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Also, the **ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering, Tome XVII [2024], Fascicule** 4 [October – December], includes scientific papers presented in the sections of:

- **ISB-INMA TEH' 2023 – International Symposium (Agricultural and Mechanical Engineering)**, organized by Politehnica University of Bucharest – Faculty of Biotechnical Systems Engineering (ISB), National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry (INMA Bucharest), Romanian Agricultural Mechanical Engineers Society (SIMAR), National Research & Development Institute for Food Bioresources (IBA Bucharest), National Institute for Research and Development in Environmental Protection (INCDPM), Research-Development Institute for Plant Protection (ICDPP), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and "Food for Life Technological Platform", in Bucharest, ROMANIA, October, 2024. The current identification numbers of the selected papers are the **#7–8** and **#11–13**, according to the present contents list.
- ICAS 2024 – International Conference on Applied Sciences, organized by University Politehnica Timisoara, Faculty of Engineering Hunedoara (ROMANIA) and University of Vitez in Travnik (BOSNIA & HERZEGOVINA), in collaboration with Academy of Romanian Scientists, General Association of Romanian Engineers – Hunedoara Branch, Association Universitaria Hunedoara, Bosnia and Herzegovina American Academy of Arts and Science and Western Balkan Alumni Association, in Travnik (BOSNIA & HERZEGOVINA), May 30 – June 1, 2024. The current identification number of the selected paper is the **#15**, according to the present contents list.

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A REVIEW OF VULNERABILITY DISCOVERY IN WEBASSEMBLY BINARIES: INSIGHTS FROM STATIC, DYNAMIC, AND HYBRID ANALYSIS

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Abstract: WebAssembly (Wasm) has rapidly gained adoption as a powerful, low–level assembly language designed to enable near–native performance in web browsers, alongside secure execution in other environments such as IoT and edge computing. Despite its secure–by–design nature, WebAssembly is vulnerable to several types of attacks, including memory safety issues, side–channel attacks, and code injection. These vulnerabilities pose significant threats to applications relying on WebAssembly, particularly in performance–sensitive and security–critical environments. This study examines existing research on static, dynamic, and hybrid analysis approaches for discovering vulnerabilities in WebAssembly binaries. By categorizing state–of–the–art methods, are highlighted both their contributions and limitations. This study aims to foster a unified framework for vulnerability discovery that aligns with the needs of both WebAssembly applications and the broader cybersecurity landscape.

Keywords: WebAssembly binaries, Vulnerability discovery, Static analysis, Dynamic analysis, Hybrid analysis

INTRODUCTION

A coalition of companies, including Mozilla, Microsoft, Apple, and Google, created WebAssembly (or "Wasm" for short) in 2015 to address the shortcomings of traditional web technologies. WebAssembly has emerged as a revolutionary technology, designed to serve as a portable compilation target for high–level languages, primarily used to improve performance in web applications and expand into other domains like the Internet of Things (IoT), blockchain, and edge computing [1–4]. It has also been recognized as an official standard by the World Wide Web Consortium (W3C).

Since its inception, Wasm has offered a portable, platform–independent, and highly efficient format that translates high–level languages into a binary instruction set that can be executed within a sandboxed environment. Currently, several programming languages, including C, C++, Rust, AssemblyScript, C#, F#, Dart, Go, Kotlin, Swift, D, Pascal, Zig, and Grain, are supported by WebAssembly, enabling a wide range of applications [5–7].

A WebAssembly binary is structured as a module, which encompasses a set of Wasm functions, the declarations of their shared global variables, and details about the linear memory where these functions and variables are stored. The execution model follows a stack–based machine, with Wasm instructions manipulating the stack by pushing and popping values. A Wasm module is run by an embedder, such as the host JavaScript engine, which manages the loading of modules, resolves imports and exports between them, and coordinates I/O operations, timers, and error handling.

