomerates, suggesting that mineral residues were effectively removed during washing and activation.



(a) (b)

Figure 1. Micrographs of sample "Vinogradarska Breskva", magnification x100:

(a) Secondary electron image (SEI) and (b) Backscattered electron composition image (BEC)



(a) (b)

Figure 2. Micrographs of sample "Vinogradarska Breskva", magnification x250:

(a) Secondary electron image (SEI) and (b) Backscattered electron composition image (BEC)

CONCLUSION

In this study, vineyard peach (*Prunus persica* var. vinogradarska breskva) stones were successfully converted into activated carbon through carbonization and KOH activation. The raw biochar exhibited a moderate surface area of 420 m^2/g, which was significantly enhanced to 2380 m^2/g after chemical activation. BJH analysis confirmed the predominance of micropores in the activated sample, while SEM micrographs clearly demonstrated the transformation from a compact, low-porosity structure into a highly porous and etched surface morphology.

The combined evidence highlights the efficiency of KOH activation in generating a well-developed microporous network with a large specific surface area, properties that are favorable for adsorption-driven applications. Compared to the untreated biochar, the activated carbon derived from vineyard peach stones demonstrates superior textural and structural characteristics, aligning with reported trends for fruit-stone-based carbons in the literature.

These findings emphasize the potential of vineyard peach stones as a sustainable precursor for high-performance activated carbon, contributing to both waste valorization and the development of environmentally friendly adsorbents for future water purification and environmental remediation technologies.

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ARTIFICIAL INTELLIGENCE AND DIGITAL PLATFORMS IN THE SERVICE OF EDUCATION FOR SUSTAINABLE DEVELOPMENT

[1] Aleksandra Ivanov, [1] Katarina Stevanović [2] dr Aleksandar Radonjić, [2] dr Željko Stanković, [2] dr Lazar Stošić, [2] dr Olja Krčadinac

[1]Architectural Technical school, [2] Faculty of Informatics and Computer science,

The University "Union - Nikola Tesla"

ssaannddrraa09@gmail.com, katarinastvnvc@yahoo.com, aradonic@unt.edu.rs, zeljko.stankovic@unionnikolatesla.edu.rs, lazarstosic@yahoo.com,

okrcadinac@unionnikolatesla.edu.rs

Abstract:

This paper explores the potential of artificial intelligence in environmental education, focusing on the use of AI-based digital tools with high school students. Through digital platforms such as social media, students created and shared educational content on environmental topics. The main hypothesis is: Students who actively use AI tools to generate and distribute content develop greater environmental awareness, both personally and among their peers. The aim was to determine whether the use of AI can enhance students' environmental awareness, digital skills, and motivation. The study involved 120 high school students divided into two groups: 60 created and shared AI-supported content, while the other 60 consumed the content. All participants completed a survey before and after the activity. The results showed that content creators demonstrated higher engagement and awareness of environmental issues. Additionally, the passive group also showed improvement in understanding ecological topics, indicating the wider impact of educational content distributed via digital platforms. The research confirms the value of AI and social media as effective tools for promoting sustainable development education and highlights the potential for innovative teaching approaches that integrate digital technologies and ecology in the classroom.

Keywords: Artificial Intelligence (AI), environmental education, digital platforms

1. INTRODUCTION

In the contemporary educational context, sustainable development holds a central position in shaping teaching content and strategies aimed at preparing students for responsible and active participation in society. Simultaneously, the growing presence of digital technologies, particularly tools based on artificial intelligence, opens up new opportunities for enhancing ecological literacy and youth engagement. The integration of these technologies into educational processes enables students not only to develop digital competencies but also to actively participate in the creation and dissemination of knowledge with broader societal significance.

This paper explores the impact of applying artificial intelligence and digital platforms in education for sustainable development through an experimental approach in which students were divided into two groups. The first group was tasked with using digital tools and AI technologies to create promotional materials on environmental protection and disseminate them via social media. The second group, which followed this content, was not involved in its creation. Through a comparative analysis of responses obtained before and after the intervention, this study examined the differences in levels of environmental awareness and engagement between active content creators and passive observers.

The aim of the study is to determine whether the active use of artificial intelligence and digital tools in the educational process contributes to the development of environmental awareness, and whether experiential learning through digital creation has a stronger impact on students compared to traditional observer-based learning models. The findings are intended to contribute to a better understanding of the potential of digital transformation in education to develop competencies essential for preserving the environment and ensuring a sustainable future.

1.1. Theoretical Notes

To ensure a clearer understanding of specific concepts, this section offers detailed explanations.

The concept of **sustainable development**, as defined in the Brundtland Report, refers to development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

Recycling is defined as the process of collecting and processing materials that would otherwise be considered waste, in order to reuse them as new products or components. This process contributes to the preservation of resources, reduction of greenhouse gas emissions, and minimization of pollution, and thus represents a key component of a sustainable, circular economy (Daoud et al., 2025).

Students used artificial intelligence tools such as ChatGPT for learning and information retrieval, while Canva and Genially were employed for creating posters, infographics, and other promotional materials. For promotion, they primarily used TikTok and Instagram.

In the field of education for sustainable development, **digital tools** and **AI platforms** enable interactive and experiential learning through simulations, visualizations, and creative content production. Such an approach not only fosters the development of digital competencies but also encourages ecological awareness, motivation, and affective engagement among students (Nagatomo, 2024).

Canva is a modern online graphic design platform that has quickly become one of the most popular tools in contemporary education. A study conducted in a vocational school in Indonesia indicates that the use of Canva significantly increased students' interest, creativity, and self-confidence, while also helping teachers integrate digital media into the teaching process without major technical barriers (Widiastuti, 2024).

There is a growing need in modern education for tools that transform static teaching materials into interactive and multimedia-rich content. One of the most advanced tools of this type is **Genially**, a digital platform recognized for enabling the creation of presentations, infographics, educational games, quizzes, and virtual tours, all serving the purpose of active and engaging learning (Hermita et al., 2022).

Prezi is an innovative digital presentation platform that significantly differs from traditional tools in its conceptual approach to visual communication. It particularly contributes to the development of digital and visual literacy for both teachers and students (Ye, Yahaya & Luo, 2024).

In the context of sustainability education, **TikTok** has proven to be an effective platform for communicating climate-related topics. Creators use emotionally impactful language and calls to action, enhancing the educational and engagement potential for youth (Pera & Aiello, 2024).

Regarding **Instagram**, studies show that the platform plays a significant role in informal education on sustainability by combining emotional engagement with practical advice for everyday life. Through emotive formats and authentic examples, Instagram can serve as a driver of behavioural change and environmental awareness among students (Bush & Löns, 2024).

1.2 Overview

Recently, a growing body of research has explored how digital platforms, artificial intelligence, and social media contribute to shaping students' environmental awareness. The study titled *"Applying Social Media to Environmental Education: Is It More Impactful than Traditional Media?"* examines how young people utilize social networks to acquire knowledge about green living and environmental protection. The research shows that although students accept environmental information shared on social media, their level of interaction with such content is often minimal, indicating potential barriers in using these channels for educational purposes (Chung et al., 2020). The paper *"Formation of Students' Environmental Awareness Through Social Media"* investigates key characteristics in the development of environmental awareness among students through social media platforms. Using a combination of analytical and survey methods, the authors identify the main elements contributing to environmental consciousness, including the effectiveness of communication, access to relevant content, and socially conditioned learning. Social networks demonstrate considerable potential for enhancing students' environmental awareness, particularly when used for educational purposes through targeted and thematically structured content (Lovochkina, Otych & Spivak, 2023). Also, "AI-driven tools offer unparalleled precision, personalization, and innovative assessment methods" (Stošić & Malyuga, 2024). Meta-study published in May 2025 titled *"Digital Natives, Digital Activists: Youth, Social Media and the Rise of Environmental Sustainability Movements"* highlights how young people use social media and hashtag campaigns for activism in the domain of sustainable development. The findings indicate that digital activism can spark both local and global action when it integrates online and offline strategies (Pandit et al., 2025). Another significant analysis, *"The Role of Social Media in Promoting Environmental Sustainability"* (Zhang, 2025), summarizes how various types of social media influence increased environmental awareness and pro-sustainability behaviors among users and communities. The results suggest that content based on interaction, personalization, and real-time communication has a more substantial effect on users. Also, "AI can automate repetitive tasks, assist in the generation of system architectures, and even make intelligent decisions based on large datasets" (Krčadinac et al., 2025).

2. MATERIALS AND METHODS

This research was conducted as part of a pedagogical experiment aimed at examining the influence of artificial intelligence and digital platforms on the development of environmental awareness among students. A total of 120 high school students participated in the study, divided into two experimental groups of 60 students each. In line with the study's objectives, a quasi-experimental design was applied, with measurements of attitudes and knowledge conducted before and after the intervention, in order to identify any changes in environmental awareness.

Both groups completed an identical questionnaire at the outset, consisting of 21 items including both closed and open-ended questions. These items were designed to assess students' levels of awareness, attitudes, and behaviors related to environmental protection, recycling, and sustainable habits. The first group of students (experimental group 1) was then involved in a series of activities that included learning about the basics of artificial intelligence, working with digital platforms (Canva, Genially), and creating promotional materials focused on ecological sustainability. Over the course of seven days, these students produced visual content - such as infographics, posters, and videos, and shared it via social media platforms, primarily TikTok and Instagram.

The second group (experimental group 2) was not engaged in the content creation process but instead followed the materials posted by their peers via social networks, without any direct participation in the production. This division enabled a comparison between the effects of active and passive participation in digital educational activities.

After a one-week period, the same questionnaire was re-administered to both groups, enabling a comparative analysis of any changes in attitudes, knowledge, and behaviors related to environmental protection. The data were analyzed using a mixed-methods approach: the quantitative analysis of closed questions involved descriptive and inferential statistics (including percentage differences and t-tests), while the open-ended responses were analyzed through qualitative content analysis by identifying dominant themes, shifts in expression, and levels of abstraction.

Main hypothesis: Students who actively participate in the creation and dissemination of environmental educational content using digital tools and social media will demonstrate a more significant increase in environmental awareness and knowledge compared to students who only passively consume the same content.

The study was conducted with the informed consent of teachers and in accordance with ethical principles, including participant anonymity and voluntary involvement.

3. RESULTS

3.1. Group of students who promoted content (experimental group 1)

The qualitative analysis of open-ended responses reveals substantial changes in the cognitive framework of students who actively participated in the promotion of environmental content. After completing the assigned activities, students demonstrated a deeper understanding of the importance of waste separation. Whereas their pre-intervention answers were mostly vague or superficial, post-intervention responses reflected more concrete reasoning, including mentions of composting and reducing landfill space. Students showed an improved ability to articulate the rationale behind organic waste separation, indicating a growth in both knowledge and environmental awareness. Moreover, students' understanding of the benefits of recycling significantly progressed. Prior to the activity, their answers were often limited to statements such as "I don't know," while after the campaign they increasingly emphasized the importance of conserving natural resources, reducing pollution, saving materials and energy, and preventing environmental degradation. This change signifies enhanced ecological consciousness and greater awareness of the broader implications of recycling. Although the definition of recycling remained relatively stable, post-intervention responses were noticeably more precise and nuanced. Concepts such as "reuse" and "pollution reduction" continued to dominate, but were explained in greater depth, suggesting improved conceptual understanding and critical thinking.

The survey analysis revealed that students from the group that promoted ecological content (experimental group 1) expressed significantly greater concern about environmental pollution after the completion of the experiment (Diagram 1). Moreover, they demonstrated an increased understanding of the importance of recycling and reported more frequent recycling behavior (Diagram 2).

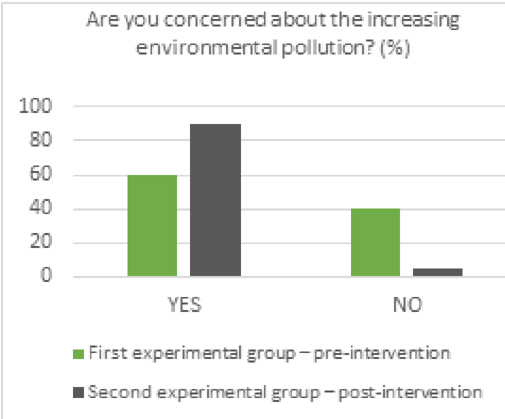

Diagram 1. *Concern about the increase in pollution*

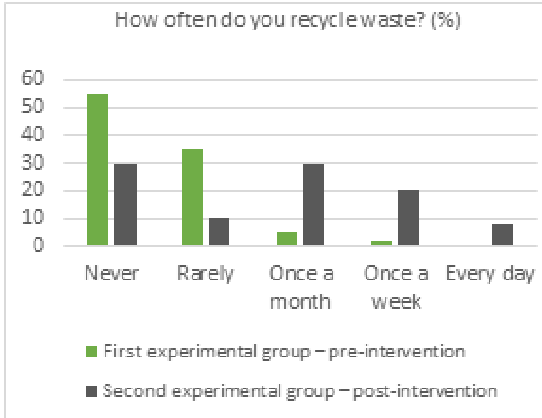

Diagram 2. *Recycling Frequency*

Regarding their own environmental behavior, students' responses remained consistent in general themes, but post-intervention statements more frequently reflected specific actions personally undertaken during the project. This suggests that experiential learning through practical tasks had a direct impact on fostering a more responsible attitude towards the environment.

3.2.2) Group of students who observed content (experimental group

Analysis of the responses from students who did not participate in content creation but merely observed the materials via social networks indicates limited, yet noticeable, changes in their level of environmental knowledge and attitudes. While most of their responses to closed-ended questions showed a consistent concern about pollution and a willingness to reduce their ecological footprint, the nature of change was predominantly cognitive and informational. Affective and behavioral dimensions remained mostly unchanged compared to the actively engaged group. The most prominent differences were observed in answers regarding recycling frequency. Initially, most students reported infrequent or nonexistent recycling habits. After exposure to the digital content, there was a shift, with some students indicating more regular engagement in recycling practices, daily or weekly. This change suggests a modest increase in awareness of how daily actions can contribute to sustainability, even among students who were not directly involved in creating educational content. In addition, understanding the purpose of waste separation improved. While many students initially responded with uncertainty, post-intervention answers reflected a better ability to verbalize the purpose of organic waste separation, using terms such as environmental protection, pollution prevention, and reuse. This suggests that passive learning through digital platforms had some positive impact on cognitive awareness.

With regard to open-ended questions, the main difference lay in the depth and richness of students' responses rather than in the emergence of entirely new ideas. Although many students had previously mentioned basic benefits of recycling or school-related activities, their post-exposure answers appeared more thoughtful, detailed, and enriched with descriptive elements. There was also an increased readiness to propose school-level initiatives such as lectures, tree planting, or the introduction of more waste bins, pointing to a slight increase in environmental engagement.

3.3 Comparative analysis of the two experimental groups

The comparison between the two experimental groups reveals notable differences in the development of environmental awareness and engagement, stemming from their respective levels of involvement in the educational process. While both groups exhibited some degree of progress after the intervention, the nature, depth, and scope of these changes differed substantially depending on whether students had an active or passive role.

Students from the first group, who were actively engaged in the creation of promotional materials on environmental topics using artificial intelligence tools and digital platforms, demonstrated a significantly higher increase in ecological awareness. Their open-ended responses reflected deeper conceptual understanding, clearer articulation of ideas, and a more nuanced use of environmental terminology. For example, after the intervention, students in this group were able to explain the purpose of waste separation with greater specificity, citing composting practices, reduction of landfill volume, and the environmental rationale behind sorting biodegradable from non-recyclable waste. Their understanding of recycling expanded from vague notions to detailed insights into resource conservation, pollution reduction, and energy savings. Furthermore, the students in the active group exhibited enhanced personal responsibility and initiative. Many reported undertaking concrete eco-friendly actions during the project, such as reducing single-use plastics, raising awareness among peers, and organizing small-scale environmental activities. Their written reflections contained a stronger emotional and ethical dimension, indicating a deeper internalization of environmental values and a willingness to engage in long-term behavioural change. In contrast, the second group, whose members passively followed the educational content shared by their peers on social media, showed more modest improvements. Their responses after the intervention suggested a higher level of environmental knowledge than before, particularly in terms of recognizing the importance of waste separation and recycling. However, the affective and behavioural components of environmental engagement remained relatively stable. Students in this group were less likely to report new personal actions taken or to suggest initiatives for improving environmental practices at school or in their communities.

Additionally, while the passive group did express greater awareness in some areas such as more frequent mentions of the environmental consequences of pollution and climate change, their descriptions often lacked the depth, clarity, and contextual richness found in the responses of the active group. In terms of linguistic and cognitive expression, the active group produced more structured and detailed answers, indicating the formative influence of creative production on critical thinking and communication skills.

This divergence suggests that direct participation in the educational production process fosters more meaningful and lasting learning outcomes. It enhances not only cognitive understanding but also emotional engagement and the motivation to act. Conversely, passive exposure to content, while not without effect, appears to yield limited impact on internalization and behavioural change. These findings align with prior research highlighting the pedagogical advantages of experiential and project-based learning, especially when implemented through digital tools that allow for expression, collaboration, and public sharing.

4. DISCUSSION AND CONCLUSIONS

The findings of this study confirm the initial hypothesis that students who actively participated in the creation and dissemination of educational environmental content using digital tools and social media demonstrated a greater increase in environmental awareness compared to their peers who only observed the same content passively. Furthermore, the main objective of the research—examining the impact of integrating artificial intelligence and digital platforms into education for sustainable development was successfully achieved.

Among students who were directly involved in content production, there was clear evidence of deeper conceptual understanding, improved ability to articulate environmental issues, and a heightened readiness to engage personally with ecological matters. These students developed not only greater knowledge but also more reflective and committed attitudes toward sustainability.

The results underscore the importance of active, experiential learning, particularly when implemented through digital environments that allow for creativity, peer influence, and public engagement. The process of creating content appears to foster a stronger connection between knowledge and action, enabling students to internalize and apply ecological principles in more meaningful ways.

For future research, it is recommended to conduct longitudinal studies to monitor the long-term effects of such interventions, as well as to explore the applicability of this approach across different age groups and educational settings. Moreover, schools should be encouraged to develop strategies that promote not only the consumption of digital educational content but also its production by students. In doing so, they can further strengthen students' environmental literacy and civic responsibility, contributing to a more sustainable and informed generation.

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TEACHING THROUGH CONTRIBUTION WITH WIKIPEDIA AS A PLATFORM FOR CRITICAL SKILL DEVELOPMENT

Dudić Dragana[1], Ratković Nebojša[2], Đokić Ana[3] and Krčadinac Olja[1]

[1]Faculty of Informatics and Computer Science, University Union Nikola Tesla, Belgrade, Serbia
[2]Wikimedia Serbia, Belgrade, Serbia
[3] Information Technology School, Belgrade, Serbia
e-mail: ddudic@unionnikolatesla.edu.rs

Abstract. We explored the use of Wikipedia on Serbian language as an educational tool to support the development of critical academic skills in higher education. The study, which involved 103 students enrolled in the Faculty of Contemporary Arts' Creative Business and Creative Communications modules, was organized into four phases: initial, informative, proactive, and evaluation. Students participated in content production through Wikipedia-based assignments, which promoted more in-depth research techniques and improved digital literacy. The student's understanding of referencing and copyright licensing significantly improved, according to structured questionnaires given in the initial and evaluation phase. Students eventually developed a more critical and engaged perspective of information, despite difficulties like navigating Wikipedia's editing guidelines and doubting the platform's legitimacy. In order to bridge the gap between traditional and digital learning, the results emphasize the importance of incorporating open educational platforms such as Wikipedia into creative curricula. By shifting students from passive consumers to active contributors, educators can foster greater engagement in a global knowledge ecosystem.

Keywords: e-learning, higher education, Wikipedia, Serbian language.

INTRODUCTION

Building students' digital literacy is more important than ever in the constantly evolving educational environment of today. Open platforms like Wikipedia offer an opportunity to connect traditional academic methods with interactive, real-world learning environments as higher education continues to develop in tandem with digital technologies. In addition to being one of the most popular information sites in the world, Wikipedia is a collaborative platform where a wide range of contributors create, discuss, and preserve knowledge.

Even though its legitimacy is still up for debate [1], Wikipedia's open-editing model has educational value because it encourages students to interact critically with the material, check their sources, and clearly communicate with a wide audience. By encouraging students to use their academic skills in a meaningful, public setting, Wikipedia-based assignments can turn passive learning into active knowledge production in university curricula.

Wikipedia's role in education has been extensively studied, but few studies have gone into great detail about concepts of digital literacy [2–6], and only one has looked at the significance of referencing and copyright licensing in this context [7].

In this study, we explored how students' academic and digital competencies can be enhanced through contributions to the Serbian-language Wikipedia. Focusing on students from the Faculty of Contemporary Arts, the research examines how structured engagement with Wikipedia supports the development of digital literacy.

MATERIALS AND METHODS

Following a research design similar to that of reference [7], our study was organized into four main phases: the initial phase, the informative phase, the proactive phase, and the evaluation phase. Each phase was carried out in sequence, with elements informed by the results of the previous phase.

The purpose of the initial phase was to assess students' existing awareness of Serbian Wikipedia and their general behavior related to Wikipedia use. The findings from this phase were used to shape the content of the informative phase. This phase was organized and delivered by representatives from Wikimedia Serbia. The training sessions were specifically tailored to the students' knowledge levels and areas of interest. Although the informative phase was designed to have a long-term impact, its immediate effects were assessed through the following two phases.

In the proactive phase, students were required to independently create at least one article on the Serbian-language Wikipedia. These articles needed to relate to their academic fields but allowed for freedom in topic selection. Students received guidance and support from Wikimedia Serbia throughout this process. After completing their assignments, students participated in the evaluation phase, where they provided feedback on the lectures, the training, and their experiences with Wikipedia editing. This feedback helped us understand the impact of the intervention and to identify any areas that required improvement.

Structured online questionnaires were administered during both the initial and evaluation phases. These surveys were created using Google Forms and distributed to students via QR codes. Conducted in Serbian, each questionnaire included ten questions designed to measure students' understanding of digital literacy in the context of Wikipedia. Four of these questions appeared in both the initial and evaluation phases, allowing us to directly compare changes in students' knowledge. Two of the repeated questions focused on referencing, and two addressed copyright licensing. The evaluation questionnaire also included six additional questions, two of which were open-ended and aimed to gather qualitative feedback on the informative phase and the role of the educators.

To analyze the data, we applied descriptive statistics and used the R programming language for more detailed evaluation. Cramér's V was used to measure the strength of associations between variables, and Fisher's Exact Test was used to detect statistically significant differences between the two phases. For questions with more than five possible answers, hierarchical clustering was performed. We calculated Gower's distance using the daisy() function to generate a distance matrix. The clusters were then formed using the hclust() function with the Ward2 method, and defined by cutting the resulting dendrogram at height three using the cutree() function. This analysis helped us identify patterns in the data and determine whether the intervention led to statistically significant improvements in students' digital literacy.

RESULTS

Understanding proper referencing guidelines and copyright licensing is a crucial aspect of digital literacy [7]. Figure 1 presents students' perceptions and understanding of the importance of proper referencing, while Figure 2 illustrates their views on copyright and licensing. Both figures compare responses from the initial and evaluation phases.

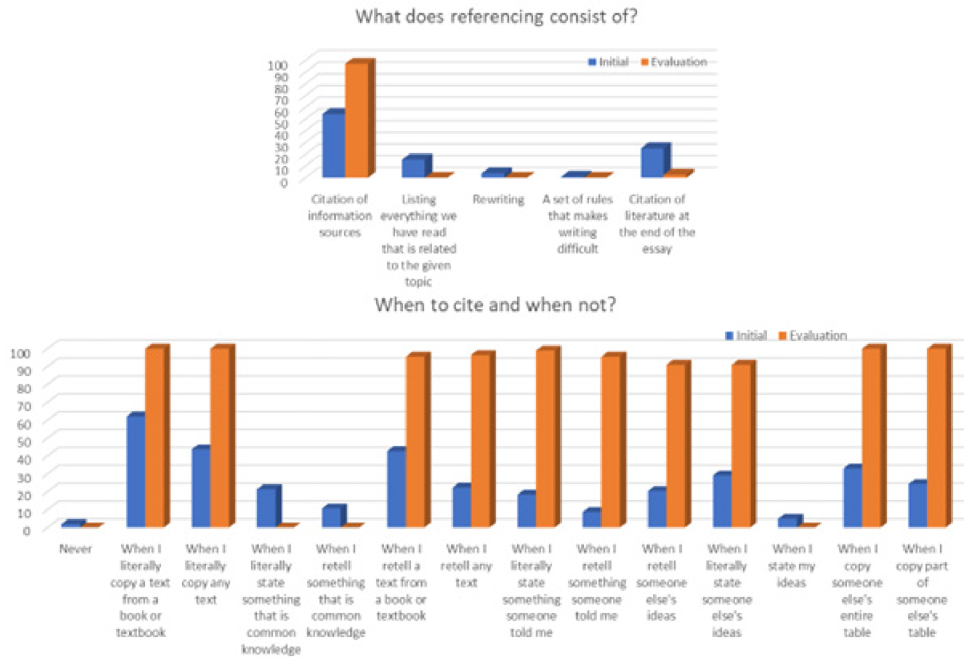

Figure 1 Frequencies of student responses related to Wikipedia referencing in the initial and evaluation phase

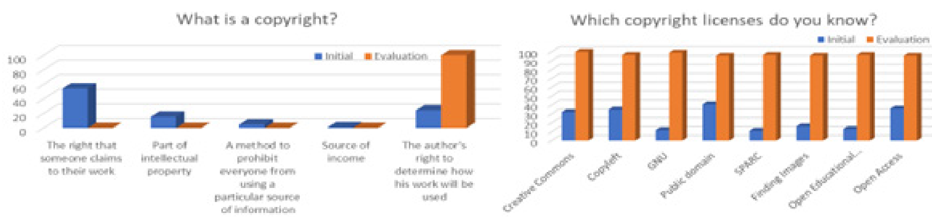

Figure 2 Frequencies of student responses related to Wikipedia copyright licensing

We compared the results of the questions common to both questionnaires:

- For question "What does referencing consist of?", we found a p-value of 0.0004 and a Cramér's V value of 0.46,
- For question "When to cite and when not?", we found a p-value of 0.04 and a Cramér's V value of 0.22.
- For question "What is a copyright?", we found a p-value of 0.37,
- For question "Which copyright licenses do you know?", we found a p-value of 0.05 and a Cramér's V value of 0.38.

DISCUSSION

The initial questionnaire highlighted a considerable gap in students' understanding of referencing and copyright licensing. Prior to the informative phase, around half of the participants were aware of referencing practices, but fewer than 10% knew when citations were required. Most students believed that referencing was only necessary when directly copying from a source, particularly from books. Additionally, a large portion of the students had never used copyright licenses, although many had some awareness of the concept, typically based on informal or incomplete definitions.

The informative and proactive phases led to a marked improvement in students' knowledge. More than 86% of participants reported a better understanding of how to reference properly, and nearly all developed a clearer grasp of copyright licensing.

Statistically significant changes were observed in three of the four questions common to both the initial and evaluation questionnaires, as confirmed by Fisher's Exact Test. The only exception was the question related to the definition of copyright. These results support the conclusion that the informative and proactive phases positively influenced students' digital literacy.

These findings are consistent with prior research [8], which identifies citation quality as a key aspect of digital literacy, and with [9], which underscores the role of copyright licensing in supporting responsible digital practices.

CONCLUSION

While previous studies have highlighted the potential mistrust stemming from Wikipedia's open-access model [10-12], this study demonstrates the educational value of integrating Wikipedia into higher education as a tool for fostering digital literacy. Students gained a deeper understanding of academic referencing, copyright licensing, and the significance of creating trustworthy and well-sourced content by actively contributing to the Serbian-language Wikipedia.

The methodical approach, which comprised both proactive and informative stages, was successful in closing the digital competency gaps and motivating students to use open knowledge platforms with consideration. These findings provide trust to the wider incorporation of open-access and collaborative resources such as Wikipedia into academic and creative curricula. They draw attention to the possibility of converting students from passive consumers into knowledgeable and engaged members of international knowledge communities.

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ANALYSING ROAD PROXIMITY TO FOREST AREAS AS A WILD-FIRE RISK FACTOR IN BOSNIA AND HERZEGOVINA

Olja Krčadinac[1], Saša Ljubojević[2] and Branko Latinović[3]

[1]The University "Union - Nikola Tesla", 11000 Belgrade, Cara Dusana 62-64, Republic of Serbia

okrcadinac@unionnikolatesla.edu.rs

[2]JPŠ "**Šume** Republike Srpske", 78000 Banja Luka, Trg Republike Srpske 8/11, Republic of Srpska

sasa.ljubojevic@sumers.org

[3]Pan-European University APEIRON, 78 000 Banja Luka, Pere Krece 13, Bosnia and Herzegovina

branko.b.latinovic@apeiron-uni.eu, stanz@medianis.net

ABSTRACT

This study analyses the relationship between the distance of forests from roads and the risk of forest fire occurrence in Bosnia and Herzegovina. Using data from the CORINE Land Cover database and the Geofabrik road network, a GIS-based methodology was applied to classify forest areas into four risk categories depending on their proximity to roads. The analysis showed that forest areas located near roads, particularly within a 200 m buffer, are significantly more exposed to fire risk caused by human activities. The results highlight the importance of incorporating road proximity into fire risk models and indicate the need for preventive measures in high-risk zones. This research provides a methodological basis for future studies that can integrate additional variables, such as meteorological conditions and historical fire records, to develop more comprehensive risk assessment models.

Keywords: Wildfire risk; GIS; road proximity; buffer analysis; forest vulnerability; Bosnia and Herzegovina

INTRODUCTION

Forest fires represent one of the most destructive factors threatening forests and forest land in Bosnia and Herzegovina. Their consequences are reflected not only in the destruction of forest ecosystems but also in economic damage, environmental degradation, and increased risk to human lives and property (Ljubojević and Stanković, 2021). Previous research has shown that human activity plays a crucial role in the ignition and spread of fires, especially in areas with dense road networks. Roads facilitate access to forests, but at the same time increase the probability of fire ignition due to discarded cigarette butts, glass, oils, fuels, and other anthropogenic factors (Milanović and Filipović, 2017). Understanding the spatial relationship between forests and roads is therefore a key element in modelling fire risk.

STUDY AREA

Bosnia and Herzegovina covers an area of approximately 51,000 km², with forests and forest land making up more than half of the territory, or about 53%. According to available data, Bosnia and Herzegovina is among the countries with significant forest resources in Southeastern Europe. Forests play a crucial role in maintaining ecological stability, protecting soil from erosion, regulating the water regime, producing timber, and mitigating climate change.

Climatic conditions are diverse ranging from moderately continental in the northern and central parts of the country, to sub-Mediterranean in Herzegovina, where dry periods are more pronounced and the risk of fire is higher. Statistical data show that several hundred fires are recorded annually, with the highest frequency occurring in the southern parts of the country.

Forest coverage in Bosnia and Herzegovina is spatially uneven. Mountainous and hilly areas, particularly in the central and eastern parts of the country, are covered with dense forests, while lowlands and areas of intensive agriculture are less forested. Figure 1 shows a map of the territory of Bosnia and Herzegovina with the distribution of forest areas, clearly illustrating the high level of forest cover and the importance of these ecosystems in the overall territory of the country (Ljubojević and Latinović, 2022)..

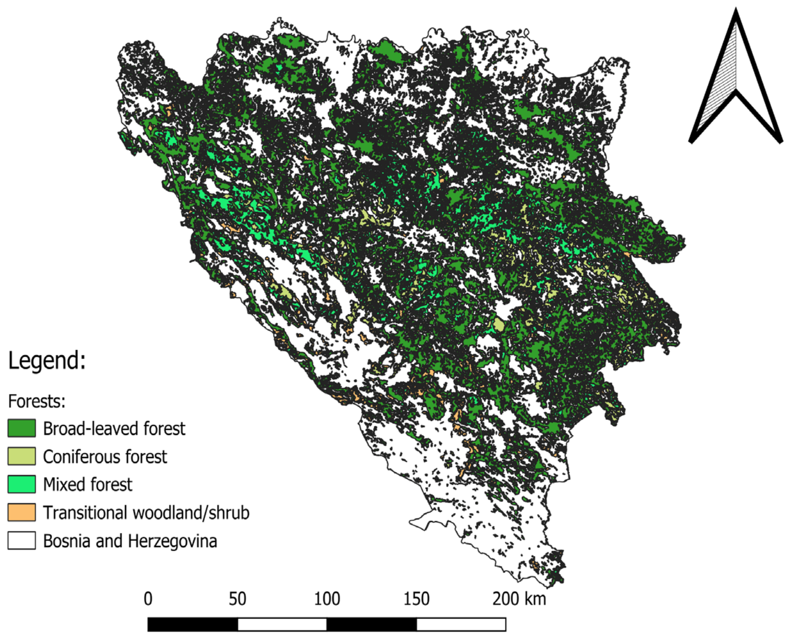

Figure 1: Territory of BiH with a representation of forest areas

DATA AND METHODOLOGY

For the purposes of this research, data from two main sources were used. Road network data were obtained from the Geofabrik database, which provides detailed information on the OpenStreetMap road infrastructure. Forest cover data were taken from the CORINE Land Cover database, which contains categorized land cover polygons for the entire territory of Bosnia and Herzegovina (Krčadinac, Ljubojević and Latinović, 2023). These two datasets were harmonized in terms of coordinate system and clipped to the state borders in order to ensure uniform spatial coverage (Novaković, 2022).

The methodological approach was based on a raster analysis that enables precise measurement of the distance of forest areas from the nearest road. In the first step, the vector layer of roads was filtered to include only those categories that realistically allow vehicle access, since these are the areas where the probability of fire occurrence is highest due to human activity. Footpaths, hiking trails, and cycle routes were excluded from the analysis. After filtering, the road network was rasterized to a cell size of 30 × 30 meters, which provided a good balance between spatial accuracy and the scope of the analysis.

Subsequently, a distance raster was generated using the Proximity (Distance) tool in QGIS, which calculated the Euclidean distance from each raster cell to the nearest road. This layer represented the basis for the risk classification. The next step was to intersect the distance raster with the forest cover polygons, which enabled the analysis to be focused only on forested areas. During this procedure, the raster values outside the forest polygons were set to 'No Data,' which eliminated irrelevant parts of the analysis.

The classification of risk was carried out based on the distance from the road. Four categories were defined: very high risk (distance less than 50 m), high risk (50–200 m), medium risk (200–500 m), and low risk (greater than 500 m). These thresholds were determined according to previous studies and logical assumptions regarding the spatial impact of human activity. The obtained raster was then symbolized in QGIS and the surface of each class was calculated. The size of one raster cell is 900 m² (30 × 30 m), which enabled the conversion of cell counts into surface areas and their expression as percentages of the total forest area.

This methodological framework made it possible to identify spatial patterns of forest fire risk associated with road proximity and to quantify the share of forest areas that fall into each risk category.

RESULTS AND DISCUSSION

The analysis of the spatial relationship between forests and the road network in Bosnia and Herzegovina has provided clear insight into the distribution of risk zones for fire occurrence. The generated distance raster and subsequent classification showed that a significant portion of forest areas lies within zones of increased risk, especially in the immediate vicinity of roads. The results confirm the initial assumption that proximity to roads strongly influences the probability of fire occurrence, primarily due to anthropogenic factors.

Table 1. Forest areas by risk classes

Category:	Distance from the road (m):	Area (ha):	Percentage (%):
Very high risk	0–50	167545.17	6%
High risk	50–200	511775.82	19%
Medium risk	200–500	819010.71	31%
Low risk	>500	1161332.73	44%
Total:		2659664.43	100%

The category of very high risk (distance less than 50 meters) encompasses forest areas directly adjacent to roads, where the possibility of ignition caused by human activity is greatest. These zones, although relatively smaller in surface compared to the total forested area, are critical because even a small ignition can develop into a large-scale fire if weather conditions are unfavourable. High-risk areas (50–200 meters) cover a considerably larger surface and represent the zones most exposed to human influence, since these areas are often accessible and frequented for logging, recreation, or transportation.

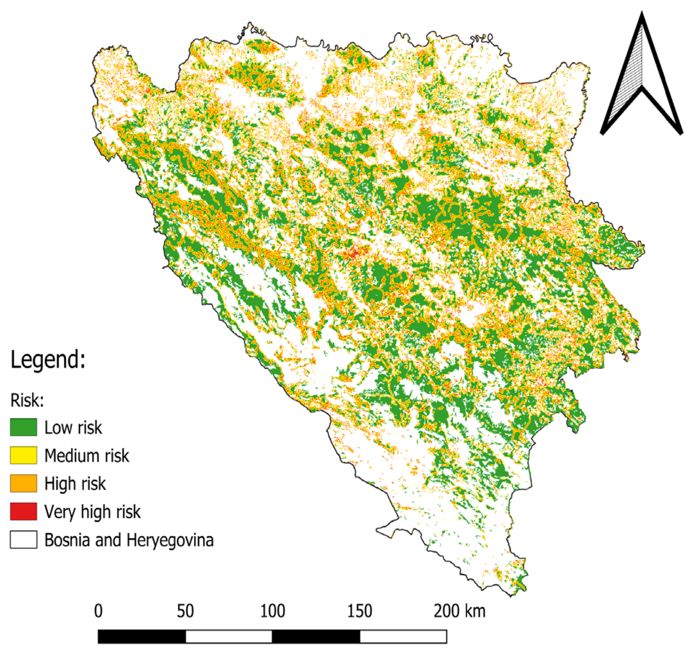

Figure 2. Classification of forest fire risk according to distance from roads.

Medium-risk areas (200–500 meters) extend deeper into the forest interior and are less directly affected by road traffic, but they remain within the potential influence of human activity, particularly in cases where trails or illegal access routes exist. Low-risk areas (more than 500 meters from roads) represent forest zones where human presence is minimal, and natural factors play a relatively greater role in fire occurrence. Nevertheless, these areas should not be considered completely safe, as extreme weather conditions and climate change increase the overall fire risk even in more remote regions.

The statistical results derived from the classification highlight the dominance of high and medium risk zones in the overall structure of forests in Bosnia and Herzegovina. This indicates that a significant part of the forested area is exposed to anthropogenic fire hazards. The spatial distribution of these zones also demonstrates that the greatest risk is concentrated around dense road networks in lowland and populated regions, while mountainous and less accessible areas show a greater share of low-risk forests.

The results also open space for further research that could combine the distance-to-road indicator with additional environmental and socio-economic variables, such as slope, vegetation type, population density, and climate conditions. Such an integrated approach would provide a more comprehensive risk model, which could be useful for planning fire prevention measures, developing early warning systems, and allocating firefighting resources.

CONCLUSION

This research has shown that the spatial relationship between roads and forest areas is one of the key factors influencing the risk of forest fire occurrence in Bosnia and Herzegovina. The applied GIS methodology, based on the calculation of distance from roads and classification of risk zones, provided clear evidence that forest areas in the immediate vicinity of roads are most endangered. Although these areas make up a smaller share of the total forest surface, they represent critical ignition zones that require increased monitoring and preventive action.

The results confirm that human activity, enabled and intensified by the presence of roads, plays a decisive role in the occurrence of forest fires. The distribution of high- and medium-risk zones suggests that preventive measures should focus on areas near dense road networks, especially in lowland and inhabited regions. At the same time, low-risk zones, although less exposed to human influence, should not be neglected due to the growing impact of climate change and extreme weather events.

The methodological framework applied in this study has proven to be reliable and can serve as a foundation for future research. By integrating additional variables such as vegetation structure, topography, meteorological parameters, and historical fire records, it is possible to develop a more comprehensive model of fire risk. Such models would contribute to better planning of firefighting resources, more efficient allocation of preventive measures, and a stronger overall system of forest protection.

Ultimately, this study emphasizes the need for a proactive approach to forest fire management in Bosnia and Herzegovina, where modern GIS tools can provide valuable support for decision-makers in forestry, environmental protection, and civil defence sectors.

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GENERAL STRUCTURAL ASPECTS OF ENERGY EFFICIENT BUILDINGS

Milan Lujić[1], Irena Parović[2], Dejan Beljaković[2], Aleksandar Milajić[2]

[1]ML Bau GmbH, Wien, Austria
[2]Faculty of Construction Management, University "Union - Nikola Tesla", Belgrade
amilajic@unionnikolatesla.edu.rs

Abstract

Zero energy buildings are still more a curiosity than a common practice, mainly because designers are usually unwilling to abandon traditional materials and design concepts. Besides that, zero energy building design requires wide knowledge not only in the scope of architecture and civil engineering but also in other fields of technology and science. Therefore, finding the optimal design should be based on proper scientific approach. This paper presents brief review of the simulation and optimization tools and the general design guidelines acquired by using hybrid simulation software consisting of genetic algorithm and EnergyPlus, as well as recommendations from the references.

Keywords: Zero energy solar buildings, energy efficiency, optimal design, guidelines.

INTRODUCTION

Zero energy solar buildings utilize solar thermal and photovoltaic (PV) technologies to generate as much energy as they need per year. Therefore, they have to be designed to be highly energy efficient and to utilize passive solar building approaches to minimize energy consumption. During the last 30 years, there has been a lot of demonstration projects and international initiatives that have promoted the development of low and net zero energy homes (Hamada et al, 2003; Hoiting et al. 2003). The most important requirement in solar-optimized building design is to select the optimal form and orientation of the building for a given site. Without this step, all the subsequent simulations of considered design options would be done only to justify decisions made on a subjective basis. The design team is faced with numerous parameters that significantly influence solar energy utilization, such as landscaping, building shape, window area, thermal and optical characteristics, PV and solar thermal collector area and orientation, thermal storage, HVAC system variables and different control strategies.

Proper design of a zero energy solar building should be based on realistic building performance simulation which adequately imitates complex environmental and physical conditions by treating time as the independent variable, which results in series of calculations, i.e. by repeated forming and solving equation sets in discrete time steps (usually one hour step). In order to properly model and analyze behavior of even the simplest building during one year, millions of equations must be formed and solved. It is obvious that true simulation methods require proper computational resources and adequate simulation software. Unfortunately, current design methods mostly depend on trial-and-error optimization using simulation tools on a scenario-by-scenario basis, in the course of which a designer generates one solution and a computer evaluates it. This can be a slow and tedious process and typically only a few scenarios are evaluated from a large range of possible choices. Therefore, it is necessary to incorporate simulation software into appropriate optimization tool which will automatically change and analyze different building features until the best solution is found.

Therefore, evolution of building simulation methods and software has closely paralleled developments in computer hardware. Numerous simulation methods and tools were developed for solar hot water and solar-PV systems modeling. These solar-focused tools either decoupled the building's thermal and electric systems or treated the building in a rudimentary manner. However, more recent versions include more rigorous treatment of building thermal processes and HVAC components. Models for active solar components and PV systems have been incorporated into the TRNSYS and ESP-r building simulation programs and EnergyPlus, first released in 2001, which has enhanced capabilities in modeling HVAC, solar technologies, design analysis, etc.

This paper presents brief review of simulation tools and generalized design guidelines, mainly from the architectural and structural point of view, as well as recommendations for HVAC, heating and other systems based on the authors' researches and gathered from the literature. Many of the guidelines are universal, i.e. applicable over a wide range of climates, but readers are encouraged to consult other literature sources for more detail on passive cooling strategies and active solar cooling technologies. There are various guidelines and empirical rules of thumb that can be used and appropriate parameters to be specified.

Two types of simulation tools are used in practice: open architecture tools (white box tools) and black box tools. Open architecture tools, such as TRNSYS, ESP-r and EnergyPlus, allow the user to examine and modify the source code to meet specific modeling needs. These tools generally take longer to learn and have less friendly graphical user interfaces, but they are more flexible for merging with different optimization tools. Black box tools, such as HOT2000, Energy10, and EE4, tend to have more intuitive and streamlined interfaces and often are used with open architecture tools, in such a way that the inputs are entered in the former and calculations are done in the latter.

The choice of proper simulation tool is only one half of the problem, because there are numerous combinations of different features and options, among which the best one (or the most appropriate one) should be found. Because of that, the search for the optimal solution should not be limited to testing several possible designs, but should be thorough, detailed and based on multidisciplinary scientific optimization methods from the scope of the operational research. During the last two decades, numerous optimization algorithms have been developed, especially in the field of meta-heuristics. Due to the complexity of the optimal green building design problem, genetic algorithms (GA) have been proven to be very useful optimization tool, mainly because they can handle nonlinear, poor-defined problems of multi-dimensional search spaces with many local minima. Another big advantage of the GAs is the possibility of relatively easy merging with open architecture tools, especially EnergyPlus. GAs have been used to optimize different building systems, including solar collector and storage tank size (Kalogirou, 2004); a low-energy community hall including shape of perimeter, roof pitch, constructional details of envelope, window types, locations and shading, and building orientation (Coley and Schukat, 2002); window size and orientation (Caldas and Norford, 2002); conceptual designs of office buildings (Grierson and Khajehpour, 2002); and HVAC sizing, control, and room thermal mass (Wright, Loosemore and Farmani, 2002). Recommendations and guidelines presented in this paper are based on the authors' researches using the GA coupled with the EnergyPlus software (Milajić, Beljaković and Milovanović, 2012), as well as the experiences and conclusions of other authors found in the literature.