WebAssembly functions as a technology that complements JavaScript, although it does not compile from JavaScript itself. Instead, it allows seamless integration, where JavaScript facilitates interaction between the Document Object Model (DOM) and WebAssembly modules within browsers [5].

The main advantage of WebAssembly is its capacity to enhance application performance while maintaining security. Despite its design for secure execution, WebAssembly is not immune to various security vulnerabilities that can be exploited by malicious actors. These vulnerabilities arise from several inherent characteristics of the WebAssembly architecture, its interaction with host environments, and its operational context within web browsers [8–10].

The key security challenges that have been identified include memory safety vulnerabilities, side–channel attacks, susceptibility to speculative execution vulnerabilities, and the complexities associated with its interaction with JavaScript [11,12]. These vulnerabilities pose serious challenges, underscoring the importance of developing robust vulnerability discovery methods for securing WebAssembly binaries. It is known that the security flaws present in memory–unsafe languages such as C and C++ can propagate into WebAssembly binaries, posing significant vulnerabilities [6].

This research explores current studies on methods for identifying vulnerabilities in WebAssembly binaries through static, dynamic, and hybrid analysis techniques.

RESEARCH METHODOLOGY

A survey was carried out to evaluate the increasing research focus on Vulnerability Discovery in WebAssembly Binaries, with insights drawn from static, dynamic, and hybrid analysis techniques. Due to the practical importance of this area, the review covers the period from 2018 to 2024. This research reviews various journal articles discussing key concepts and real–world applications.

Research on static analysis methods

Static analysis refers to the examination of WebAssembly code without executing it, relying on code inspection to identify potential vulnerabilities. This method typically involves analyzing the program's structure, control flow, and data flow to detect patterns that could lead to security issues. For example, static analysis tools can focus on identifying risks such as memory access violations, type errors, or control flow integrity (CFI) problems. By analyzing code at compile–time, static analysis can provide early detection of vulnerabilities, although it may struggle with issues that only emerge during runtime. This section discusses three prominent static analysis tools – Wassail, Wasmati, and WASP1 – focusing on their methodologies, strengths, and limitations. The development of these tools offer a unique approach to vulnerability detection, from Wassail's focus on information flow to Wasmati's use of code property graphs and WASP1's execution model. While these tools have their respective limitations, they represent critical advancements in securing WebAssembly applications.

- Wassail stands out as the pioneering static analysis tool developed exclusively to identify vulnerabilities in WebAssembly binaries [13,14]. It utilizes a summary–based, compositional analysis technique that focuses on tracking information flow throughout the program.

This approach generates a summary for each WebAssembly function, detailing how information is transmitted within the function. These individual summaries are integrated when analyzing function calls, offering a comprehensive view of the information flow across the whole binary. The analysis itself is performed on a Control Flow Graph (CFG), where data flow analysis identifies potential vulnerabilities related to the movement of sensitive or insecure information within the program.

Stiévenart et al. [15] applied a program slicing (a broad technique that, based on specific criteria, trims a program down to its smallest form while still fulfilling those requirements) and their experiments demonstrated that program slicing reduced binary sizes to 52% of their initial size. They concluded that this technique could also be beneficially applied to loop analysis. On the other hand, Wassail's summary–based approach is particularly noteworthy for its scalability [16]. Compositional analysis has been shown to scale effectively in other domains, as it reduces the complexity of analyzing large binaries by focusing on individual functions before aggregating their effects at a higher level. However, the scalability of Wassail itself has not been thoroughly evaluated, leaving questions about its effectiveness in analyzing larger, more complex WebAssembly binaries [16]. Nonetheless, Wassail's ability to detect information flow vulnerabilities makes it a valuable tool in identifying a wide range of security issues, including unauthorized access to memory or improper handling of sensitive data. While Wassail's focus on information flow is crucial for preventing data leakage and breaches, its reliance on function summaries may lead to limitations in detecting vulnerabilities that arise from complex interactions between functions or external inputs. Therefore, Wassail might be more suitable for smaller binaries or binaries with well–defined and isolated function boundaries. Future work could explore expanding Wassail's capabilities to cover inter–function vulnerabilities and improve its evaluation in larger–scale applications.