LANDSCAPING, FLOOR PLAN AND ORIENTATION

Generally, a rectangular floor plan is the best one for passive solar design, with the longer (east-west) axis of the house oriented within 10 degrees of true south.8 In case that a house has to have off-south orientation, east is better than west because it will help in heating the house during the morning and avoid direct sunlight in the afternoon. The ideal length-to-width ratio is 1.3-1.5 (Milajić, Beljaković and Milovanović, 2012; Chiras, 2002). In addition, a two-story compact house is better than a single-story house because its exterior building envelope is smaller per unit size of floor space. The layout of the interior space should be designed in such a way that daily activities correspond to the changes of natural lighting and temperature, i.e. the sun's path across the sky.8 Besides that, internal layout should promote natural ventilation by using large open spaces and openings for air in order to enable flow between floors and between north and south zones. If the partition walls are needed, it is recommendable to orient them in the northsouth direction because it would enable better ventilation (CMHC, 1998). Landscaping is an important element of any given passive solar design. Trees can improve the performance by providing a barrier from the incoming cold wind as well as by providing a shade during the summer. On the other hand, trees can also be detrimental in the performance of the designed passive house because they can block incoming solar radiation. Therefore, the trees should be located at least three times their projected height away from the south wall of the house (Milajić, Beljaković and Milovanović, 2012; Chiras, 2002). If the PV is used, shading on the modules should be avoided as much as possible, because even a little or partial shade on the modules can significantly influence the performance of the whole system, since cells are typically connected in series.

THERMAL MASS, WINDOWS AND SHADING

The term *thermal mass* describes the ability of a given material to store heat and to absorb and release it at a rate roughly in step with a building's daily heating and cooling cycle. Due to their density, concrete and masonry products do this well. Timber absorbs heat too slow to offer much effective thermal mass, while steel conducts heat too fast to be in synch with a building's natural daily heat flows. Additional thermal mass is required if the south-facing window area is larger than 8% of the total heated floor space (Milajić, Beljaković and Milovanović, 2012; Chiras, 2002). Indirectly heated mass (by warm air from living space) requires roughly four times more area than the same mass heated directly (exposed to the sun) to provide the same thermal effect (Chiras, 2002). Carpets reduce effectiveness of thermal mass by up to 70% and vinyl floors can reduce effectiveness by up to 50% (CMHC, 1998). The optimal amount of glazing depends on the total heated floor area, total thermal mass and other design parameters. In general, for direct passive solar heating, south-facing glazing should be 7-12% of total floor space (Milajić, Beljaković and Milovanović, 2012). If there are two or more solar features, total amount of south-facing glass can be increased but should not exceed 20% of the heated floor space. Automatically controlled blinds can enable effective use of south facing window areas up to 20% of floor area (Athienitis and Santamouris, 2002). One large window is preferred to several small windows. It is recommended to locate the operable windows on opposite walls in the direction of prevailing summer winds because natural cross-ventilation can reduce or eliminate the need for mechanical ventilation. The proper design and placement of shading devices is an important element in passive solar design. As a general rule, overhangs should be used in such a way that they do not shade windows on December 21 but shade 50-100% of the windows on June 21(CMHC, 1998). Blinds placed on the outside of the building will not heat up the indoor environment and will thus help reduce the cooling load. The control of the blinds can be coupled to the control of the heating and cooling equipment to help these systems to work together.

HVAC SYSTEMS

The interactions between the south-facing windows, thermal mass and the heating system need to be designed to ensure adequate comfort levels. The temperature in the heating season should only go above 25°C for 4% of the heating season (CMHC, 1998). In cases where a house has a south zone with higher solar gains and reaches higher temperatures than adjacent zones, circulating fans should be turned on when the hot space is 3–4°C hotter than the cold space. In the summer, ventilation through mechanical or passive measures should allow roughly ten air changes per hour, with most exhaust coming from hot spaces. Whenever there is a need for exhaust in the heating season, a heat recovery ventilator with effectiveness 80-85% should be used. When installing radiant-floor heating systems, it is important to provide insulation underneath the floor and around the perimeter of the foundation (5–10 cm of rigid foam insulation is reported to work well (Chiras, 2002). Radiant systems can also be utilized for radiant cooling although residential applications are not common and are even discouraged by some manufacturers because condensation can occur on the cool panels during a hot, humid day. Residential buildings, as opposed to commercial ones, have much higher rates of outdoor air infiltration from open windows and doors, making it more difficult to provide humidity control. If properly designed and controlled, the condensation problem can be overcome as long as radiant panels are maintained at a temperature above the dew-point temperature. If the building envelope is adequately designed to minimize daily temperature variations and radiant panel surface areas are sufficient, panels at temperatures above the dew point can sufficiently cool a given space.

AUXILIARY HEATING SYSTEMS AND DOMESTIC HOT WATER

Even if the solar energy is used for heating both the space and domestic hot water, there will still be a requirement for an auxiliary heating source for extended periods of cold weather and for extended overcast conditions with limited insolation. It is important to consider the total heat load that the auxiliary heater will need to provide. If the house can meet 90% of its heating requirements with solar, it may not make sense to install an expensive heating system to provide heating annually worth only 1-2% of its price (Athienitis and Santamouris, 2002). Although tankless heaters can constantly provide users with hot water at high energy-efficient performance compared to storage devices, they can draw large amounts of power in an unpredictable manner. This is acceptable for systems based on natural gas, but if electricity is used, this could drive up peak loads and create problems for utilities. This can be solved by using smart tanks that are heated from the top down, providing the ability to control the heated volume and to have faster recovery of usable water. Smart tanks with predictive control can be used to heat only the amount of water that would be required by users at a given time (Dennis, 2003).

Annual thermal performance of systems with smart solar tanks could be 5–35% higher than the thermal performance of traditional solar DHW systems, depending on hot-water consumption and consumption patterns (Furbo et al. 2003). They are most attractive if most hot-water consumption takes place in the evenings and least attractive when consumption is evenly distributed throughout the day. Reduced consumption during the day allows for a greater volume of water available to store the solar energy. The volume of the smart solar tank can be smaller than the volume of a traditional tank. Even though the estimated cost of a small solar smart tank is estimated to be 10% higher than traditional solar systems with electric auxiliary heating, the performance/cost ratio is about 25% using the smart tank.

CONCLUSION

Various design guidelines for the design of low and net zero energy solar homes are presented. It is important to understand the limitations of using general guidelines when making a design because they provide a range of possible solutions that have been found to work well. However, they do not provide necessarily the most optimal values to use for a particular design and only detailed simulation can help determine situation-specific optimal values. Advances in computing power have resulted in development of new design tools, such as GA-based optimization methodology, so the designers can determine the most costeffective mix of technologies that needs to be introduced to achieve the net zero target.

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DEVELOPMENT OF THE RENEWABLE ENERGY SOURCES IN THE REPUBLIC OF SERBIA – CASE STUDY OF THE WIND POWER PLANT „ČIBUK 1" IN THE TERRITORY OF THE MUNICIPALITY OF KOVIN

Rista Popović, M Arch, PhD candidate

Union Nikola Tesla Univesrity, *Energoprojekt Industrija*, Beograd

popovicrista2@gmail.com

Prof dr Tatjana Kosić, dia

Union Nikola Tesla University, Department of Architecture and Urbanism

ABSTRACT

Studies conducted by the Provincial Secretariat for Energy, Construction, and Transport indicate that the Republic of Serbia belongs to regions with significant potential for the use of wind energy. It has been proven that electricity generated by wind turbines is cheaper than that produced by thermal or nuclear power plants, and their operation does not cause pollution or harmful impacts. Using the wind power plant *„Čibuk 1"*, located in the munucipality of Kovin, as a case study, this paper explores the process of planning and constructing this wind park. This wind power plant , which spans an area of 37 km² whit an installed capacity of 142.5MW, currently represents the larges energy project in the field of wind energy in the Western Balcan and, as such, provides a suitable basis for research. The analysis of technical, legal, and regulatory conditions for integrating wind farms into the power grid in this paper aims to provide useful knowledge from pratcice into the potential, possibilities, and limitations associated with the use of this type of renewable energy. The scientific contribution of this paper lays down in providing a boarder perspective on the use of wind energy in the Republic of Serbia and the importance of utilizing this resource to relieve the power grid while simultaneosly preserving the environment.

Key words: *Energoprojekt*, renewable energy sources, wind power plant, Čibuk *1*.

INTRODUCTION

The importance of renewable energy sources in the modern world

Renewable energy refers to energy obtained from natural sources that are renewed faster than they are consumed. These include solar, wind, hydro, geothermal and biomass energy. The importance of renewable energy lies in its potential to provide sustainable energy solutions, while at the same time mitigating the negative effects of climate change (Amaka et al., 2025). In order to achieve the goal of zero net CO2 emissions set by the *Climate Protection Act for 2050*, more and more countries in the world are rapidly implementing the energy transition from fossil fuels to renewable energy sources. Although the key basis, the importance of the use and development of renewable energy sources in the modern world is not only a matter of climate change and environmental protection, but a number of other factors appear that contribute to an increasing number of countries deciding to develop the sector of renewable energy sources, namely:

- Energy independence, which reduces the need to import fossil fuels and increases national security in situations where there are frequent interruptions in the supply of fossil fuels.
- Economic growth and creation of new jobs. This factor includes the opening of factories for the production of equipment, the development of techniques and technology, the training of engineers and technicians, the establishment of services for the maintenance of plants for the production of renewable energy sources, the inflow of capital and foreign investors, etc.
- Market control - by accumulating large amounts of electricity from renewable sources, the opportunity for market control, export and price control is gained.

Renewable energy sources in the Republic of Serbia: Pioneering contribution of *Energoprojekt*

Founded in 1951 in Belgrade with the aim of contributing to the country's post–World War II reconstruction, *Energoprojekt* gradually became the largest construction company in the country, and later one of the key players in the global construction industry. It specialized in the construction of a wide range of facilities, particularly in the fields of hydro and thermal power plants, concrete dams, water management systems, industrial plants, and more (Jokšić & Petković, 1961). From the first hydroelectric power plants built more than 50 years ago, through the first grid-connected solar power plant in the Republic of Serbia commissioned in 2011 (installed on the rooftop of the *Energoprojekt's* office building), to *"***Čibuk** *1"* (currently the largest wind farm in the Western Balkans), *Energoprojekt* can be regarded as one of the pioneers in the design and construction of facilities for the utilization of renewable energy sources in this region.

Aim of the Paper and Methodology

The focus of this paper is on exploring the potential for wind energy utilization in the Republic of Serbia, as the second most dominant renewable energy source, following hydropower, which ranks first with nearly 70% of the total renewable energy production, generated by large and small hydroelectric power plants. Using the *"*Čibuk *1"* wind farm, designed by *Energoprojekt*, as a case study, the aim of this paper is to position this facility as a reference model within the construction industry in the region with regard to wind energy usage, given that it is a completed project that has been successfully commissioned and connected to the grid. The case study method, as the main scientific approach in this paper, supported by an analytical-descriptive method for the analysis of technical and legal aspects of the project, will be used to identify key phases in design, challenges, and engineering solutions. By understanding the essential elements, operational principles of the wind farm, required infrastructure, legal and other constraints, this paper aims to contribute to the enhancement of knowledge regarding the implementation of renewable energy sources in the field of wind energy in the Republic of Serbia.

THEORETICAL FRAMEWORK OF THE RESEARCH

Wind Energy Potential in the Republic of Serbia

Depending on geographical location, natural resources, and other potentials, each country approaches the utilization of the most suitable renewable energy source for its conditions. Although hydropower has been exploited for decades, largely thanks to *Energoprojekt* which designed and constructed numerous hydroelectric power plants (such as Đerdap HPP, Bajina Bašta HPP, Potpeć HPP, etc.), the Republic of Serbia is also characterized by windy areas that today represent the main untapped potential for the use of renewable energy sources.

The first studies aimed at determining the feasibility of wind energy utilization in this region were conducted in the early 2000s, establishing that the power systems of Serbia and Montenegro (SCG) are structurally very favorable for the installation of wind turbines (Radičević et al., 2003). In the following years, several significant investigations were carried out, such as (Gburčik et al., 2006), where the "Košava area" was identified as the windiest region, encompassing the Danube Basin from Slankamen to Golubac, and from Smederevska Palanka to Zrenjanin.

The most well-known and comprehensive study on this subject is the "Wind Atlas of the Autonomous Province of Vojvodina" (Katić & Ćosić, 2008), which clarifies many issues over more than 60 pages. The study states that approximately 1,300 MW of wind turbine generation capacity could be installed in the Republic of Serbia in the future, with an annual electricity production of around 2,300 GWh. The areas identified as having the highest wind intensity are Fruška Gora, Vršački Breg, and Southern Banat—precisely the region where, 11 years later, the construction of the largest wind farm in the Western Balkans, *"*Čibuk *1"* was completed.

General Operating Principles and Characteristics of Wind Turbines

The first wind turbine for electricity generation was constructed by Charles F. Brush in the USA in 1887. It featured a rotor with a diameter of 17 meters, consisting of 144 blades, and a 12 kW generator, but it was not very efficient (Sørensen et al., 2013). As a result of technological advancements in this field over the following century, modern wind turbines emerged, typically equipped with rotors having three blades and generators rated between 3 and 6 MW, which are currently the most widespread worldwide. Regarding wind turbines relevant to this study and used in our region, turbines with a capacity of 2.5 MW are predominantly utilized, characteristic of countries with less developed grid infrastructure.

The operating principle of a wind turbine is actually very simple. Wind energy is used to rotate the turbine, which converts the kinetic energy of the wind into electrical energy. The amount of energy that can be generated depends on the size of the rotor — the longer the blades, the greater the torque and the more energy is produced (Navarrete et al., 2019). The key components of a wind turbine are: the rotor, blades, brake, gearbox, low-speed shaft (driven by the rotor and connected to the gearbox), high-speed shaft (connected from the gearbox to the generator), generator, housing (nacelle), and tower.

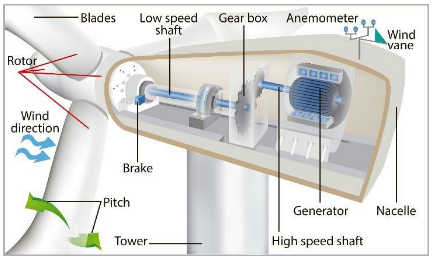

Figure 1. Wind turbine parts (Navarrete et al., 2019: Expert Control Systems Implemented in a Pitch Control of Wind Turbine: A Review: IEEE Access, Vol.7, 2019, p 2.)

Thus, a wind turbine represents a complete functional assembly of a system for converting the kinetic energy of wind into mechanical rotational energy of the turbine, and subsequently into electrical energy produced by the wind generator. The reason for having two shafts and a gearbox is that the wind generator produces electrical energy most efficiently at high rotational speeds. The brake and blade pitch control system are used in cases of strong winds, when it is necessary to reduce the rotor's rotational speed to prevent damage to the components, or during maintenance when the turbine needs to be completely stopped.

Environmental Aspects of Wind Turbine operation

Throughout the entire life cycle of a power plant — from construction, fuel exploitation, operation, transportation, maintenance, to decommissioning (removal of the facility) -pollutant emissions are expressed per unit of energy produced (usually per 1 kWh). According to the authors (Lago et al., 2009), the following table presents the amounts of these emissions, demonstrating that, compared to others, wind power plants produce the least pollution over their entire lifetime per 1 kWh of generated energy:

Table 1. Emissions of pollutants in the entire life cycle expressed per unit of produced energy 1 kWh (Lago et al., 2009: Wind Energy – The Facts, part V, Environmental Issues: EWEA European Wind Energy Association, p. 326)

	Wind Power Plant	TPP Coal	Nuclear Power Plant	Solar Power Plant	Biomass Power Plant
Carbon dioxide, fossil (g/1 kWh)	**8**	**836**	**8**	**53**	**83**
Methane, fossil (mg/1 kWh)	**8**	**2554**	**20**	**100**	**119**
Nitrogen oxides (mg/1 kWh)	**31**	**1309**	**32**	**112**	**814**

NMVOC (mg/1 kWh)	**6**	**71**	**3**	**20**	**66**
Particulates (mg/1 kWh)	**15**	**147**	**17**	**107**	**144**
Sulphur dioxide (mg/ 1 kWh)	**32**	**1548**	**46**	**0**	**250**

However, the large-scale use of wind energy, which contributes to mitigating climate change, may involve trade-offs with biodiversity, a phenomenon known as the "green–green" dilemma. The coexistence of renewable energy infrastructure and wildlife can mean that emission reduction targets are achieved at the expense of environmental conservation goals (Sander et al., 2024). Although wind turbines reduce CO_2 emissions, contributing to the fight against climate change, they can pose threats to birds, bats, and habitats, negatively impacting biodiversity. The importance of this dilemma lies in highlighting that ecological decisions are not always straightforward and require thorough assessment of the wind farm's entire life cycle, local impacts on nature and communities, and a broader view of sustainability beyond just climate considerations.

Investment Aspects

With the adoption of the Energy Law in the Republic of Serbia in 2011, the legal framework for the utilization of renewable energy sources was established, defining the system of "feed-in" tariffs and the status of privileged electricity producers. These tariffs represent guaranteed purchase prices per kWh for a period of 12 years, which is used as the basis for investment return estimation. According to (Safner et al., 2013), wind farm construction projects in the Republic of Serbia are investments that, under the mentioned "feed-in" tariff system, prove profitable for investors over a multi-year period. The advantages of investing in wind farm construction lie in the fact that maintenance costs are the only significant expenses once the project is fully realized. Nonetheless, there remains a possibility of unforeseen costs arising from environmental and biodiversity impacts or potential dissatisfaction within the local community.

CASE STUDY: THE WIND POWER PLANT "ČIBUK 1" IN THE TERRITORY OF THE MUNICIPALITY OF KOVIN

General Project Information

The *"*Čibuk *1"* wind farm covers an area of approximately 37 km² and is located in southern Banat, near the village of Mramorak, on agricultural land at the northern edge of the Kovin municipality. Geographically, it is situated southeast of Belgrade and southwest of Pančevo, in the flatlands of Vojvodina

- a region identified in the relevant literature from the previous sections of this paper as having the most prominent wind conditions. The implementation of the *"*Čibuk *1"* project lasted approximately seven years. To address all components of this large-scale wind farm within the Detailed Design, it was necessary to develop more than 39 separate designs, reports, and studies - ranging from standard construction, electrical, and mechanical engineering designs, to the construction of a substation and control/operations building, access road projects, hydrant and sewage systems, and specialized wind power plant systems, such as protection and control systems or grid connection infrastructure.

Technical Characteristics and Operation

The *"*Čibuk *1"* wind farm has a total installed capacity of 142.5 MW, consisting of 57 wind turbines, each with an individual installed capacity of 2.5 MW. In the future, the construction of the *"*Čibuk *2"* wind farm is planned, with the same capacity as *"*Čibuk *1"* (Figure 2). For the construction of the *"*Čibuk *1"* wind farm, the selected wind turbine was the **"2.5-120" model** manufactured by the American company **General Electric.**

A specific feature of this turbine is its low cut-in wind speed of 3.0 m/s, while at a wind speed of 12.0 m/s, the turbine shuts down for safety reasons (Backović et al., 2013). At a wind speed of 3.0 m/s, the turbine delivers 25 kW, and at the maximum permitted wind speed of 11.5 m/s, it produces 2,528 kW of electrical power (For appearance of the wind turbine, see figures 3 and 4).

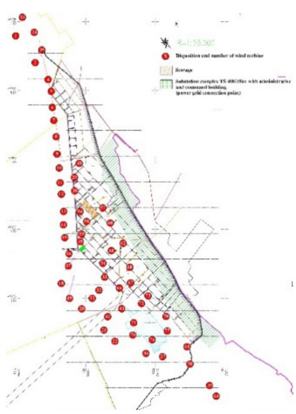

Figure 2.

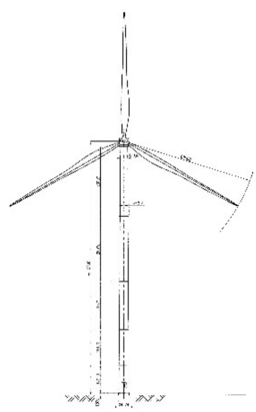

Figure 3.

Figure 4.

Figure 2*. Site Plan of the "***Čibuk** *1"and "***Čibuk** *2", R 1:25000 with the arrangement of wind turbines and the substation complex (Source: Vetroelektrana "***Čibuk** *1", Glavni Projekat, Opšta dokumentacija, Lokacijske dozvole, saglasnosi i prilozi, crtež broj E12050-G002);* ***Figure 3****. Wind turbine external appearance (Source: Vetroelektrana "***Čibuk** *1", Glavni projekat, Knjiga 2: Kompleks vetroelektrane, mašinski projekat – Mašinski projekat vetroagregata, crtež broj M12024-M002);* ***Figure 4****. Appearance of wind turbine on site (Source: Authors of the paper).*

Each wind turbine is equipped with its own control system that autonomously manages all operational processes (Dragumilo et al., 2013). During the analysis of technical solutions in accordance with the Geotechnical Study, an octagonal foundation was adopted for the wind turbine, with a circumscribed circle diameter of 20.00 meters. The foundations are supported by piles with an average length of 16.00 meters (Miletić et al., 2013) (For wind turbines base plan and section, see Figure 5).