- Wasmati builds upon the foundation laid by Wassail by introducing a more sophisticated approach to vulnerability detection in WebAssembly binaries through the construction of a Code Property Graph (CPG) [17].

The CPG is a multi–layered data structure that combines information about the program's execution order, control flow, data dependencies, and other relevant properties. By searching for specific patterns in CPG sub–graphs, Wasmati can detect vulnerabilities such as buffer overflows, use–after–free errors, and other memory corruption issues that are common in low–level code like WebAssembly.

One of the primary challenges Wasmati addresses is the rapid growth of the CPG due to the inability to statically determine the targets of indirect calls. Indirect calls, which allow a function to call another function based on runtime information, complicate static analysis because their targets are not known until the program is executed. Wasmati mitigates this issue by introducing optimizations during the CPG generation process. These optimizations include adding annotations, caching intermediate results, and using more efficient graph traversal algorithms, reducing the complexity of analyzing indirect calls. The scientists reported that this tool could construct a CPG for a WebAssembly binary in an average of 58 seconds, demonstrating its efficiency [17]. Brito et al. [18] by leveraging optimized techniques for CPG generation and four distinct query back–ends, it efficiently identifies various vulnerability types in WebAssembly binaries code. Extensive testing across diverse datasets demonstrated its scalability and reliability, making it a valuable solution for analyzing complex, real–world WebAssembly applications [18]. Additionally, Wasmati was found to have a low false positive rate, meaning it could accurately identify vulnerabilities without flagging benign code as malicious. This is a significant improvement over some other static analysis tools, which often suffer from high false positive rates, leading to wasted time and effort in manual verification. However, like Wassail, Wasmati has its limitations. The reliance on CPG construction can result in scalability issues as the size of the binary increases. Moreover, while Wasmati can efficiently detect certain types of vulnerabilities, it may struggle with more complex attack patterns that require a deeper understanding of runtime behaviors, such as race conditions or time–of–check to time–of–use (TOCTOU) vulnerabilities. Nevertheless, Wasmati's ability to detect structural vulnerabilities in WebAssembly binaries makes it an important tool for static analysis in the WebAssembly ecosystem.

- WASP1 introduces a hybrid approach to static analysis by combining symbolic execution with concolic execution [19]. Concolic execution is a technique that merges concrete and symbolic execution to explore all feasible execution paths within a program, maximizing code coverage and increasing the likelihood of discovering hidden vulnerabilities. Symbolic execution allows the tool to generate concrete inputs for different execution paths, ensuring that all paths are explored and tested for potential issues. WASP1 is specifically designed to uncover vulnerabilities such as integer overflows, buffer overflows, and memory access violations in WebAssembly modules. Unlike purely static analysis techniques, concolic execution enables WASP1 to examine the effects of inputs on the execution of the binary, allowing for a more comprehensive analysis. To demonstrate its effectiveness, the authors of WASP1 developed a framework called WASP–C, which allows for the testing of C programs by converting them into WebAssembly binaries and then analyzing them with WASP1. The results of the WASP–C framework showed that WASP1 could effectively uncover a range of bugs and vulnerabilities in the tested programs. However, one limitation of WASP1 is that it requires access to the high–level source code of the program to perform its analysis. This constraint means that WASP1 is primarily useful for open–source programs or situations where the source code is available, limiting its applicability in cases where only the compiled WebAssembly binary is available. WASP–C showed competitive results against other tools in symbolic execution tasks, focusing on byte–level granularity for Wasm code. Despite this limitation, WASP1's use of symbolic execution provides a powerful tool for vulnerability discovery. Its ability to maximize code coverage ensures that even deeply hidden vulnerabilities can be identified, making it particularly useful for identifying security issues that arise from edge cases or rare execution paths.