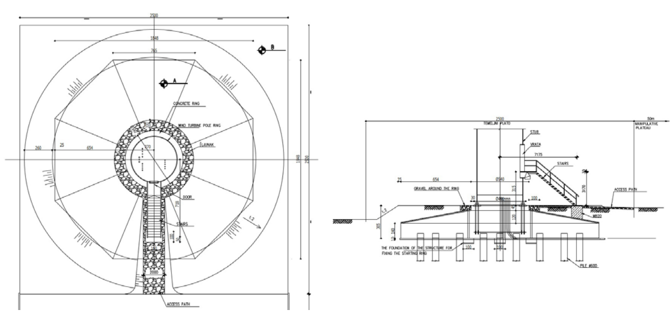

*Figure 5. Wind turbines foundations base plan and section (Source: Vetroelektrana "***Čibuk** *1", Glavni Projekat, Knjiga 2: Kompleks vetroelektrane, građevinski projekat temelja vetroagregata crtež broj G12056-G002)*

RESEARCH RESULTS

Based on a systematic analysis of the technical, infrastructural, legal, and environmental aspects of the *"*Čibuk *1"* wind farm, using original technical documentation, a preliminary tabular model was developed for the analytical assessment of key parameters of wind power facilities under similar spatial, climatic, and regulatory conditions. The purpose of this model is to serve as a reference point in the initial planning phase of wind farms and to enable a quick evaluation of land use, required infrastructure, and expected energy production outcomes, taking into account the optimal technical configurations of an already implemented system.

Methodological Framework for Defining Input Parameters

With the aim of developing a practical model for the preliminary planning of wind farms, the key input parameters were defined based on a techno-spatial analysis of the already implemented *"*Čibuk *1"* project. As the largest wind farm in the Republic of Serbia, *"*Čibuk *1"* provides reference values that are reliable and applicable to similar locations. The selected input parameters were determined according to the following criteria: wind turbine capacity, turbine layout, safety (buffer) zone, and access roads. Based on the adopted parameters, a tabular overview of average values was developed to enable the assessment of technical, spatial, and environmental characteristics of wind farms by capacity (table 2).

Table 2. Presentation of the assessment of technical, spatial and environmental characteristics of wind power plants (Source: Authors of the paper)

Number of Wind Turbines	Total installed Capacity (MW)	Annual Energy Production (GWh)	Number of Household Supplied Annually	Land Use (ha)	Access Roads (km)	CO_2 Reduction (t/year)
3	**~7.5MW**	**~25GWh**	**~6.000**	**~7,64ha**	**~1.26km**	**~19,500**
6	**~15MW**	**~50GWh**	**~12.000**	**~15,28ha**	**~2.52km**	**~39.000**
9	**~30MW**	**~100GWh**	**~24.000**	**~30.56ha**	**~5.04km**	**~78.000**

Uncertainty Analysis: Although the results presented in the table of average values are based on real input parameters from reliable sources, it is necessary to consider potential uncertainties in the estimations that may affect the reliability of the model. Therefore, uncertainty analysis is essential in order to examine possible scenarios and ensure that the results can be effectively used within both design and investment frameworks. The main sources of uncertainty may include: **the distance between wind turbines, topographical and infrastructural conditions, legal regulations, and technological variations.**

DISCUSSION AND CONCLUDING REMARKS

This paper is designed to integrate theoretical foundations with the analysis of a specific example – the first large-scale wind power plant in the Republic of Serbia, developed within modern regulatory and infrastructural frameworks. Through the case study of the *"*Čibuk *1"* wind farm, the complexity of the wind farm design process is demonstrated, involving a wide range of technical disciplines such as power engineering, civil engineering, transport engineering, spatial planning, and environmental protection.

As part of this study, a tabular framework was developed, which may be considered a methodological innovation in the early-stage design of wind farms. Unlike complex and demanding software tools such as WAsP (Wind Atlas Analysis and Application Program), which according to (Çelik et al., 2021) are applied in later phases of project development (for wind atlas creation, resource assessment, and turbine micro-siting), the proposed tabular approach in this paper enables a quick, approximate, and systematic evaluation of key infrastructure requirements. In the initial phase - when the basic spatial and technical concept is being established - using a simple tabular model may offer greater practical value than software that requires additional time for configuration and data processing. Instead of relying exclusively on software tools based on statistical or theoretical assumptions, this methodology compiles information derived from the reference project *"*Čibuk *1"*, in which all input data used in the tabular framework were empirically validated through an already implemented project.

Certainly, the aim of this paper is not to provide an alternative to highly specialized software tools, but rather to contribute to the development of a complementary methodology tailored to the early stages of wind farm design - one that can be applied without the need for costly analyses. In this way, the tabular model not only enhances the understanding of the infrastructure requirements of wind power plants but also creates an opportunity for its further refinement and integration into more complex systems for planning renewable energy sources, which could be particularly useful in countries planning large-scale wind farms for the first time.

ACKNOWLEDGEMENTS

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AIR POLLUTION FROM HOSPITALITY ESTABLISHMENTS – CHARACTERISTICS AND PROPOSED MEASURES

Ivana Stošić[1], Tatjana Kosić[2], Bogdan Lazić [3]

[1,2,3] Faculty of Construction Management, University Union Nikola Tesla, Belgrade

E-mail of the coresponding author: istosic@unionnikolatesla.edu.rs

Abstract

Hospitality facilities constitute a significant segment of the building stock and, by their function, fall under the tourism sector - an industry that substantially contributes to raising living standards and, indirectly, to the broader economic development of a country. Consequently, the assessment of air pollution originating from hospitality establishments represents a key parameter in the formulation and implementation of measures aimed at its mitigation, as part of the broader requirements for the preservation, protection, and recovery of ecological systems. Air quality in urban environments pertains to the presence or absence of airborne pollutants that may adversely affect human health and the environment. In such areas, restaurants are recognized as notable sources of air pollution due to various food preparation processes, fuel combustion, and emissions from ventilation systems. These activities result in the release of numerous gases and particulate matter, which can degrade air quality and pose health risks. Major pollutants include carbon monoxide (CO), nitrogen oxides (NOx), and grease particulates (PM10 and PM2.5). An analysis of current mitigation options for air pollution from hospitality sources indicates considerable potential for further research and innovation in this area. The study identifies a selection of feasible pollution control measures that can be directly implemented in hospitality facilities. Effective strategies for pollution reduction involve a combination of regulatory frameworks, technological advancements, and the promotion of sustainable practices.

Keywords: air pollution, urban air quality, hospitality industry, sustainable practices

INTRODUCTION

Air pollution represents one of the most serious environmental challenges of modern society, with significant impacts on human health, biodiversity, and climate change (Thomas, 2017). While industry, transportation, and the energy sector are often recognized as the main sources of pollution, the role of hospitality establishments in the emission of harmful substances into the atmosphere is increasingly coming into focus (Robinson et al., 2018). Hospitality establishments, including restaurants, cafés, and bars, use various food preparation technologies, fuel combustion systems, and ventilation equipment that can emit considerable amounts of pollutants into the atmosphere (Lyu et al., 2022).

Processes such as frying, baking, and cooking release various gases, grease particles, and odors, while the combustion of fuels contributes to the emission of carbon monoxide (CO), nitrogen oxides (NOx), and fine particulate matter (PM10 and PM2.5) (ElSharkawy & Ibrahim, 2022). Although these emissions are localized, in urban environments with a high density of hospitality establishments they may cumulatively and significantly degrade air quality, affecting respiratory health as well as the aesthetic and olfactory characteristics of the environment (Chang et al., 2021).

Given the growth of tourism and the increasing number of hospitality establishments in cities, it has become necessary to examine their ecological consequences and to develop effective strategies for reducing emissions (Robinson et al., 2018). The aim of this paper is to analyze the characteristics of air pollution originating from hospitality establishments and to present proposed measures for its reduction. Particular attention is placed on the identification of key pollutants, the assessment of their impact on air quality and human health, and the proposal of effective strategies for emission reduction. By combining regulatory approaches, technological solutions, and the promotion of sustainable practices, the goal is to contribute to the preservation of urban air quality and the protection of the environment.

CHARACTERISTICS OF AIR POLLUTION FROM HOSPITALITY ESTABLISHMENTS

The main sources of air pollution in hospitality establishments are kitchens, ventilation and heating systems, as well as the use of solid fuel or gas stoves (Lyu et al., 2022). During food preparation, various pollutants are released, including grease particles, smoke, carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and characteristic odors (ElSharkawy & Ibrahim, 2022). These emissions are not only locally present but can also spread into the surrounding environment through ventilation systems, thereby contributing to the degradation of urban air quality (Robinson et al., 2018).

Of particular concern are PM2.5 and PM10 particles, which are small enough in diameter to penetrate deep into the respiratory system, causing pneumonia, exacerbation of asthma, cardiovascular issues, and other chronic health disorders (Lyu et al., 2022). Grease particles generated during frying and grilling can accumulate on the surfaces of ventilation ducts, further obstructing system performance and increasing the risk of secondary emissions into the surrounding environment (Chang et al., 2021).

Poorly maintained or outdated ventilation and flue gas exhaust systems further increase the concentration of pollutants both inside the establishment and in its immediate surroundings (ElSharkawy & Ibrahim, 2022). The use of solid fuel stoves or traditional gas appliances may additionally contribute to CO and NOx emissions, which is particularly pronounced in establishments with limited air circulation (Robinson et al., 2018).

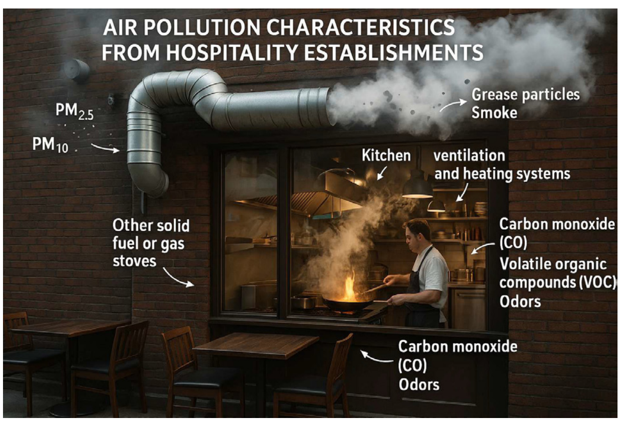

Figure 1 - Impact of restaurant ventilation on urban air quality

In addition to the physico-chemical characteristics of emissions, an important factor is the spatial context in which the establishment is located. In densely populated urban areas, the cumulative effect of emissions from multiple restaurants and cafés can lead to an increase in local concentrations of pollutants, thereby significantly deteriorating air quality and increasing health risks for the population (Lyu et al., 2022).

Taking all these factors into account, it is clear that hospitality establishments, although often overlooked as a source of pollution, play a significant role in the urban ecosystem and that there is a need for the implementation of appropriate preventive and corrective measures (Chang et al., 2021).

IMPACT OF AIR POLLUTION FROM HOSPITALITY ESTABLISHMENTS

Emissions from hospitality establishments have multiple consequences, both on human health and on environmental quality in urban areas (Robinson et al., 2018). Toxic substances generated during cooking processes, including PM2.5 and PM10 particles, carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs), can cause both acute and chronic health problems (Lyu et al., 2022). Fine particles such as PM2.5 penetrate deep into the lungs and bloodstream, potentially triggering inflammatory processes, aggravating asthma, causing respiratory infections, and contributing to cardiovascular disorders (ElSharkawy & Ibrahim, 2022).

Beyond their direct impact on health, air pollution from hospitality establishments also affects the quality of the urban environment. Deposits of grease particles and organic compounds can contaminate building facades, sidewalks, and surrounding surfaces, leading to aesthetic degradation and increased maintenance costs of urban spaces (Chang et al., 2021). Poorly maintained ventilation systems further contribute to the spread of odors and particles in the immediate surroundings, influencing the microclimate and quality of life of residents living near such establishments (Robinson et al., 2018).

In urban areas with a high concentration of restaurants and cafés, the cumulative effects of these emissions become significant (Lyu et al., 2022). Studies have shown that in densely populated city districts, local concentrations of PM2.5 and VOCs can be considerably higher compared to average urban levels, thereby increasing the risk of respiratory and cardiovascular diseases among local populations (ElSharkawy & Ibrahim, 2022).

In addition to human health, pollution from hospitality establishments also affects the surrounding ecosystem. Cultural heritage sites, green areas, and trees may be impacted by particle deposition, which reduces photosynthetic activity and degrades the aesthetic quality of urban spaces (Chang et al., 2021). This further emphasizes the need for preventive and corrective measures to mitigate the negative impact of hospitality establishments on the urban environment (Robinson et al., 2018).

PROPOSED MEASURES FOR REDUCING AIR POLLUTION FROM HOSPITALITY ESTABLISHMENTS

Considering the identified impacts and characteristics of emissions, effective reduction of air pollution in hospitality establishments requires a comprehensive approach that incorporates technological, regulatory, and organizational measures (Chang et al., 2021).

Technological Measures

- **Advanced filters and grease separators:** The installation of high-quality grease filters and electrostatic precipitators significantly reduces emissions of PM2.5 and PM10 particles, as well as greasy aerosols (Lyu et al., 2022).
- **Thermal oxidation and VOC absorption systems:** Efficient combustion of organic compounds decreases emissions of volatile organic compounds and unpleasant odors, thereby improving air quality both inside the establishment and in its surroundings (ElSharkawy & Ibrahim, 2022).
- **Regular maintenance of ventilation systems:** Proper cleaning and servicing of ventilation ducts prevent grease accumulation and secondary emissions of pollutants (Chang et al., 2021).
- **Use of cleaner energy sources:** Transitioning from solid fuel stoves to electric or low- emission gas appliances reduces overall emissions of CO and NOx (Robinson et al., 2018).

Regulatory Measures

- **Emission standards:** Introducing legal regulations that define maximum allowable concentrations of PM, CO, NOx, and VOC emissions for hospitality establishments (ElSharkawy & Ibrahim, 2022).

- **Inspections and controls:** Regular inspections of ventilation systems and the implementation of technological solutions ensure compliance with prescribed standards (Lyu et al., 2022).
- **Urban planning and zoning:** Locating hospitality establishments in line with air flow dynamics and at adequate distances from residential and public spaces reduces cumulative negative impacts on air quality (Chang et al., 2021).

Promotion of Sustainable Practices

- **Optimization of food preparation processes:** Reducing frying time, using smaller amounts of oil, and applying less polluting cooking techniques (Robinson et al., 2018).
- **Staff education:** Raising awareness about the importance of preserving air quality and properly maintaining equipment contributes to continuous emission reduction (Chang et al., 2021).
- **Implementation of "green kitchens":** Using energy-efficient appliances, reducing waste, and recycling materials lower the overall ecological footprint of establishments (Lyu et al., 2022).

The implementation of these measures contributes to reducing the negative impact on human health and the environment, improves the microclimate in urban areas, and enhances the sustainability of the hospitality sector. Effective implementation requires coordination between establishment owners, regulatory bodies, and local communities, as well as continuous monitoring of the effects of applied strategies (ElSharkawy & Ibrahim, 2022).

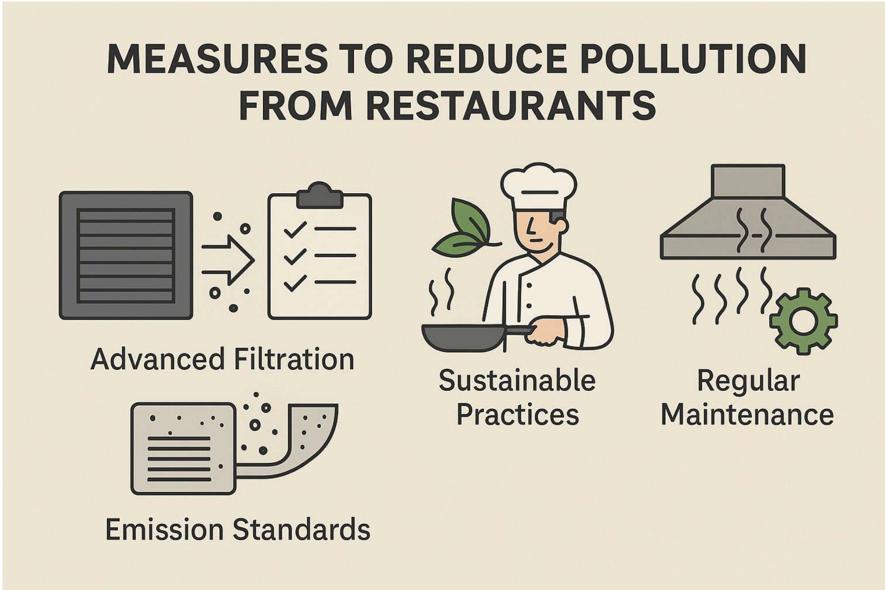

Figure 2 - "Proposed Strategies for Mitigating Restaurant Emissions"

CONCLUSION

Air pollution originating from hospitality establishments represents a complex and often underestimated problem in urban environments (Robinson et al., 2018). The analysis of emission sources and characteristics has shown that food preparation, the use of energy equipment, and inadequately maintained ventilation systems generate significant amounts of gaseous and particulate pollutants, among which PM2.5 and PM10 particles are of particular concern (Lyu et al., 2022). Their impact on human health, quality of life, and ecological balance requires a serious and systematic approach (ElSharkawy & Ibrahim, 2022).

The proposed measures—ranging from the application of advanced filters and energy-efficient technologies, through stricter regulatory frameworks and regular inspections, to the promotion of sustainable practices and staff education—demonstrate that there are realistic and applicable strategies for reducing this type of pollution (Chang et al., 2021). Their implementation requires cooperation between hospitality establishment owners, local governments, and state institutions, with the active involvement of experts and the public (Robinson et al., 2018).

The results of this research indicate that reducing air pollution from hospitality establishments is not only technically and regulatorily feasible but also essential for improving the quality of life in urban areas and for preserving sustainable development (Lyu et al., 2022). This topic also opens space for further research and innovation, particularly in the development of new filtration technologies and the optimization of energy systems, thereby guiding the hospitality sector toward more sustainable and environmentally responsible practices (ElSharkawy & Ibrahim, 2022).

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TWO REALITIES OF ARCHITECTURE: FROM TECHNOLOGICAL EUPHOIA TO IRONY OF POPULAR CULTURE

Tatjana Anđić, Vladimir Stevanović

University „Union-Nikola Tesla", Faculty of Construction Management

Belgrade, Serbia

zecevictatjana@yahoo.com

ABSTRACT:

This paper examines and compares two seminal architectural manifestos of the 20th century: „Vers une Architecture" (1923) by Le Corbusier and „Learning from Las Vegas" (1972) by Robert Venturi, as articulations of fundamentally divergent theoretical positions, modern and postmodern. Le Corbusier advocates for functionality, universalism and abstract forms, conceptualizing architecture as a rational and technically efficient „machine for living". In contrast, Venturi contests modernist dogma by affirming symbolism of popular culture as valid architectural language. Both authors engage with the material reality of their time. Le Corbusier literally adopts the forms of technical and industrial civilization (silos, airplanes, factory chimneys, ocean liners) as a model for architecture. Venturi ironically draws from the seemingly banal visual vocabulary of popular culture (commercial streets of Las Vegas, including neon signage, billboards and vernacular landscapes) using ambiguity to challenge modernist orthodoxy. Through this comparative analysis, the paper reflects on the paradigmatic shift in 20th century architectural theory, from the abstract universalism of modernism to the contextual embedded language of postmodernism. While Le Corbusier reduces architecture to essential functional components, Venturi emphasizes complexity, contradiction and layered meaning. Ultimately, the study concludes that the tension between these contrasting approaches remains vital, offering a framework for critical reflection on the interplay between form, function, context, and user experience in contemporary architecture.

Key words: Le Corbusier, Robert Venturi, Vers une Architecture, Learning from Las Vegas, modernism, postmodernism, architectural theory, form and function, symbolism in architecture

INTRODUCTION

The architecture of the 20th century was marked by great theoretical conflicts that shaped the way we look at, and build space today. The book „Vers une Architecture" [Fig. 1] by the Swiss-French architect Le Corbusier is a manifesto of modernist thought and a rational approach to construction. In this book, Le Corbusier declares that architecture should follow functionality, simplicity and universal principles of beauty, relying on analogies with machines, ships and cars as symbols of progress and precision. This text formed the foundations of the modernist paradigm, calling for the rejection of historical styles in favor of a new, logical and functional architecture. In contrast, the book „Learning from Las Vegas" [Fig. 2] by Robert Venturi, Denise Scott Brown and Steven Isenour, presents a critique of modernism and its reexamination through the prism of postmodern thinking. Venturi rejects the idea of universality and functional „purity", advocating an architecture that embraces symbolism, irony, complexity and meanings taken from popular culture. Through analysis of the city of Las Vegas, the authors indicate the importance of communication in architecture and restore the importance of ornament and sign. This comparative analysis of two opposing theoretical directions provides an insight into the transformation of architectural thought and values in the modern age.

Fig. 1: „Vers une Architecture", bookcover

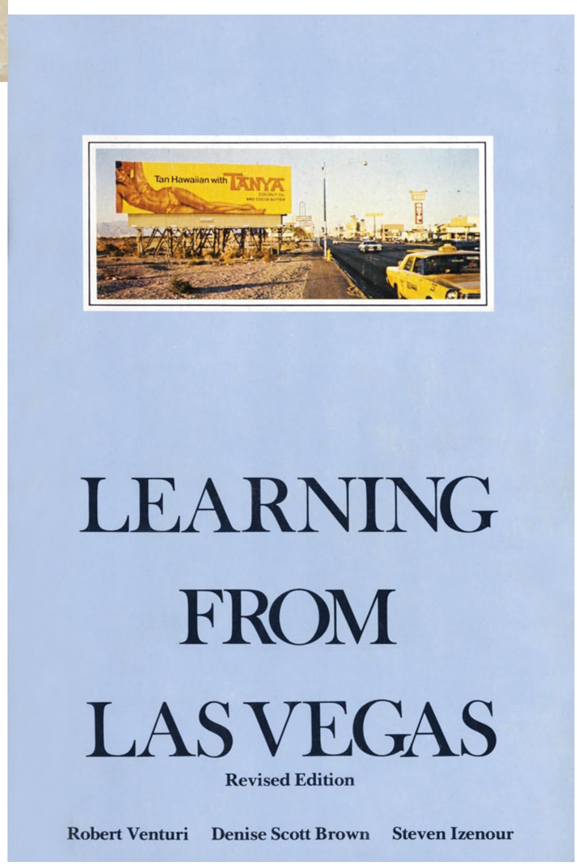

Fig. 2: „Learning from Las Vegas", book cover

VERS UNE ARCHITECTURE

The book „Vers une Architecture" by Charles-Édouard Jeanneret, better known under the pseudonym Le Corbusier, is one of the most important written works of modern architecture. First published in 1923, this book represent the manifesto of the modernist movement and a seminal text that shaped twentieth century architectural thinking. In this book, Le Corbusier emphasizes the principles of rationalism, functionality and aesthetics based above all on proportions, simplicity and technical progress. Also, he declares that architecture should reflect the spirit of the industrial age and be based on functional needs rather than ornamentation and tradition. The book „Vers une Architecture" caused a strong impact on modern architecture, but also harsh criticism. While many celebrated his vision of functionality and rationality, others felt that his approach neglected not only the emotional, but also the social aspects of housing. Critics have often pointed out that his cities, as well as buildings, can seem somewhat cold and inhuman.

The main principles of „Vers une Architecture" are the primacy of functionality, the aesthetics of the modern age and criticism of every type of ornament. Le Corbusier was fascinated by the technical achievements of his time, such as cars, ships and airplanes. He believed that architects should learn from engineers who design functional, rational and aesthetically pleasing objects. For him, the airplane was a symbol of perfection, and he often used airplanes as a metaphor for the perfect union of function and form. The book declares that airplanes represent the pinnacle of human genius due to their rational construction. In addition to airplanes, the automobile also appears as an inspiration for house design: He compares the automobile industry to architecture, criticizing buildings as „obsolete" compared to the efficiency and progress of automobiles[1].

The book „Vers une Architecture" had a significant impact on contemporary architecture, shaping not only the aesthetic principles of modernism but also the approach to urbanism, design and functionality. Ideas presented became the main rappers for the development of 20th century architecture, while some of the key influences includes the influence on modernism, because Le Corbusier is considered one of the founders of the modernist movement, along with architects such as Walter Gropius, Mies van der Rohe and Alvar Aalto. Principles presented in the book, became the foundation for the International Style, which is characterized by clean lines, minimalism, the use of industrial materials (concrete, steel, glass), and primarily focus on functionality[2]. Practical applications of these

1 Le Corbusier. (1986). Towards a new architecture. Dover Publications. 88-95

2 Le Corbusier. (1986). Towards a new architecture. Dover Publications. 30-50

ideas can be seen in modernist buildings around the world, including residential and public buildings as well as business centers. Le Corbusier radically changed the concept of housing. His principles of functionality and efficiency had a huge impact on the design of residential buildings in the mid 20th century, especially in the post-war period when it was necessary to provide mass housing. The Unité d'Habitation project, first realized in Marseille between 1947–1952, became the prototype for apartment blocks around the world. The concept of integrating apartments, commercial spaces and common facilities has inspired many architects. His ideas about modulor (the previously mentioned system of proportions) and serial production inspired prefabrication and an industrial approach to the construction of residential buildings.

Through this book and his later works, he promoted the idea of modern urbanism based on zoning and functional organization of space. His vision of tall buildings in green spaces has become a key element of urban planning, especially in North and South America, Europe and Asia. The idea that residential, commercial and industrial spaces should be physically separated became the basis for many urban plans of the 20th century. However, his vision of cities was often criticized as too rigid and dehumanizing. Examples such as the socialist blocs in Eastern Europe were often directly inspired by his ideas, but later proved unsuitable for human interaction and social cohesion[3]. Le Corbusier was among the first to integrate technology and industrial methods into building design. His approach enabled efficient construction using prefabricated elements, new materials, such as reinforced concrete and steel, as well as the application of industrial standards in architecture. These techniques became the basis for mass construction in the second half of the 20th century. His use of raw concrete (béton brut) in projects such as the Unité d'Habitation and the Chapel at Ronchamp (although not part of this book, they reflect its principles) became an inspiration for Brutalism, an architectural style that developed between 1950s and 1960s. Brutalism focuses on monumental forms and the use of materials with emphasized functionality[4].

Although his ideas initially celebrated progress and modernization, they were later criticized for their perceived „coldness“ and lack of humanity. His models of social housing often proved to be unadapted to human needs, because they neglected social dynamics. Urban plans that relied on the separation of functions led to the creation of monotonous, unattractive and partially isolated communities. Nevertheless, architects and theoreticians today are reevaluating

3 Le Corbusier. (1986). Towards a new architecture. Dover Publications. 30-50

4 Curtis, R. (1996). Modern architecture since 1900 (3rd ed.). Phaidon Press. 342-350

his work, recognizing the importance of a balance between functionality, aesthetics and human needs. Le Corbusier laid the foundation for many contemporary architectural practices. Its concepts and principles are still being studied and reinterpreted. His ideas revolutionized architecture and urban planning, paving the way for a more rational, functional and technologically advanced approach to design. Although some of his visions have been criticized for social and emotional flaws, his contribution is undeniable, while contemporary architects continue to find inspiration in his principles. From all of the above, it can be concluded that the book „Vers une Architecture" was and remains the key manifesto of the modernist movement.

LEARNING FROM LAS VEGAS

The book „Learning from Las Vegas", written by Robert Venturi, Denise Scott Brown and Steven Isenour, was published in 1972 and represents a key text of postmodernist architecture. This book is known for questioning modernist principles and highlighting the importance of popular culture, signs and symbolism in architecture. Their exploration of Las Vegas brought a whole new perspective on urban planning and design. The main thesis of this book and its context is analyze of the architecture and urbanism of the city of Las Vegas as an example of a city that relies on communication through signs, symbols and popular aesthetics. They argue that architecture does not have to be functionalist and minimalist (as proposed by modernism), but can be rich in meaning and references from popular culture[5]. Their key thesis is that Las Vegas, with its flashing advertisements, kitschy buildings and symbolic forms, has much to teach architects about communication and the relationship between people and space. The authors introduce two concepts to describe different approaches to architecture[6]:

1. Duck: Building whose shape is entirely based on symbolism. The name comes from a duck shaped store in Long Island, which itself is a huge symbol of what it sells (ducks and eggs). This approach emphasizes form and metaphor as the main elements of architecture.
2. Decorated Shed: Simple building whose identity and meaning comes from the addition of signs or decorations represents the approach Venturi prefers because it allows for functional flexibility and communication

5 Venturi, R. (1966). Complexity and contradiction in architecture. Museum of Modern Art. 78-95

6 Venturi, R. (1966). Complexity and contradiction in architecture. Museum of Modern Art. 122

through signs, an example being typical buildings along the Las Vegas freeway, such as motels or restaurants with large neon signs.

The authors use Las Vegas as a laboratory for research of architectural symbolism and the behavior of space users. Their analysis focuses specifically on neon signs, where Venturi declares that these signs are crucial to understanding space and interaction, as they serve as guides through the city and convey messages over a distance. It also studies the freeway and the car as a kind of specific spatial experience, because Las Vegas was primarily designed for car users, not pedestrians, which is revolutionary in the context of urbanism. This dynamic changes the way the city is perceived. Venturi directly criticize modernist principles, especially abstract, universal aesthetics that ignore historical, social and cultural contexts. Authors believe that modernism favors functionality at the expense of symbolism and meaning. Also, that architecture should be inclusive, thus reflecting popular culture and everyday life. This criticism was part of the wider postmodernist movement, which emphasized pluralism, historical reference and symbolism in architecture. At the same time, they advocate the idea that architecture should speak through signs, decorations and context. He suggests that architects should recognize the importance of symbolism in shaping space, even when that symbolism comes from „low" or „popular" culture. Venturi's famous phrase from this book is „Less is a bore", which represents a direct opposition to Mies van der Rohe's modernist slogan „Less is more". Venturi thus emphasizes the need for richness of meaning and layering of architectural forms[7].

The book significantly influenced postmodernist architecture and urbanism, offering an alternative to modernist dogma. Key influences include laying the groundwork for postmodernist architects such as Michael Graves, Charles Moore, and Philip Johnson, who used historical references, ironic elements, and symbolic forms in their work; analysis of Las Vegas inspired acceptance of commercial aesthetics and popular culture as legitimate elements of design. In terms of urbanism and spatial design, this book changed the way cities and spaces are analyzed, focusing on users, communication and symbolism. Finally, Venturi introduced a humanistic approach to architecture, which includes sociological, cultural and anthropological aspects[8]. It follows from the above that this is a provocative book that changes the paradigm of architecture and urbanism, call-

7 Tafuri, M. (1976). Architecture and utopia: Design and capitalist development. MIT Press. 175-188

8 Brown, S. (2013). Having words: Critical writings on architecture. Architectural Association. 55

ing for the rejection of the rigidity of modernism and the acceptance of the rich symbolism of everyday life. Their work illuminates the importance of communication, functionality and cultural context, providing a new vision of architecture that reflects the complexity and diversity of contemporary society.

COMPARATIVE ANALYSIS OF THE BOOKS

The books discussed here represent two fundamentally different paradigms in architecture, reflecting profound changes in society, technology and culture during the 20th century. While Le Corbusier strives to create a universal, rational and functional architecture based on abstract principles, Venturi point to the importance of symbolism, context and everyday experience in architectural expression[9]. Le Corbusier, writing in the context of industrialization and social transformations at the beginning of the 20th century, sees architecture as a tool for reshaping society. In „Vers une Architecture", he defines architecture as a discipline that should free itself from historical embellishments and traditions, focusing on rationality and functionality. Its principles, such as „machine for living' and „form follows function', express a belief in universal values and the power of technology to improve the quality of life. In his opinion, architecture should be strictly geometric, minimal and efficient, while decoration and local specifics represent superfluous elements that disturb the purity of the design.

In contrast, the book „Learning from Las Vegas", represents a radical reaction to modernist rigidity. In this section, the authors analyze the urban landscape of Las Vegas, a city that symbolizes consumer culture, kitsch and the fragmentation of modern society. Instead of dismissing these phenomena as unimportant or inauthentic architecture, Venturi embrace and understand them as legitimate expressions of contemporary social life. They emphasize the importance of symbolism in architecture, where elements such as neon signs, advertisements and decorations become crucial in the communication between the building and its user. Their famous slogan „Less is a bore", opposes Le Corbusier's „Less is more"[10], affirming richness, layering and diversity as the core values of architecture.

Le Corbusier's idealism and Venturi's pragmatism are also reflected in their approaches to urbanism. Le Corbusier projects cities as strictly rational, hierarchical structures in which each element (housing, work, recreation) is separated and functionally defined. His plans, like „Radiant City", reflect a desire

9 Frampton, K. (1992). Modern architecture: A critical history (3rd ed.). Thames & Hudson. 201-205

10 Curtis, R. (1996). Modern architecture since 1900 (3rd ed.). Phaidon Press. 342-350

for order and control in urban space. On the other hand, Venturi analyze the urban chaos of Las Vegas, where functions overlap and space is shaped according to the needs of cars and markets. They do not offer visionary plans, but indicate how architecture reflects social realities and values. One of the key differences between the two books lies in their relationship to meaning. For Le Corbusier, the meaning of architecture is inherent and derived from proportions, purity of form and universal rules. He believes that architecture speaks a universal language that transcends the specificities of culture or place. Venturi sees architecture as a tool for communication with its users, where meaning emerges from specific context, symbolism and cultural references. He advocates a semiotic approach, analyzing how architectural elements convey messages and how and in what way they are connected to everyday life[11].

The influences of these books on architectural theory and practice are profound. „Vers une Architecture" laid the foundations of modernism, shaping the practice of architects such as Mies van der Rohe, Walter Gropius and Alvar Aalto. Their ideas dominated the mid 20th century, especially in the context of mass housing construction and urban planning projects. However, the rigidity of modernism drew criticism for its neglect of the cultural and emotional aspects of architecture. This is where the book „Learning from Las Vegas" appears as a pioneering manifesto of postmodernism, which introduces pluralism, diversity and symbolism as central values of architectural practice[12]. Venturi's book not only redefines architectural theory but also opens up space for experimentation with styles, forms and meanings.

The two books are not only opposed, but also complement each other. While „Vers une Architecture" emphasizes universality and rationality, „Learning from Las Vegas", celebrates context, symbolism and human spontaneity. Together, they form a dialogue between idealism and realism, between the universal and the local, each in its own way providing a basis for understanding the complexity of contemporary architecture.

THE INTERACTION OF THE BOOKS AND THE INFLUENCE ON ARCHITECTURE IN GENERAL

„Vers une Architecture" by Le Corbusier and „Learning from Las Vegas", by Robert Venturi, Denise Scott Brown and Stephen Isenour represent two key points in the history of architectural thought. These books, although at first glance

11 Curtis, R. (1996). Modern architecture since 1900 (3rd ed.). Phaidon Press. 342-350

12 Frampton, K. (1992). Modern architecture: A critical history (3rd ed.). Thames & Hudson. 201-205

opposed, together form a dynamic dialogue between modernism and postmodernism, shaping the fundamental direction of architecture during the 20th and 21st centuries. Le Corbusier's book places architecture on the pedestal of rationality and universality, striving for perfection through strict geometric forms, minimalism and functionality. His vision of architecture is not only aesthetic or technical, but socially transformative. „Vers une Architecture" is a manifesto of faith in the power of architecture to shape a better society, freed from chaos. However, this idealism, when translated into practice, can seem rigid and alienating, ignoring the emotional, cultural and symbolic needs of space users.

In contrast to this book, „Learning from Las Vegas", presents a critique of modernist uniformity, revealing that architecture must be in dialogue with its context, users and everyday life. Venturi and colleagues affirm pluralism and symbolism, indicating that architecture is not only a rational response to technical needs but also a means of communication and culture. Their exploration of the urban landscape of Las Vegas celebrates spontaneity, contradiction and layering, pointing to the importance of understanding social and economic realities.

The mutual relationship of the books is reflected in their contribution to the theory and practice of architecture. „Vers une Architecture" laid the foundations of modernist practice, bringing order and rationality to the world of architecture, while „Learning from Las Vegas", opened the door to the deconstruction of that system, allowing the expression of complexity, locality and symbolism. Although seemingly contradictory, these two books are not irreconcilable; they offer two opposite but complementary views on architecture. Their influence on architecture in general is also profound and pervasive. Le Corbusier's modernism shaped the appearance of numerous cities, bringing standardization and functionality, while Venturi's postmodernism introduced flexibility, irony and cultural awareness. Together, these books pose a fundamental question of architecture: should architecture guide society towards ideals or reflect its real, often chaotic, contradictory values?

The contribution of these books to architectural thought lies in creation of a space for dialogue between universal principles and local specificities, between idealism and realism. Their mutual relationship reminds us that architecture is not only a technical discipline, but also a social art, which should balance the functional, aesthetic and symbolic needs of people. Their combined legacy shapes contemporary architecture, which embraces both order and chaos, rationality and emotion, past and future. Criticism reflects the complexity of their influence and the controversies they caused in architectural theory and practice.

Both books have been praised for their innovation and influence, but have also been the subject of considerable criticism.

CONCLUSION

Comparative analysis of these books illuminates the profound ideological and aesthetic difference between modernism and postmodernism in architecture. While Le Corbusier promotes rationality, functionality and universality as the basic principles of contemporary architecture, Venturi emphasizes the importance of symbolism, context and complexity, calling for the acceptance of everyday aesthetics and pluralism of meaning. These opposing viewpoints point to the evolution of architectural thought of the 20th century in terms of elitism and populism, but also to the constant need for dialogue between form, function and meaning in contemporary space. However, there is a thin line between elitism and populism. Although Le Corbusier pleads for abstract forms (which he considers to be the origin of elite culture, because as abstract they are not understandable to everyone), he takes them *ad verbatim*, in a literal way, from the world of technology. On the contrary, Venturi, although at first glance it seems that he deals with the banal and popular, he actually does so through irony, which is definitely not a characteristic of someone who would be labeled a populist.

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CIRCULAR ECONOMY THROUGH EMPLOYMENT IN CIRCULAR SECTORS

Stoimenov Suzana[1)] Gračanac Aleksandar[2)] Marijana Joksimović[3)]

[1)] University Union Nikola Tesla", Faculty of Entrepreneurial Business and Real Estate Management, Belgrade

[2)] University Union Nikola Tesla", Faculty of Entrepreneurial Business and Real Estate Management, Belgrade

[3)] Alfa BK University, Faculty of Finances, Banking and Auditing , Belgrade, Serbia

stoimenovsuzana@gmail.com

Abstract

The paper analyzes the transition towards a circular economy (hereinafter CE) from the perspective of the number of employees in the field of the circular economy, as an indicator of the competitiveness of the analyzed countries (EU member states, former members, and candidate countries).

The aim of this paper is to present, based on data obtained from the Eurostat website, whether and to what extent there is a trend of growth in the number of employees in CE sectors for the analyzed period (2020–2023), as well as whether the number of employees in CE sectors is higher in developed countries compared to developing ones.The subject of the paper is to answer the question of the number of employees in the field of CE, with the aim of monitoring the competitiveness of the analyzed countries, given that the number of employees has been designated by the European Commission as a CE sub-indicator.

Since CE is a priority of EU economic policy, monitoring the degree of its implementation in EU member states, former members, and candidate countries has been defined as the subject of research due to its relevance and importance.

The contribution of this paper lies in the adequate analysis and overview of employment in CE-related fields, as well as in the examination of the higher level of CE in developed countries compared to developing ones, which is considered a prerequisite for employment, either through the creation of new jobs or the increase in the number of employees in the field of CE.

The growth of employment in CE sectors contributes to the development of the circular economy by strengthening the economic base, accelerating innovation, fostering social transition, and creating sustainable patterns of production and consumption..

Key words: circular economy, competitiveness, circular jobs

INTRODUCTION

The circular economy (CE) has become a central strategy for sustainable development, aiming to decouple economic growth from resource use while minimizing environmental impacts. It emphasizes the reuse, recycling, and restoration of materials, fostering innovation, competitiveness, and the creation of new jobs (European Commission, 2015; Ellen MacArthur Foundation, 2013; Kirchherr, Reike & Hekkert, 2017). Employment in CE sectors is particularly important, as it reflects both the practical implementation of circular practices and a country's adaptation to sustainable economic models (Mitrović & Jandrić, 2022).

Monitoring this transition requires relevant indicators, including competitiveness, innovation, and the number of employees in CE sectors, which provide measurable insights into progress.

This paper analyzes CE indicators with a focus on employment in circular economy sectors across 30 European countries from 2020 to 2023. By examining trends, comparative statistics, and variations between countries, the study highlights the level of CE implementation, the role of employment as a key indicator, and its implications for sustainable economic development in Europe.

MATERIALS AND METHODS

The research method applied in this paper includes:

- Collection and systematic analysis of available data on CE indicators in the fields of competitiveness and innovation;
- Systematic analysis of the number of employees in CE sectors, based on data from the Eurostat website;
- Extraction and integration of data with the aim of addressing the topic of CE through the lens of the number of employees in CE sectors.

RESULTS AND DISCUSSION

CE Indicators (Competitiveness and Innovation – Number of Employees in the CE Sector)

The literature review focused on analyzing the concept of the circular economy, the relationship between the circular economy and indicators used to monitor the transition towards a circular economy, as well as the number of employees in CE-related fields. According to the Circular Economy Monitoring Framework published in 2018 at the EU level, the development of the CE is tracked through four areas: production and consumption, waste management, secondary raw materials, and competitiveness and innovation. The CE Monitoring Framework was updated in May 2023 by the European Commission and now includes a new area: global sustainability and resilience.

The area of CE competitiveness and innovation can, according to the Eurostat database, be monitored through the following indicators and sub-indicators :

- ✓ **The indicator of private investment, jobs, and gross value added** with the corresponding sub-indicators (gross investment in tangible goods, number of employees, and value added at factor cost)."
- ✓ **The indicator of the number of patents related to recycling and secondary raw materials**, with the corresponding sub-indicator (Patents for climate change mitigation technologies related to wastewater treatment or waste management)."

Based on the review and analysis of the literature, it can be concluded that competitiveness and innovativeness are important elements of the transition towards a circular economy, while the number of employees in circular economy sectors is a key indicator of this transition, as it allows for measurement and monitoring. Data from the Eurostat database were presented and analyzed on a sample of 30 EU countries for the adopted research period from 2020 to 2023. A time span of four years was assumed to be sufficient for drawing reliable conclusions and for comparative analysis of the available relevant and comparable data on the number of employees in the field of the circular economy.

Indicators are crucial for making decisions about future directions: 'In general, indicators are variables that provide relevant information for decision-making' (Moraga et al., 2019, p. 455), and therefore the selection of indicators is very important for monitoring the transition towards a circular economy."

Circular Economy – Concept and Definition

The circular economy represents activities in which innovations are introduced and competitiveness is strengthened while preserving the environment; in other words, the circular economy is considered a driver of enhanced competitiveness. There are numerous interpretations of the circular economy (by academics, international organizations, and NGOs). According to the European Commission (2015, p. 2): 'The circular economy aims to maintain the value of products, materials, and resources for as long as possible by returning them to the product cycle at the end of their use, while minimizing waste generation.' (Thus, the European Commission has conceptualized its definition of the circular economy around product reuse and waste minimization)."

According to the Ellen MacArthur Foundation (2013), the circular economy is an industrial system designed to be restorative and regenerative.

(According to Kirchherr, Reike, and Hekkert, 2017, p. 229): "The circular economy represents an economic system based on business models that replace the end of life through reduction, alternative reuse, recycling, and restoration of materials in production, distribution, and consumption processes, operating at the micro level (products, companies, consumers), meso level (eco-industrial parks), and macro level (city, region, nation, and beyond), with the aim of achieving sustainable development, which includes creating a high-quality environment, economic prosperity, and social justice for the benefit of present and future generations. This is enabled by new business models and responsible consumers."Thus, this definition defines the circular economy as an economic system.

"The circular economy aims for a competitive economy that creates green and decent jobs and maintains resource use within planetary boundaries." (UNECE, 2024, p. 54)

Supporting this is the view expressed by (Grdić, Krstinić, Nizić & Rudan, 2020), according to which the advantages of the new economic model (circular economy) are reflected in the reduction of harmful environmental impacts, increased resource productivity, creation of new jobs, reduced dependence on imported raw materials, enhanced economic competitiveness, and the promotion of sustainable economic development."

According to (the Circular Economy Action Plan, For a Cleaner and More Competitive Europe 2020, p. 19), circularity will have a positive net effect on job creation, but it is necessary for workers to acquire the skills required by the green transition.

"Under the influence of the circular economy, it is possible to:

- **Create entirely new jobs (job creation);**
- **Substitute existing jobs (job substitution);**
- **Eliminate certain jobs (job destruction);**
- **Redefine some jobs (job redefinitions);** " (Mitrović & Jandrić, 2022, p. 3)

"The transition to a more circular economy could result in a net increase of 700,000 jobs in the EU by 2030." (European Commission, 2020, p. 8). In the context of circular economy development, STEM knowledge (science, technology, engineering, mathematics) is also of particular importance." (Mitrović & Jandrić, 2021, p. 164)

Number of employees in circular economy sectors for the period 2020–2023

Data on the number of employees in circular economy sectors were obtained from the Eurostat database for the period 2020–2023. An analysis of the available data from the Eurostat website was conducted. In the context of the sub-indicator, the number of employed persons in the CE sector is defined 'as the total number of persons working in the field of circular economy and in jobs related to the circular economy, or as a percentage of the total number of persons' (European Commission, 2018b, p. 43). With an increase in jobs in the circular economy, the number of employees within the CE also rises, which serves as an indicator of the implementation and advancement of the circular economy in a country. Data and statistics are key parameters for monitoring the progress and transition of a society.

A comparison of countries was carried out based on the number of employees in circular economy sectors. The following tables present the results: (Table 1) shows the number of employees for the analyzed countries for the period 2020–2023, and (Table 2) presents the minimum, maximum, average, and standard deviation for the same period, according to Eurostat data. It can be concluded that in developed countries, the number of employees in this sector is significantly higher, which practically indicates that competitiveness and innovativeness in these countries are at a higher level.

Table 1: Number of Employees in Circular Economy Sectors

	PI Number of Employees in Circular Economy Sectors				
	Države EU / kandidati / bivše članice	**2020**	**2021**	**2022**	**2023**
1	Аустрија(Austria)	64,690	71,734	65,022	65,849
2	Белгија (Belgium)	65,053	70,371	61,965	61,760
3	Бугарска (Bulgaria)	101,818	102,385	94,319	95,233
4	Хрватска (Croatia)	72,872	75,346	66,553	66,309
5	Данска (Denmark)	44,584	47,132	42,049	41,556
6	Финска (Finland)	44,169	45,575	43,543	41,773
7	Француска (France)	565,301	597,322	533,892	537,036
8	Холандија (Netherlands)	112,792	119,839	108,104	110,564
9	Италија (Italy)	537,384	578,336	515,093	507,749
10	Кипар (Cyprus)	12,483	13,514	13,464	13,849
11	Литванија (Lithuania)	58,690	63,976	58,707	61,452
12	Латвиа (Latvia)	33,944	33,425	31,373	32,971
13	Мађарска Hungary)	120,286	130,399	108,280	109,363
14	Немачка (Germany)	746,870	783,930	731,414	771,814
15	Грчка (Greece)	82,112	97,477	79,328	76,522
16	Пољска (Poland)	417,514	435,868	401,558	411,141
17	Португал (Portugal)	127,530	139,375	119,809	117,372
18	Румунија (Romania)	204,328	239,087	200,489	198,459
19	Словачка (Slovakia)	67,009	67,492	63,216	64,966
20	Словенија (Slovenia)	32,014	30,686	27,241	29,463
21	Шпанија (Spain)	446,859	460,871	402,408	428,345
22	Шведска (Sweden)	79,310	87,963	74, 235	79,323
23	В.Британија (United Kingdom)	542,918	549,618	556,802	563,692
24	Ирска (Ireland)	36,671	44,945	27,824	36,056
25	Босна и Херцеговина (Bosnia and Herzegovina)				
26	Србија (Serbia)				
27	Малта (Malta)	8,348	9,700	7,883	8,145
28	(Луксенбург) Luxenbourg	7,980	8,265	19,435	21,482
29.	Естонија(Estonia)	23,835	27,113	48,923	54,510

30.	Чешка(Czechia)	137,525	153,934	137,340	137,827

Source: author based on https://ec.europa.eu/eurostat/data/database), Date of access 25.3.2025

Tabela 2: Min,max, prosek i st. devijacija za period 2020-2023.god				
	2020	**2021**	**2022**	**2023**
min	(Luxenbourg)7980	(Luxenbourg)8265	(Malta) 7883	(Malta)8145
max	(Germany)746870	(Germany)783930	(Germa-ny)731414	(Germa-ny)771814
prosek	171246,04	181631,36	165723,89	169449,32
st.dev	208283,40	217716,10	201492,21	206983,18

Source: author based on https://ec.europa.eu/eurostat/data/database), *Date of access* 25.3.2025

Germany ranks first in terms of the parameter (number of employees per year) for the period 2020–2023, with a value nearly four times higher than the average, which in 2020 amounted to approximately 170,000 new jobs. Among the analyzed countries that also had above-average values are the United Kingdom, Spain, Romania, Poland, Italy, and France. Low numbers of employees were observed in Luxembourg, Malta, and Estonia during the analyzed period (2020–2023). Maximum values were recorded in Germany every year, confirming that it is the largest employer in circular economy sectors in the EU. The number of employees in Germany's circular economy sectors increased until 2021, then declined in 2022, and began to recover in 2023. The decline in employment in CE sectors was not unique to Germany but was part of a broader European decrease caused by the energy crisis, inflation, and post-pandemic effects.

Developing countries are well aware of the sustainability challenges associated with urbanization and industrial development—challenges that include pollution, water scarcity, and a rapid increase in waste generation. Without new approaches, these problems will only intensify alongside population growth and economic development, and will be further exacerbated by climate change. (Chatham House, 2017, p.6)

The most developed countries in the world, including those in the EU, actively promote the creation of an environment that stimulates knowledge and innovation. Based on the presented data, it can be concluded that developed countries are committed to the transition to a circular economy, as they invest more significantly than others in employment within CE sectors.

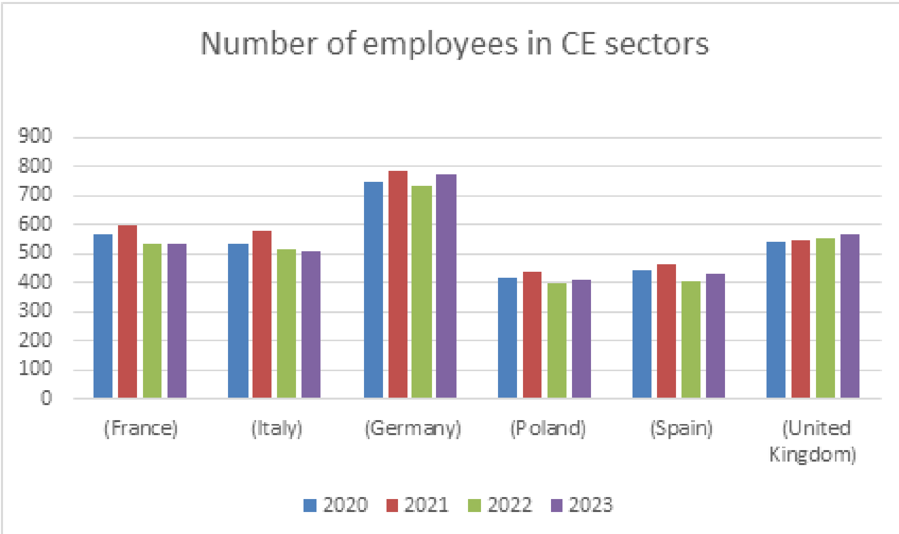

Figure 1: Number of employees in CE sectors
Source: author based on https://ec.europa.eu/eurostat/data/database), *Date of access* 25.3.2025

CONCLUSION

The benefits of the circular economy are reflected in the creation of new jobs and employment opportunities, since the components of the circular economy are not only environmental but also economic and social, relating to new jobs:

- whether they require educated personnel for innovative activities;
- or personnel for physical work, as the emphasis is on repairs to save resources.

An analysis of Eurostat data shows that the number of employees in sectors that can be classified as part of the circular economy has been increasing in recent years. Developed countries demonstrate a higher level of CE implementation compared to developing countries.

The EU is one of the regions taking measures to support the implementation of sustainable development strategies and the transition from a linear economic model to a circular economy.

The transformation of the economy towards a circular model is inevitable, and monitoring progress through defined sub-indicators is a prerequisite. Enhancing a country's circularity contributes to economic growth, and to improve circularity, the implementation of circular thinking is necessary at every stage.

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LEADERSHIP, WORKFORCE, AND OPERATIONS MANAGEMENT IN INDUSTRY 4.0

Tatjana Ilić-Kosanović

University "Union - Nikola Tesla"
tilickosanovic@unionnikolatesla.edu.rs

Damir Ilić
School of Engineering Management

Abstract: Industry 4.0 introduces major changes to the operational functioning of contemporary organizations through the adoption and implementation of digital technologies, automation, and the integration of networked systems. This paper studies the role of leadership, workforce management, and operations management in the process of digital transformation. A mixed-methods research approach was applied, combining a systematic literature review with empirical research conducted through questionnaires and interviews with managers and employees in organizations applying principles of Industry 4.0.

The findings indicate that transformational leadership, continuous workforce training, and digitally enhanced operations management play a pivotal role in the successful implementation of digital solutions. The analysis confirmed a strong interdependence among these dimensions, emphasizing the necessity of an integrated approach to operations management, human resources management, and leadership practices. Practical implications highlight the importance of investing in human resources, developing new leadership paradigms, and strategically aligning technological advancements with both, the operations and organizational culture. Directions for future research are proposed, including longitudinal studies and the analysis of ethical challenges associated with digitalization.

Keywords: Industry 4.0; leadership; workforce management; operations management; digital transformation; organizational culture; innovation.

INTRODUCTION

Industry 4.0 represents one of the most important transformations in the present-day business environment, as it involves the integration of advanced digital technologies, automation, artificial intelligence (AI), Big Data analytics, and the Internet of Things (IoT) into both, manufacturing and service oriented industries (Deloitte, 2025). This fourth industrial revolution affects not only technological development but also the way organizations are led, how the employees are managed, and how operational processes are optimized (Szalavetz, 2019; Gaspar, Julião, 2021; Merten, Schmidt, & Winand, 2022). In this context, leadership, human resources management, and operations management emerge as critical factors in the successful transition toward digital business practices (Fettermann, Cavalcante, de Almeida, & Tortorella, 2018; Kazancoglu, & Ozkan-Ozen, 2018; Choi, Kumar, Yue, & Chan, 2022; Khatri, Dutta, & Raina, 2022; Hossain, Fernando, & Akter, 2025; Maharani, & Palupiningtyas, 2025).

Leaders in the era of Industry 4.0 face challenges that go beyond traditional managerial practices, as they, now, must combine strategic thinking with a profound understanding of digital technologies and processes and their impact on organizational structures (Hossain, Fernando, & Akter, 2025). At the same time, workforce management acquires a new dimension, requiring employees not only to obtain and possess technical competencies, but also to demonstrate flexibility, adaptability to continuous change, teamwork abilities, and innovative thinking (Kazancoglu, & Ozkan-Ozen, 2018; Obermayer, Csizmadia, & Hargitai, 2022; Le, Jeenanunta, Ueki, Intalar, & Komolavanij, 2025; Maharani, & Palupiningtyas, 2025). Operations management, on the other hand, focuses on efficiency, flexibility, and the sustainability of business processes, leveraging the full potential of digital solutions, AI, IoT, and Big Data analytics (Fettermann, Cavalcante, de Almeida, & Tortorella, 2018; Kazancoglu, & Ozkan-Ozen, 2018; Bai, Dallasega, Orzes, & Sarkis, 2020; Choi, Kumar, Yue, & Chan, 2022; Felsberger, & Reiner, 2020).

Given these considerations, the aim of this paper is to analyze the interdependence of leadership, workforce management, and operations management within the framework of Industry 4.0, as well as to emphasize the challenges and opportunities arising from their transformation. Special attention is given to analyzing how contemporary management approaches can contribute to competitive advantage and sustainable organizational development in the digital age.

A systematic analysis of academic articles, books, and professional reports, from the period of 2016 to 2025 is conducted. The primary sources included the Scopus, Web of Science, and Google Scholar databases. Inclusion criteria encompassed works related to Industry 4.0, leadership, workforce management, and operations management.

This paper implements a mixed-methods research design, combining a review of relevant literature with an empirical analysis of the perspectives of experts and employees in organizations that have initiated the process of digital transformation.

1. LITERATURE REVIEW

Industry 4.0, as a concept grounded in the digitalization and interacting of production and business processes, significantly modifies the structure and dynamics of organizational management (Kittisak, 2020; Popa, Ștefan, Olariu, & Popa, 2024). According to Schwab (2016), the fourth industrial revolution amalgamates physical, digital, and biological systems, thereby creating new business models and presenting challenges for both managers and employees.

Research in the field of leadership indicates that traditional management styles are increasingly losing applicability in digital environments, while adaptive, transformational, and digital leadership are emerging as key success factors. Leaders in Industry 4.0 must combine technical knowledge, strategic vision, and the ability to motivate employees to accept innovations (Kittisak, 2020; Khatri, Dutta, & Raina, 2022; Hossain, Fernando, & Akter, 2025).

The workforce is also a significant focus of numerous studies (Horváth, & Szabó, 2019; Alharbi, 2020; Obermayer, Csizmadia, Hargitai, 2022; Maharani, & Palupiningtyas, 2025). Researchers emphasize that digital transformation requires new skill sets, including analytical abilities, creative problem-solving and advanced digital competencies (Ghosh, Hughes, Hodgkinson, & Hughes, 2022; Zhao, Chen, & Wang, 2022; Montero Guerra, & Danvila-Del Valle, 2024; Le, Jeenanunta, Ueki, Intalar, & Komolavanij, 2025; Tsekouropoulos, Vasileiou, Hoxha, Theocharis, Theodoridou, & Grigoriadis, 2025). In addition, changes in the work environment require continuous employee training and adaptation to new work models such as hybrid work (Kaasinen, Schmalfuß, Özturk, Aromaa, Boubekeur, Heilala, & Walter, 2020).

Operations management in the context of Industry 4.0 is characterized by a shift from traditional linear processes to intelligent, networked, self-regulating, and sustainable systems (Bai, Dallasega, Orzes, & Sarkis, 2020; Szalavetz, 2019; Kittisak, 2020; Robert, Giuliani, & Gurau, 2020; Choi, Kumar, Yue, & Chan, 2022; Felsberger, & Reiner, 2020). The use of Big Data analytics, AI, and IoT, enables operational process optimization, cost reduction, and increased flexibility. At the same time, researchers stress out that digitalization introduces significant challenges related to data security, system resilience, and sustainability (Robert, Giuliani, & Gurau, 2020; Kittisak, 2020; Haleem, Javaid, Singh, Shanay Rab, & Suman, 2022; Khatri, Dutta, & Raina, 2022; Popa, Ștefan, Olariu, & Popa, 2024).

Based on the literature review, it can be concluded that the interconnection between leadership, workforce management, and operations management in the era of Industry 4.0 remains insufficiently explored as an integrated concept. Most studies focus on individual dimensions (e.g., digital leadership or process automation), while there is a clear need for a holistic approach.

2. MATERIALS AND METHODS

A questionnaire and semi-structured interviews were employed in the empirical segment of the research. The study included 120 respondents from manufacturing and service organizations in Serbia. The participants included executives, human resource managers, and employees involved in digital transformation projects. The questionnaire consisted of 25 closed and semi-open questions, while interviews were conducted with 15 senior-level managers to gain deeper insights into perceptions of the challenges and opportunities presented by Industry 4.0. Quantitative data were processed using SPSS 18 statistical program, while qualitative data were analyzed using thematic coding techniques.

This methodological framework enables the integration of theoretical insights with practical experiences, thereby contributing to a deeper understanding of the interdependence between leadership, workforce, and operations management in the era of Industry 4.0. Main hypothesis is developed as:

H_1 Leadership, workforce, and operations management are interdependent dimensions in the process of digital transformation.

3. RESULTS

Basic descriptive indicators (mean, standard deviation, minimum, maximum, and frequencies) were first analyzed to gain insight into the sample structure and general response trends. The results showed that the majority of respondents had experience with digital projects (62%), while 38% were just starting to implement Industry 4.0 technologies. To assess the reliability of the instrument, Cronbach's Alpha coefficient was calculated, yielding a value of 0.87, which indicates high internal consistency of the scale.

Application of Pearson's correlation coefficient revealed significant positive relationships between:

- transformational leadership and employee motivation ($r = 0.61$; $p < 0.01$);
- workforce training and success of digital implementation ($r = 0.57$; $p < 0.01$);
- operational management efficiency and the degree of process digitalization ($r = 0.64$; $p < 0.01$).

To examine predictors of successful Industry 4.0 implementation, multiple regression analysis was conducted. The results indicated that transformational leadership (β = 0.42; $p < 0.01$), and continuous employee training (β = 0.36; $p < 0.01$) are significant predictors of digital transformation success, whereas traditional forms of leadership showed low statistical significance (β = 0.09; $p > 0.05$).

ANOVA test results indicated significant differences in perceived implementation effectiveness between larger and smaller organizations ($F = 4.87$; $p < 0.05$), with larger organizations achieving better outcomes due to greater resources and more developed structures for digital training.

This confirms that leadership, employee training, and operations management are interdependent factors, with leadership and workforce having a direct influence on the effectiveness of digital transformation, while operations management functions as a moderating variable.

Key findings of the research:

1. Leadership in the time of Industry 4.0. Questionnaire analysis revealed that the majority of surveyed managers (72%) believe that traditional leadership styles are no longer effective in the context of digital transformation. Instead, transformational and participative leadership approaches were ranked as the most effective. Interviews confirmed that leaders with advanced digital competencies and strategic vision are more successful in motivating employees to accept change and adopt new technologies.

2. Workforce and emerging competencies. Respondents emphasized that the most desirable skills in Industry 4.0 include digital literacy, analytical thinking, complex problem-solving abilities, and adaptability. As many as 65% of employees acknowledged as the crucial element, a need for additional training to meet new job demands. A particular challenge was identified in smaller organizations, where resources for training are limited.

3. Operations management and process efficiency. Quantitative analysis showed that organizations implementing some aspects of digital transformation (automation, IoT, data analytics) experienced a 15–25% increase in efficiency compared to those that had not. Interviews stressed out that the most significant

barriers to implementing digital solutions include high costs, employee opposition, and the absence of standardized processes.

4. Integrated approach. Correlation analysis demonstrated a statistically significant relationship between leadership styles, employee training levels, and the degree of successful implementation of digital solutions ($p < 0.01$). This supports our hypothesis that leadership, workforce, and operations management are interdependent dimensions in the process of digital transformation.

4. DISCUSSION

The research findings confirm the conclusions of earlier research, which emphasize that leadership and workforce play a decisive role in the successful implementation of Industry 4.0 (Horváth, & Szabó, 2019; Ghosh, Hughes, Hodgkinson, & Hughes, 2022; Khatri, Dutta, & Raina, 2022; Obermayer, Csizmadia, Hargitai, 2022; Zhao, Chen, & Wang, 2022; Hossain, Fernando, & Akter, 2025). However, this study further highlights an integrated perspective, namely, that digital transformation is not only a technological process, but also a complex process requiring organizational adaptation and modification (Merten, Schmidt, & Winand, 2022; Montero Guerra, & Danvila-Del Valle, 2024), which is including:

1. Leadership in Industry 4.0. Leaders must develop not only technical, digital, competencies, but also emotional intelligence and the ability to motivate employees. Their role is no longer limited to decision-making, it now includes enabling change and creating and promoting the innovative organizational culture. This strengthens the need to shift from traditional to transformational leadership (Kittisak, 2020; Khatri, Dutta, & Raina, 2022; Hossain, Fernando, & Akter, 2025; Le, Jeenanunta, Ueki, Intalar, & Komolavanij, 2025).

2. Workforce as a crucial factor. The workforce represents the crucial component. Results indicate that continuous education and skill development are critical for supporting digital transformation. Organizations that invest in employee training achieve better outcomes in terms of efficiency and innovation, while those that neglect this aspect encounter resistance and delays in implementation (Kaasinen, Schmalfuß, Özturk, Aromaa, Boubekeur, Heilala, & Walter, 2020; Ghosh, Hughes, Hodgkinson, & Hughes, 2022; Zhao, Chen, & Wang, 2022; Montero Guerra, & Danvila-Del Valle, 2024; Maharani, & Palupiningtyas, 2025; Tsekouropoulos, Vasileiou, Hoxha, Theocharis, Theodoridou, & Grigoriadis, 2025).

3. Operations management in the digital era. Operations management acquires a new dimension, transitioning from a linear and reactive model to a proac-

tive, intelligent, and networked system. However, challenges such as high costs, employee resistance, and lack of standardization demand a strategic approach that integrates technological investment with organizational development (Fettermann, Cavalcante, de Almeida, & Tortorella, 2018; Horváth, & Szabó, 2019; Felsberger, & Reiner, 2020; Gaspar, Julião, 2021; Khatri, Dutta, & Raina, 2022).

4. Integrated contribution. The most significant contribution of this research lies in confirming that leadership, workforce management, and operations management are not isolated domains, but interconnected elements. Their synergy is essential for success in Industry 4.0. Without visionary leadership, there are no motivated employees and without suitable workforce training, technological implementation cannot be effective (Felsberger, & Reiner, 2020; Kittisak, 2020; Kaasinen, Schmalfuß, Özturk, Aromaa, Boubekeur, Heilala, & Walter, 2020; Gaspar, Julião, 2021; Choi, Kumar, Yue, & Chan, 2022; Zhao, Chen, & Wang, 2022; Hossain, Fernando, & Akter, 2025).

5. CONCLUSION

Industry 4.0 represents a significant turning point in the development of modern organizations, introducing new business models based on digital technologies, automation, and interrelated processes. The research has shown that success in this transition depends on an integrated approach involving the organized roles of leadership, workforce management, and operations management.

Leadership in the era of Industry 4.0 must be transformational, visionary, and innovation-oriented, as traditional inflexible models no longer produce results in a dynamic and complex digital environment. The workforce faces the need for continuous development of new competencies, particularly digital literacy, analytical and problem-solving skills, and adaptability. Third, operations management must ensure efficient, flexible, and sustainable processes through the application of technologies such as IoT, AI, and Big Data analytics.

Practical implications of this research suggest that organizations must develop training and professional development programs for employees, promote transformational leadership and digital literacy among managers, invest in technologies while simultaneously strengthening a flexible, change-ready organizational culture, integrate human resource and operations management strategies into a cohesive digital transformation framework.

Future research directions include a more detailed examination of the role of cultural factors and national culture specificities in the adoption of Industry 4.0, longitudinal studies following changes in organizational performance during digital transformation, deeper analysis of the ethical and social implications of digitalization, particularly in the areas of data security and employment protection.

Successful implementation of Industry 4.0 is not solely a technological issue, but an organizational process that requires cooperation among leadership, a competent and motivated workforce, and effective operations management. Only through such integrated approach can organizations achieve sustainable competitive advantage and long-term development in the digital age.

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CYBERSECURITY STRATEGIES FOR THE TRANSITION FROM INDUSTRY 4.0 TO INDUSTRY 5.0

Damir Ilić
School of Engineering Management
damir.ilic@fim.rs

Tatjana Ilić-Kosanović
University "Union - Nikola Tesla"

Duško Tomić
College of Security and Global Studies, American University in the Emirates, Dubai, United Arab Emirates

Abstract:

Cybersecurity is essential for protecting digital infrastructure, especially during the transition from Industry 4.0 to Industry 5.0. While Industry 4.0 introduces connectivity through the Internet of Things (IoT) and Artificial Intelligence (AI), it also exposes new vulnerabilities. Industry 5.0, on the other hand, brings an anthropocentric approach, emphasizing ethics and sustainability, which requires development of new security strategies. This research examines key principles such as confidentiality, integrity, and availability of data, with a focus on securing IoT devices, robotics, and collaborative systems. Effective protection involves implementing Zero Trust architecture, utilizing AI for threat detection, applying blockchain technology, and fostering cyber culture and system resilience. Security approaches must align technological safeguards with ethical values to ensure a trustworthy and reliable digital ecosystem.

Keywords: Cybersecurity, Industry 4.0, Industry 5.0, IoT, Human-Centered Design.

INTRODUCTION

Cybersecurity is a critical practice dedicated to protecting computer systems, networks, and digital information from unauthorized access, data breaches, theft, and disruptions to services. At its core, cybersecurity aims to safeguard the digital infrastructure that powers modern society, encompassing a wide range of areas such as information security, network security, operational security, application security, IoT security, cloud security, and infrastructure security. As the digital landscape expands and becomes more interconnected, the role of cybersecurity has become even more significant in defending sensitive data and systems from an ever-growing array of cyber threats. The primary goal of cybersecurity is to ensure the confidentiality, integrity, and availability of data within cyberspace. This includes detecting potential threats early, managing cyber incidents efficiently, and facilitating a swift recovery when breaches occur (Khalid et al., 2020; Rohatgi et al., 2023; Wisdom et al., 2025).

Although cybersecurity is often viewed as a technological issue, it is increasingly seen as a fundamental aspect of every organization's strategy. Many companies are heavily investing in cybersecurity infrastructure, employing advanced tools and strategies to minimize risks and protect against the financial and reputational damage caused by cyberattacks (Tee & Johnson, 2020).

In today's interconnected world, cybersecurity spans several critical domains. Hardware and software tools are deployed to safeguard network security and prevent unauthorized access, while information security focuses on protecting sensitive data from unauthorized viewing, alteration, or destruction. Other crucial areas, such as cloud security and application security, ensure that systems in the cloud and software applications remain resilient against vulnerabilities. Techniques like penetration testing and continuous monitoring help organizations stay one step ahead of cyber threats and ensure that their digital operations are secure (Khalid et al., 2020; Rohatgi et al., 2023).

As digital transformation accelerates, particularly with the advent of Industry 4.0, the need for cybersecurity grows exponentially. Industry 4.0, characterized by interconnected, cyber-physical systems and the integration of IoT, has revolutionized manufacturing, improving efficiency and enabling large-scale customization. However, these innovations also introduce new cybersecurity risks as the number of connected devices and systems increases. Effective cybersecurity is essential in protecting the integrity of these complex environments and ensuring the safe operation of smart factories and industrial processes (Schwab, 2016). The fusion of information technology (IT) and operational technology (OT) in Industry 4.0 further complicates the security landscape, creating vulnerabilities that must be addressed through robust defense strategies (Leong et al., 2020; Tee & Johnson, 2020; Wisdom et al., 2025).

Looking ahead, Industry 5.0 represents a new phase that balances technological advancement with anthropocentric values, promoting collaboration between humans and machines. While this shift offers immense potential for improving industrial processes, it also presents unique cybersecurity challenges. The expanded attack surface created by IoT devices, robotics, and augmented reality means that protecting systems from cyberattacks becomes more difficult. As Industry 5.0 evolves, ensuring the privacy and security of data, particularly as it pertains to human-machine interactions, will be a growing concern. Moreover, as more personal and sensitive information is integrated into these systems, cybersecurity strategies will need to adapt to safeguard human well-being and prevent exploitation by malicious actors (Tee & Johnson, 2020; Chemmalar Selvi, 2023; Wisdom et al., 2025).

MATERIALS AND METHODS

Cyber security

Cybersecurity refers to the practice of protecting computer systems, networks, and digital information from unauthorized access, data breaches, theft, and disruptions to services. Broadly speaking, it encompasses the security of anything that exists in the digital or cyber realm (Khalid et al., 2020). This includes areas like:

- Information security;
- Network security;
- Operational security;
- Application security;
- Internet of Things (IoT) security;
- Cloud security;
- Infrastructure security.

The main goal of cybersecurity is to safeguard users and systems from potential threats as effectively as possible. It also plays a crucial role in ensuring that incidents are detected early, managed efficiently during the event, and followed by a swift recover process (Rohatgi et al., 2023). Cybersecurity encompasses technological measures aimed at ensuring the confidentiality, integrity, and availability of data within cyberspace. It is closely linked to other domains of security and is considered essential across various industries due to its role in protecting sensitive information from misuse, theft, and cyberattacks. As digital connectivity expands, the risk of data exploitation for financial or strategic purposes increases. Many organizations view cybersecurity primarily as a technological concern. Despite awareness of potential threats and their impact on operations, companies often avoid disclosing specific vulnerabilities. In recent years, large enterprises have significantly enhanced their cybersecurity infrastructure, investing heavily in new strategies and IT advancements to mitigate risks (Tee & Johnson, 2020).

Cybersecurity involves protecting hardware, software, and infrastructure within the digital space. It can be categorized into several key areas (Khalid et al., 2020):

- Hardware and Software Tools
    - These tools are essential for network security. They help prevent unauthorized access, misuse, and disruptions to systems and infrastructure. Strong network protection ensures that a company's internal and external assets remain secure.
- Information Security
    - This area focuses on protecting sensitive data—such as financial records, intellectual property, and customer information—from unauthorized viewing, alteration, or destruction. Its main goal is to maintain the confidentiality and integrity of critical information. Cloud Security
- Cloud security
    - Cloud security refers to building secure systems and applications using cloud service providers like Amazon Web Services, Google Cloud, Microsoft Azure, and Rackspace. It ensures that data stored and processed in the cloud is protected from breaches and vulnerabilities.
- Application Security
    - Application security involves implementing various protective measures within software and services to defend against cyberattacks. This includes techniques like white-box, black-box, and gray-box testing, which help identify and fix vulnerabilities in the code, prevent unauthorized access, and ensure proper validation of user input (Rohatgi et al., 2023).

Cyber security in Industry 4.0

The Fourth Industrial Revolution, as defined by Klaus Schwab, is a profound transformation driven by a convergence of technologies that blur the boundaries between the physical, digital, and biological worlds. It is distinguished by its unprecedented speed, scope, and complexity, fundamentally altering how we live, work, and interact. Schwab emphasizes that this revolution is not merely about technological advancement, it challenges our very notions of identity, ethics, and society (Schwab, 2016).

In Germany, this revolution is often referred to as Industry 4.0, a term introduced at the Hannover Fair in 2011. It highlights the emergence of "smart factories" where cyber-physical systems collaborate globally in flexible, adaptive ways. These systems enable mass customization of products and the development of entirely new business models (Schwab, 2016)**.** Industry 4.0 leverages cutting-edge technologies and the rapid advancement of machinery and tools to address global challenges and enhance industrial performance. At its core, this concept focuses on applying advanced information technologies to implement Internet of Things (IoT) services. By integrating engineering expertise into production processes, operations become faster and more streamlined, with minimal interruptions. As a result, products achieve higher quality, production systems become more efficient and easier to maintain, and overall costs are reduced (Wang et al., 2016; Leong et al., 2020; Santos et al., 2024; Wisdom et al., 2025).

Cybersecurity is crucial in Industry 4.0, as it protects systems, networks, and data from malicious activities like cyberattacks, unauthorized access, data theft, and system disruptions. With the increase in connected devices and systems, cybersecurity is more important than ever. Its main goal is to safeguard data while maintaining system performance. Many organizations face daily attacks, making it vital for factories to be aware of vulnerabilities and prepared for potential threats. In Industry 4.0, effective identity and access management, along with secure communication systems, are essential as connectivity and the use of standard protocols increase. The fusion of information technology (IT) and operational technology (OT) creates further challenges for cybersecurity. Many governments now consider cybersecurity a top national priority, recognizing the risk of unauthorized access and theft of business information (Khalid et al., 2020; Santos et al., 2024).

As network connections grow, cyberattacks become more frequent and dangerous, leading to financial losses, system crashes, data breaches, and other issues. The widespread use of IoT devices has heightened the need for strong cyber defense. Many large companies now invest heavily in IT security, strengthening their defenses and developing strategies to minimize the risks of cyber threats (Leong et al., 2020; Santos et al., 2024).

In Industrial IoT (IIoT) systems, identifying key assets like hardware and data is essential before addressing cybersecurity. This helps to (Khalid et al., 2020; Santos et al., 2024; Wisdom et al., 2025):

- Identify vulnerabilities: Weaknesses in protocols, devices, or software can lead to unauthorized access or DoS attacks.
- Recognize cyber threats: Can come from hackers, malware, or natural disasters.
- Assess risks from attacks: Include breaches in data confidentiality, integrity, or availability.
- Develop security countermeasures: Secure networks with firewalls, use multi-layer defenses, and control remote access with VPNs. Regular updates and monitoring are crucial for ongoing protection.

Many companies still use isolated or non-networked systems for managing production. However, with Industry 4.0 bringing more connectivity and standardized communication protocols, the risk of cyber threats has grown significantly. That's why it's now crucial to ensure secure communication and implement advanced identity and access controls for both machines and users (Galar Pascual et al., 2020; Khalid et al., 2020; Santos et al., 2024).

Core Security Principles in Industrial IoT (IIoT) can be stated out as (Galar Pascual et al., 2020):

1. Confidentiality: Protects sensitive data from unauthorized access using encryption and access control. Essential for medical, business, and military information.
2. Integrity: Ensures data remains accurate and unaltered. Prevents manipulation by internal or external threats, especially critical in systems like remote health monitoring.
3. Availability: Guarantees that systems and services are accessible when needed. Protects against failures, cyberattacks, and ensures timely operation.
4. Authenticity: Verifies identities of devices and users. Enables secure communication between machines and humans using strong authentication methods.
5. Nonrepudiation: Prevents denial of actions taken by users or devices. Important for accountability in systems like digital payments.

6. Privacy: Controls how data is shared and stored. Covers device, storage, communication, processing, identity, and location privacy to protect user and system information (Khalid et al., 2020).

Cyber security in Industry 5.0

Industry 5.0 (I5.0) is a concept that places human well-being at the heart of industrial production. It emphasizes anthropocentric technology, meaning that technological systems, organizations, and workplaces should be designed to meet human and social needs. However, this approach still faces unresolved challenges. Unlike Industry 4.0 (I4.0), which focuses heavily on automation and digitalization, I5.0 seeks a more balanced and collaborative relationship between humans and machines. It aims to either adapt humans to existing technologies or develop technologies that align with social and organizational needs, though finding a definitive solution remains difficult (Chemmalar Selvi, 2023; Kour, et al., 2024).

Despite discussions about including ethical, sustainable, and social perspectives in I4.0, the reality has been a continued emphasis on technological advancement over improving working conditions. That's why I5.0 pushes for a shift toward human-centered design (Machado & Davim, 2025). Industry 5.0 introduces a new era of technological advancement, blending human creativity with intelligent machines. While this brings many benefits, it also introduces significant cybersecurity challenges. As more devices and systems become interconnected, such as IoT, robotics, and augmented reality, the number of potential entry points for cyberattacks grows. This expanded attack surface makes it easier for hackers to infiltrate industrial environments (Chemmalar Selvi, 2023).

The volume of data generated by Industry 5.0 is immense, coming from sensors, smart devices, and collaborative platforms. Protecting this data from unauthorized access and breaches is increasingly difficult, especially when trying to comply with privacy regulations. The interaction between humans and machines, which is central to Industry 5.0, also presents vulnerabilities. Cybercriminals can exploit weaknesses in these interfaces or use social engineering to manipulate users into giving up sensitive information (Chemmalar Selvi, 2023; Chemmalar Selvi, 2023). Supply chains become more complex and interconnected, making them attractive targets for attackers who can exploit weaker links to inject malicious code or gain unauthorized access. Malware and ransomware pose serious threats, capable of disrupting industrial control systems, encrypting data, and causing financial and operational damage (Machado & Davim, 2025).

Another concern is the lack of standardized security protocols across different technologies and vendors. Without integrating security from the design phase, systems may be left exposed to exploitation. The human factor also plays a role, employees and contractors with privileged access can unintentionally or deliberately compromise systems, leading to insider threats (Radid et al., 2024). Denial of service attacks are particularly damaging in Industry 5.0, where continuous connectivity and real-time data are essential. These attacks can halt operations and result in significant economic losses.

To mitigate these risks, a robust cybersecurity strategy is essential. This includes implementing strong network protections, encryption, access controls, regular software updates, employee training, and incident response plans. Collaborating with technology providers to ensure security is built into systems from the start is also crucial. As Industry 5.0 continues to evolve, safeguarding critical assets, data, and infrastructure must remain a top priority (Chemmalar Selvi, 2023; Radid et al., 2024).

RESULTS

The evolution of Industry 4.0 and Industry 5.0 has significantly reshaped the industrial sector by embedding advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cloud computing into manufacturing systems. These innovations have led to remarkable gains in efficiency, automation, and customization. However, they have also introduced complex cybersecurity challenges due to the increased connectivity and data exchange across devices and platforms (Adeniyi et al., 2024; Moeti, 2024).

Industry 4.0, characterized by cyber-physical systems and intelligent automation, has created a highly interconnected environment that is vulnerable to cyber threats. Each connected device represents a potential entry point for malicious actors, making security a critical concern (Kour et al., 2024). As the industrial landscape transitions toward Industry 5.0, which emphasizes human-centric design, sustainability, and collaboration between humans and machines, the cybersecurity risks become even more nuanced. The integration of AI-driven systems and sensitive data flows demands robust security frameworks to ensure resilience and trustworthiness (Breque et al., 2021; Chemmalar Selvi, 2023; Adeniyi et al., 2024; Moeti, 2024).

A comprehensive understanding of these vulnerabilities is essential for developing effective mitigation strategies. Researchers have proposed various approaches to enhance cybersecurity, including the use of blockchain, AI-based threat detection, and resilient system architectures. These solutions aim to safeguard industrial operations while supporting the broader goals of Industry 5.0, such as ethical innovation and sustainable development (Breque et al., 2021; Kour et al., 2024; Moeti, 2024).

As industries progress from the automation-driven model of Industry 4.0 to the more human-centered vision of Industry 5.0, cybersecurity must evolve to meet new expectations. While Industry 4.0 focused on digitalization and interconnected systems, Industry 5.0 emphasizes ethical innovation, sustainability, and the integration of human values into technological development. This shift calls for cybersecurity strategies that go beyond technical protection and embrace social responsibility (Kour, et al., 2024; Moeti, 2024; Radid et al., 2024).

A key aspect of cybersecurity in Industry 5.0 is anthropocentric design, systems must be built with human behavior, usability, and ethics in mind. This involves creating intuitive user interfaces, raising awareness among employees, and embedding privacy safeguards directly into technological frameworks (Breque et al., 2021; Adeniyi et al., 2024; Kour, et al., 2024).

Resilience also becomes a central priority. Industrial systems must be capable of resisting and recovering from cyber threats without disrupting operations. Techniques like predictive maintenance, real-time monitoring, and AI-driven anomaly detection play a vital role in ensuring this robustness (Breque et al., 2021; Moeti, 2024; Radid et al., 2024). The Zero Trust Architecture model gains importance in this context. It operates on the principle that no user or device is inherently trusted; every access request must be verified. This approach is especially relevant in collaborative environments where humans and machines work side by side.

As technologies like the Internet of Things (IoT), cyber-physical systems, and intelligent robotics become more widespread, their secure integration is essential. These systems must be protected against vulnerabilities, and blockchain can be used to ensure secure and transparent data exchange. Data protection and privacy remain critical. Encryption, compliance with regulations, and advanced methods such as federated learning help safeguard sensitive information while supporting innovation (Butollo, 2018; Adeniyi et al., 2024; Santos et al., 2024; Moeti, 2024).

Finally, cybersecurity must align with sustainability goals. This means designing protocols that are energy-efficient and reducing the environmental impact of digital infrastructure—reflecting the broader values of Industry 5.0. In essence, cybersecurity in Industry 5.0 is not just about defending systems, it's about building trust, promoting ethical use of technology, and ensuring that innovation serves both people and the planet (Chemmalar Selvi, 2023; Moeti, 2024; Radid et al., 2024).

As Industry 5.0 evolves, cybersecurity strategies must go beyond traditional defenses and embrace a more human-centric approach, integrating ethical governance and focusing on privacy-first designs. As Santos et al. (2024) point out, the collaborative nature of Industry 5.0 systems necessitates a focus on safeguarding not only data but also the well-being of human operators. To achieve this, systems must be built with privacy-focused architectures and cyber-physical safety mechanisms that ensure the protection of both digital and human assets in an interconnected environment (Adeniyi et al., 2024; Radid et al., 2024).

A key element of these evolving cybersecurity strategies is the adoption of Zero Trust frameworks, which assume no entity, whether inside or outside the network, is inherently trustworthy. These frameworks, combined with AI-driven threat detection, are becoming foundational in safeguarding smart manufacturing systems. Kour et al. (2024) stress out the need for continuous authentication and behavioral analytics to counter increasingly sophisticated and adaptive attacks that target the growing complexity of Industry 5.0 environments. By constantly verifying identities and monitoring behaviors, organizations can better detect anomalies and prevent intrusions before they cause significant damage.

Additionally, the integration of emerging technologies such as blockchain and edge computing presents new cybersecurity challenges. These technologies promise increased data integrity and real-time processing, but they also require advanced security protocols to prevent vulnerabilities. Wisdom et al. (2025) emphasize the importance of securing digital twins and IoT devices throughout their entire lifecycle, from development to decommissioning. This ensures resilience and sustainability in Industry 5.0 ecosystems, where interconnected systems and devices may present unique risks at every stage.

Lastly, workforce empowerment plays a pivotal role in strengthening cybersecurity defenses. Khando, Gao, Islam, & Salman (2021) and Kour et al. (2024) argue that building a culture of cyber awareness and implementing training programs are essential to equip employees with the knowledge to recognize threats and practice cyber hygiene. By fostering a mindset where every employee is an active participant in defense efforts, companies can significantly enhance their overall cybersecurity posture. In essence, the future of cybersecurity in Industry 5.0 hinges on a holistic approach that combines advanced technologies with human-centric design, continuous adaptation to emerging threats, and an empowered workforce (Khando, Gao, Islam, & Salman, 2021).

Table 1. Cybersecurity Evolution from Industry 4.0 to Industry 5.0 (Source: Authors, based on results)

Dimension	Industry 4.0	Industry 5.0
Core Focus	Automation, digitalization, efficiency	Anthropocentric design, sustainability, ethical innovation
Technological Drivers	IoT, AI, Big Data, Cloud Computing	Edge Computing, Blockchain, Federated Learning, Human-Machine Collaboration
Cybersecurity Challenges	Device-level vulnerabilities, network exposure	Ethical data use, behavioral risks, complex human-machine interfaces
Security Strategies	Firewalls, encryption, centralized monitoring	Zero Trust Architecture, AI-driven threat detection, privacy-by-design
Resilience Mechanisms	Reactive recovery, basic anomaly detection	Predictive maintenance, real-time monitoring, adaptive AI systems
Privacy Approach	Data protection through encryption and access control	Embedded privacy safeguards, compliance, decentralized data governance
Human Role	Limited to system operation and oversight	Active collaboration, cyber awareness, ethical decision-making
Sustainability Integration	Minimal focus on environmental impact	Energy-efficient protocols, lifecycle security, eco-conscious infrastructure
Governance & Ethics	Technical compliance and risk management	Ethical governance, social responsibility, human well-being

DISCUSSION

This article explores how Industry 4.0 and Industry 5.0 have transformed the industrial landscape through technologies like IoT, AI, and big data. While these innovations have boosted efficiency and automation, they have also introduced complex cybersecurity risks. Industry 4.0 focused on automation and interconnected systems, but its increased connectivity made it more vulnerable to cyber threats (Wisdom et al., 2025). Industry 5.0 builds on this foundation with a shift toward human-centered innovation, ethical design, and sustainability, raising the need for more advanced and adaptive cybersecurity strategies. Cybersecurity in this new era must go beyond technical defenses. It should include intuitive design, embedded privacy protections, and employee education.

Resilience is essential, with systems capable of recovering quickly from attacks using tools like predictive maintenance and AI-driven threat detection (Breque et al., 2021; Adeniyi et al., 2024; Radid et al., 2024). Zero Trust architecture plays a key role, especially in environments where humans and machines collaborate. It ensures that every access request is verified, helping prevent sophisticated attacks (Adeniyi et al., 2024). Data protection remains vital, with blockchain and encryption enhancing trust and transparency. Privacy must be safeguarded through secure data practices and regulatory compliance. Sustainability also influences cybersecurity, pushing for energy-efficient solutions that minimize environmental impact. Empowering the workforce through training and awareness is crucial, as is the ability to adapt to evolving threats. Emerging technologies like edge computing, digital twins, and blockchain require robust security throughout their lifecycle (Khando, Gao, Islam, & Salman, 2021; Kour et al., 2024).

CONCLUSION

Cybersecurity in Industry 5.0 demands the new approach, one that combines advanced technologies like AI, blockchain, and Zero Trust with anthropocentric design and ethical governance. It is not just about protecting systems; it is about building resilience, safeguarding privacy, and ensuring adaptability in the face of emerging threats. One of the key insights is that cybersecurity must go beyond defense. It should foster trust, guarantee safety, and support an environment where technological innovation and human well-being are equally valued. In essence, Industry 5.0 calls for cybersecurity strategies that are collaborative and flexible. These strategies must integrate ethical principles and human values while addressing the growing complexity and risks of new technologies.

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CAPITAL MANAGEMENT AND PLANNING IN BANKING SECTOR

Jugoslav Aničić[1], Ana Anufrijev[1], Vuk Miletić[2], Miljana Barjaktarović[3], Saša Stefanović[4]

[1]University „Union – Nikola Tesla", Cara Dusana 62-64, Belgrade, Serbia
[2]The College of Academic Studies „Dositej", Nusiceva street 12a, Belgrade, Serbia
[3]Faculty of Business Economics and Entreprenurship, Mitropolita Petra 8 street, Belgrade, Serbia
[4] Higher Business School of Vocational Studies „Čačak"

ajugoslav@yahoo.com

Abstract: The impact of financial market globalization, capital flow liberalization and changes in macroeconomic environment has positioned the capital adequacy ratio as one of the most critical indicators of a bank's operational performance. This ratio reflects the relationship between a bank's available capital and its risk-weighted assets, with the minimum required level prescribed by the Basel Accords—internationally accepted standards in the banking systems of developed economies. Under regulatory pressure to implement these principles, banks are compelled to strengthen their capital base and maintain adequate capital levels. Bank's capital management strategy must be defined in advance, incorporating the expectations of all relevant stakeholders, including shareholders, investors, depositors and the bank's management.

Keywords: capital adequacy, Basel principles, capital management strategy

INTRODUCTION

In recent decades, the role of financial management in banks has undergone significant changes due to the globalization of financial markets, the liberalization of capital flows and shifts in the macroeconomic environment. The scope of strategic decisions in modern financial management encompasses three main areas (Van Horne & Wachowicz, 2008):

- investment decision-making,

- financing decision-making and
- asset management decision-making.

These core areas of financial management take on additional specific characteristics within the banking sector, primarily due to regulatory efforts aimed at protecting depositors and ensuring the stability of the financial system. The focus of financial management in banks extends beyond capital acquisition to include maintaining an adequate level of capital in line with the inherent risks of banking operations. On one side lies the shareholders' expectation of profit, while on the other stands the need to ensure depositor security and compliance with regulatory requirements.

Capital adequacy ratio has become one of the key indicators of a bank's performance and financial soundness worldwide. Basel Principles were introduced with the aim of regulating capital adequacy, structured around three pillars: minimum capital requirements, supervisory review, and market discipline. Despite the comprehensive regulatory framework governing banking operations, the global financial crisis of 2008 highlighted the ongoing need for enhanced regulation within the global financial system.

BASEL PRINCIPLES

Banking literature typically identifies three measures of capital (Djukić, 2021):

- book value capital (nominal capital);
- regulatory capital (capital based on supervisory principles);
- market value capital.

Bank's book value capital represents the amount of capital calculated based on generally accepted accounting principles, whereby banks typically present their assets and liabilities in the balance sheet at acquisition or issuance value. However, in conditions of changing interest rates, uncollectible receivables, and similar events, significant deviations may occur between the book value and the market value of a bank's capital.

Regulatory capital, based on prudential accounting principles, emerged as a result of efforts by regulatory institutions to enhance the safety of banks. Critics argue that regulatory capital is not necessarily more accurate than book value capital, as it may merely give the appearance of financial strength by including items such as subordinated debt, minority interest in subsidiaries and other instruments. These inclusions can mislead potential investors regarding the actual strength of a bank's capital (Rose, 2012).

Market value capital is only accessible to stakeholders if a bank's shares are actively traded on the capital market. In fact, market value is considered the most accurate indicator of how well a bank is protected from insolvency risk. Existing and potential depositors can more easily assess whether a bank provides sufficient protection for their funds based on the market value of its assets and liabilities. This facilitates rational decision-making and helps prevent adverse selection and excessive risk-taking in both banking and financial markets.

Capital adequacy is expressed as a ratio between a bank's available capital and its risk-weighted assets. The Basel Accord of 1988 stipulated that a bank's available capital must equal at least 8% of its risk-weighted assets. This is a minimum threshold and national regulatory bodies may impose higher requirements. According to the Basel Accord, banks must ensure continuous compliance with capital adequacy standards and are therefore required to submit reports to regulatory authorities on a monthly or quarterly basis.

Due to a range of shortcomings in the original 1988 Basel Accord, Basel Committee adopted a revised framework in 2004, known as Basel II. The objectives of Basel II included:

- enhancing the safety and stability of the international financial system;
- promoting fair competition among banks;
- developing more accurate risk measurement approaches;
- improving the reliability of risk assessment;
- focusing on internationally active banks.

Basel II introduced three approaches to assessing credit risk: standardized, foundation internal ratings-based (F-IRB) and advanced internal ratings-based (A-IRB). Key innovations in the standardized approach compared to Basel I included:

- new categories of risk-weighted assets;
- revised risk weights for specific asset classes;

- expanded use of credit risk mitigation techniques;
- increased reliance on external credit ratings for determining risk weights, particularly for exposures to sovereigns, foreign banks and corporations.

The global financial crisis of 2008 led the Basel Committee to define a comprehensive set of reform measures under a new framework known as Basel III. These measures aimed to:

a) enhance the banking sector's ability to absorb shocks from financial and economic stress, regardless of the source; b) improve risk management and governance practices; and c) increase the transparency of banks and their disclosure practices.

Basel II was the first framework to introduce the concept of internal credit rating systems, enabling banks to implement credit risk analysis based on internal methodologies. In line with Basel II recommendations, most internationally active commercial banks have aligned their regulatory capital with internal rating procedures. However, internal rating systems often produce results that differ from external credit rating agencies, particularly regarding rating stability, migration patterns and time homogeneity (Engelmann, Hayden, Tasche, 2003).

External reports are typically based on data observed over specific time intervals and rely on statistical and mathematical models to project future trends. In contrast, internal credit rating systems focus on detailed, in-depth analysis of a bank's individual credit portfolio. These systems evaluate the current state and forecast future movements of the portfolio, taking into account various indicators that depend not only on macroeconomic trends (the basis of external reports), but also directly on the portfolio structure, risk concentration, diversification and overall exposure to specific credit categories.

The Basel III Accord was approved by G20 member countries in 2010. The corresponding legal framework in the European Union was adopted in 2013, with implementation beginning the following year. The key body responsible for implementing Basel III in the EU is the European Banking Authority (EBA). The EBA conducts semi-annual monitoring on a sample of EU banks to assess the impact of Basel III on the European banking system.

To address shortcomings in Basel II, Basel III introduced two minimum liquidity standards:

- the Liquidity Coverage Ratio (LCR), which measures short-term liquidity and requires banks to hold sufficient high-quality liquid assets to withstand 30-day stress scenarios; and
- the Net Stable Funding Ratio (NSFR), which addresses long-term liquidity by requiring banks to maintain a stable funding profile in relation to the composition of their assets and off-balance-sheet activities (Mirković, 2012).

Banks operating in the Republic of Serbia are required, under the Decision on Capital Adequacy, to calculate the following indicators:

- the Common Equity Tier 1 Capital Adequacy Ratio;
- the Tier 1 Capital Adequacy Ratio; and
- the Total Capital Adequacy Ratio.

This regulation also provides a detailed definition of risk-weighted assets. A bank's capital must never fall below EUR 10,000,000 (converted to RSD at the official middle exchange rate of the National Bank of Serbia on the date of calculation).

To monitor the level of special provisions for estimated losses, the National Bank of Serbia requires banks to submit:

- the Report on Classification of On-Balance-Sheet Assets (Form KA-1);
- the Report on Classification of Off-Balance-Sheet Items (Form KA-2);
- the Leverage Ratio Report (Form LR1);
- the Overview of Exposure Amounts Included in the Leverage Ratio Calculation by Risk Weight (Form LR2); and
- the Overview of Exposure Types Included in the Leverage Ratio Calculation (Form LR3).

CAPITAL PLANNING IN BANKS

To support ongoing operations and ensure the long-term sustainability of the institution, a bank's capital serves the following five functions: First, it acts as a buffer against the risk of bank failure by absorbing financial and operational losses. Second, through paid-in capital, the bank's founders not only obtain the license to operate but also ensure the organization and functioning of the bank before any liquidity inflows from deposits are secured. Third, capital contributes to building customer trust and serves as a safeguard for the bank's creditors, including depositors, by demonstrating the bank's financial strength. Fourth, capital provides a foundation for growth, enabling the expansion of services, the implementation of new information systems with modern software solutions and the overall enhancement of asset and liability management efficiency. Fifth, capital serves as a regulator of growth, helping ensure that the pace of the bank's expansion remains sustainable over the long term.

Regulatory authorities and financial markets require that a bank's capital grows at a rate comparable to the growth of its credit portfolio and other risk-weighted assets. To protect public funds from large-scale losses, safeguard deposits and promote trust in the banking sector, supervisory bodies limit a bank's risk exposure by setting capital adequacy standards.

In developed financial markets, capital planning emerged in response to increasing pressure from both market forces and regulators for banks to strengthen their capital base and maintain adequate capital levels. According to Rose (2012), the capital planning process can be divided into four stages:

- Stage one: development of a comprehensive financial plan for the bank;
- Stage two: determination of the appropriate level of capital for the bank;
- Stage three: estimation of internally generated capital through retained earnings;
- Stage four: evaluation and selection of capital sources that best align with the bank's needs and strategic objectives.

When choosing appropriate methods of capital raising, several factors must be considered, including: conditions in the capital market (especially when long-term securities are to be issued), the rights and interests of existing shareholders and the management's confidence in its profit forecasts. Capital can be raised through various means such as issuing shares or debt securities, selling other asset items, or increasing the growth rate of profits. Broadly, all sources of capital can be classified as either internal or external.

Internal capital growth stems from the bank's dividend policy—specifically, decisions on how much of the net profit will be retained to support business expansion and how much will be distributed to shareholders. An optimal dividend policy is one that maximizes shareholder value. To retain current shareholders and attract new ones, the return on equity must at least match the returns offered by alternative investments of comparable risk.

When selecting a form of external capital raising, the primary consideration is the impact on shareholder returns, typically measured by earnings per share. Other important factors include the relative cost of different capital-raising instruments (e.g., interest, fees and other expenses), the associated risk profile, the bank's overall risk exposure, the effect of regulatory requirements on the bank's capital structure and market dynamics such as fluctuations in capital and real estate prices.

Bank's capital management strategy is determined in advance and reflects management's risk–return preferences. This strategy defines how capital is allocated across business lines and must incorporate the expectations and requirements of all relevant stakeholders, including shareholders, investors and internal management. Through its capital strategy, a bank ensures transparent communication with both internal and external stakeholders. According to Choudhry (2012), a comprehensive capital strategy document should include:

- the extent to which risk-taking is aligned with stakeholder needs and expectations;
- how capital allocation and mobilization constraints are integrated with the bank's funding capabilities and aligned with specific business lines;
- the bank's tolerance for income volatility; and
- the operational framework for each business line, considering its risk exposure and the nature of its activities.

CONCLUSION

The globalization of banking activities at the end of the 20th century also led to the globalization of financial crises, highlighting the need for comprehensive risk management and the establishment of strict behavioral standards for banks and other financial market participants. This prompted the adoption of the Basel Accords I, II and III by the Basel Committee on Banking Supervision. At the core of the Basel principles lies the objective of ensuring an adequate level of capital aligned with the bank's risk profile, as well as selecting an appropriate structure of funding sources and asset allocations. These elements are intended to support the achievement of the bank's development goals and shareholder expectations on the one hand, while safeguarding depositor interests and ensuring compliance with regulatory requirements on the other.

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ECONOMIC POLICY IN THE FUNCTION OF SOLVING ECONOMIC CRISES

Olgica Nestorović [1], Dušan Aničić [2], Marijana Milunović [3], Gordana Bejatović [4], Boris Latinović [5]

[1] Republika Srbija,VLADA,Kancelarija za reviziju sistema upravljanja sredstvima Evropske unije, olgica.n@yahoo.com

[2] Fakultet za ekonomiju i finansije, Univerzitet Union – Nikola Tesla, Beograd, Srbija

anicic.dusan@yahoo.com

[3] Fakultet za ekonomiju i finansije, Univerzitet Union – Nikola Tesla, Beograd, Srbija

mmilunovic@unionnikolatesla.edu.rs

[4] Fakultet za ekonomiju i finansije, Univerzitet Union – Nikola Tesla, Beograd, Srbija

gordana.bejatovic@yahoo.com

[5] Fakultet za ekonomiju i finansije, Univerzitet Union – Nikola Tesla, Beograd, Srbija,

blatinovic@unionnikolatesla.edu.rs

Abstract: Until the beginning of the 20th century, economic fluctuations characteristic of business cycles were considered a natural phenomenon, accepted as an inevitability in economic movements. This viewpoint began to change in the mid-1930s with the Keynesian Revolution, marking the start of viewing business cycles as phenomena that can be influenced and regulated. The aim of economic policy is to explain how policymakers should respond to specific economic problems and which measures and instruments to apply in order to restore the economy to a state of equilibrium. The primary goals of economic policy are maintaining full employment, achieving zero inflation, balancing the balance of payments, and a balanced budget. Recent economic crises have been marked by a simultaneous decline in production and employment, an energy crisis, all accompanied by high inflation rates. This has made the measures and instruments available to policymakers more complex in their efforts to achieve the set goals of stable growth and development of the global economy.

Keywords: economic policy, macroeconomics, market mechanism, government intervention

Economic development of Serbia, during transitional period, was based on a neoliberal development concept and inefficient privatization, which led to a negative change in the country's economic structure. After the year 2000, there were periods of relatively high GDP growth rates, but with a neglect of industrial development: the highest growth was achieved in service activities closely related to large, economically unjustified imports, while the development of the real sector of economy lagged behind. The consequences of such economic policies include low competitiveness of the economy in international contexts, a negative trade balance, neglected regional development, unfavorable migration trends accompanied by the departure of young population abroad, low living standard of population and so on.

Macroeconomic environment

Competitiveness of the Serbian economy, when viewed on a global scale, has been low throughout the entire transition period, largely due to flawed economic policies implemented since the year 2000. Key mistakes stem from relying on the development of non-tradable sectors, while the development of manufacturing industry, agriculture and other branches of the real sector remained neglected. Undeniable is the negative impact of the inefficient and, to a large extent, corrupt privatization process, which led to the closure of manufacturing enterprises in the industrial sector, uncontrolled imports, trade deficits and more.

Macroeconomic trends in the Republic of Serbia over the past few years have been strongly influenced by adverse effects from the environment caused by geopolitical tensions, as well as the intensification of the global energy crisis, resulting in a slowdown in economic growth and increased inflationary pressure. However, thanks to achieved financial stability and the growth momentum from previous years, as well as significant inflows of foreign investments, a stable exchange rate has been maintained and the number of employees is experiencing a slight increase.

We will analyze the state of the economy in the Republic of Serbia through the achieved results in 2022 and previous years, based on the reports of the Business Registers Agency, formed on the basis of submitted financial reports of economic enterprises during that period.

Economic activity in the Republic of Serbia, measured by Gross Domestic Product (GDP), increased by 2,3% in 2022, according to data from the Statistical Office of the Republic of Serbia and the National Bank of Serbia (Table 1).

Industrial production grew at a rate of 1,7%, which is considerably slower compared to the previous year, 2021. The existing economic trends have impacted international trade. Exports increased by 26,3% compared to the previous year, but imports grew faster - by 34,8%, leading to a further increase in the trade deficit.

The rise in energy prices globally, as well as agricultural and industrial raw materials, has stimulated inflationary pressures in the domestic economy, resulting in an inflation rate of 15,1% at the end of 2022, compared to 7,9% in the previous year. The exchange rate remained relatively stable and the number of employed persons increased by 1,8% compared to the previous year.

Table 1: Basic macroeconomic indicators

DESCRIPTION	**Year**	
	2022	**2021**
Gross domestic product (in millions of dinars - current prices)	7.090.743,9	6.270.097,0
Gross domestic product - growth rate	2,3	7,5
Industrial production	101,4	106,3
Annual inflation rate (consumer price index)	15,1	7,9
Exports (in millions of euros)	27.604,7	21.858,0
Imports (in millions of euros)	39.008,7	28.935,3
Foreign trade deficit (in millions of euros)	11.404,0	7.077,3
Number of employees (in thousands)	2.253	2.213
Exchange rate of dinar to the euro (as of December 31)	117,32	117,58

Source: Republic Institute of Statistics of Serbia (2023), National Bank of Serbia (2023)

At the end of 2022, there were 135.490 economic enterprises operating in the Republic of Serbia, employing 1.281.412 workers, representing an increase of 5.375 employees compared to the end of the previous year. Looking at the sectors, non-tradable sectors were more prevalent in the economy - there were 86.095 (79,1%) economic enterprises operating in these sectors, employing 748.604 workers (58,4%). In terms of specific sectors, the highest number of economic enterprises operated in the sectors of Wholesale and Retail Trade, Manufacturing Industry, Construction, Information and Communication, Transport, Professional, Scientific, Information and Technical Activities.

The largest number of employees were in the Manufacturing Industry sector (31,4%), followed by the Wholesale and Retail Trade sector (18,3%) and Transport and Storage sector (8,1%). The increase in the number of employees compared to the previous year was highest in the Information and Communication sector, followed by the Professional, Scientific, Innovative and Technical Activities sector.

In the structure of Serbian economy, when observed by the size of enterprises, micro-enterprises predominate, accounting for 93.064 (85,5%) of them. On the other hand, there were 528 large enterprises, employing the highest number of workers – 450.049 or 35,1% of employees. The number of small enterprises was 13.172 with 333.356 employees, while there were 2.092 medium-sized enterprises with 270.770 employees. The division into micro, small, medium and large enterprises was carried out in accordance with the Accounting Law (Official Gazette of RS, No. 73/2019 and 44/2021-other law), based on criteria such as the number of employees, generated revenues and the value of business assets.

A significant number of enterprises operated without any employees, numbering 32.139 or 29,5%. Micro-enterprises dominate their structure, followed by 303 small, 25 medium-sized, and 7 large enterprises. An analysis from the perspective of the number of employees shows that after enterprises without employees, the majority were those employing between 2 to 5 workers, followed by enterprises with a single employee. Over 250 employees were employed by 614 enterprises, which accounted for 43,4% of the workforce.

Financial performance of companies

Analysis of the achieved business results of companies in 2022 was conducted based on the data from the Business Registers Agency (BRA), which were obtained by systematizing the submitted financial reports by the companies.

Financial statements represent a direct product of the accounting reporting system which, by its essence and purpose, reflect the performance (achievements) of a company for a specific period, its financial-structural position, as well as its liquidity position on a chosen balance sheet date. Primary purpose of their preparation lies in providing information to various stakeholder groups who rely on them in the process of making business decisions. Financial reporting supplies important information to all existing and potential participants in the financial market, affirming itself as a significant factor that enhances its functioning (Ćeha, et. all. 2023) .

Financial reporting connects top management and executive activities of the company, providing essential information to both internal and external users. Therefore, there needs to be a strong link between financial reporting, the efficiency of financial markets and the development of market economy (Gajić, Medved, 2014).

In 2022, companies in the Republic of Serbia operated under the influence of growing global instability and increased risks caused by numerous international conflicts, energy crises and strong inflationary pressures. Despite these challenges, companies demonstrated resilience to external shocks and continued the trend of successful operation from the previous period.

According to the data from Table 2, the total revenues generated at the level of the economy amounted to 17.772.856 million dinars, representing an increase of 19,2% compared to the previous year. The majority of the total revenues were generated by economic enterprises through their primary activities. At the same time, total expenses amounted to 16.721.985 million dinars, representing an increase of 18,8% compared to the previous year.

Revenues from financing increased by 61% compared to the previous year, while financial expenses increased by 30%, resulting in an improvement in the overall financing result. As a result, economic enterprises in the financing sub-balance recorded a loss that was 28% lower compared to the previous year. All of this resulted in a positive net result at the level of the economy amounting to 864.190 million dinars, representing an increase of 26.3% compared to the previous year.

Table 2: Structure of income, expenses and results of business companies (in millions of dinars)

DESCRIPTION	**Year**		**Index**
	2022	**2021**	
Business income	17.285.581	14.490.569	119,3
Business expenses	16.143.910	13.583.118	118,9
I Business result	**1.141.671**	**907.451**	**125,8**
Financial income	195.673	121.550	161,0
Financial expenses	242.335	186.389	130,0
II Funding result	**-46.661**	**-64.839**	**72,0**
III Result from other activities	**-44.138**	**-9.050**	**487,7**
IV Result before tax	**1.044.209**	**827.738**	**126,2**
VNet result	**864.190**	**683.976**	**126,3**

Source: Agency for Business Registers, 2023.

Positive performance of the economy, for the eighth consecutive year, has been achieved through conducting business activities. Additionally, there has been an increase in the yield on sales revenue, which has impacted the rate of operating and net profit. Moreover, rates of return on total assets and equity have also experienced growth. Furthermore, economic enterprises have managed to finance interest expenses from the achieved results, leading to an increase in the interest coverage ratio - as shown in Table 3.

Table 3: Profitability indicators at the economy level

DESCRIPTION	Year	
	2022	2021
1. Rate of return on equity (after taxes)	11,4	9,9
2. Rate of return on total assets (after tax)	4,8	4,3
3. Rate of business profit	6,9	6,6
4. Net profit rate	5,2	5,0
5. Interest coverage ratio	11,25	10,65

Source: Agency for Business Registers, 2023.

Serbia's economy needs a new development strategy based on increasing investments, providing greater support to export-oriented enterprises and investing in infrastructure. This will create the foundation for long-term, sustainable economic development and enable a larger participation of SMEs (Small and Medium-sized Enterprises) in overall economic activities. This would imply a correction of the current economic policy, which relies on indiscriminate imports and foreign investments and a shift towards a developmental economic policy where domestic investments and industrial production take precedence.

Conclusion

Creators of economic policy should learn from the negative outcomes of implementing the neoliberal model of economic development during the transitional period and shift towards a developmental policy where infrastructure development, private and public investments – both domestic and foreign – as well as increasing industrial production, are prioritized. By leveraging the positive effects offered by the EU accession process through economic policy, a more significant role for the small and medium-sized enterprises (SMEs) sector and entrepreneurship in economic and overall social development can be expected. Institutions responsible for economic development must address numerous obstacles and limitations still present to facilitate economic growth and enable competitive performance of economic entities in the developed international market.

On their part, companies must address internal weaknesses and maximize the use of internal reserves because relying solely on external sources of financing creates an unfavorable financial structure for the company, which is unsustainable in the long run. Economic recovery will be challenging due to the prolonged impact of the economic crisis, so it is necessary to redirect investments into companies engaged in manufacturing and exporting products with a higher degree of processing, focusing on strategic sectors that will contribute most to stable and dynamic economic development and achieving the country's economic and development policy goals.

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