Static analysis techniques have the following advantages: early detection, comprehensive coverage, and scalability. Their limitations include false positives/negatives, lack of contextual information, and complexity in analysis.

- **Research on dynamic analysis methods**

In contrast, dynamic analysis involves examining WebAssembly binaries while they are being executed, providing real–time insights into how the program behaves in different scenarios. This approach is particularly useful for identifying vulnerabilities that arise from the interaction of the code with the execution environment, such as buffer overflows, race conditions, or unauthorized memory access. While dynamic analysis offers the advantage of catching runtime–specific issues, it typically requires more

computational resources and may not cover all execution paths of the program.

- Szanto et al. [20] proposed an innovative approach to detecting vulnerabilities in WebAssembly binaries through the implementation of a taint–tracking technique. Taint tracking is a widely–used method in software security to monitor the flow of sensitive data, such as personal information or cryptographic keys, through a program's execution, helping to identify potential vulnerabilities like information leakage or code injection attacks.

What distinguishes Szanto et al.'s [20] approach is its ability to apply taint tracking without requiring modifications to the underlying structure of the WebAssembly binary, thereby preserving the integrity of the original code. To achieve this, they developed a custom virtual machine (VM) that runs natively within JavaScript, which is particularly significant because of the prevalent use of WebAssembly in web applications. By integrating the taint–tracking system into a JavaScript–based VM, Szanto et al. [20] ensured compatibility with existing web technologies, enabling seamless deployment in real–world web environments. The method works by assigning a tainted label to each allocable byte in WebAssembly's memory section and each variable on the stack. This granularity in labeling ensures that every potentially sensitive data point is monitored throughout the execution, thereby improving the precision of taint propagation analysis. A key advantage of this technique is its non–intrusiveness.

Unlike traditional taint–tracking methods that often require binary rewriting or instrumentation, Szanto et al.'s [20] method avoids these invasive alterations, reducing the risk of introducing new vulnerabilities or bugs into the system. This aspect is critical for security–sensitive applications, where even minor modifications to the code can lead to unintended side effects. Additionally, by preserving the original binary structure, their approach ensures better compatibility with existing WebAssembly compilers and execution environments. However, this precision and non–intrusiveness come at a cost in terms of runtime performance.

Szanto et al. [20] reported that the overhead introduced by their taint–tracking technique scales mostly linearly with the execution time of the WebAssembly binary. In practice, this means that the system can incur a performance penalty of up to 100% compared to uninstrumented execution. While such an overhead might be prohibitive for performance–critical applications, it is worth noting that in many security contexts, this trade–off is acceptable. Ensuring the safety and security of sensitive data flows often justifies increased computational costs, especially in web applications that handle personal user information or financial data. The technique proposed by Szanto et al. [20] contributed to the growing body of research aimed at enhancing WebAssembly binaries security, a field that has gained considerable attention due to the increasing adoption of WebAssembly in both client–side and server–side applications.

- TaintAssembly. TaintAssembly [21] introduced a sophisticated taint–tracking mechanism tailored for detecting vulnerabilities in WebAssembly binaries that distinguishes itself through its integration with the V8 JavaScript engine, which is the backbone of widely used platforms such as Google Chrome and Node.js [22].

This strategic modification leverages the existing infrastructure of V8, enabling more efficient and seamless taint tracking within web environments where Wasm is increasingly prevalent. TaintAssembly opted for a more integrated approach by modifying the V8 engine itself to embed taint–tracking functionalities directly into the execution pipeline of WebAssembly binaries. By doing so, it minimized the need for external interventions or the creation of auxiliary VMs, thereby streamlining the taint–tracking process and enhancing performance efficiency. TaintAssembly supports taint tracking for a comprehensive set of data types, including integers (i32, i64) and floating–point numbers (f32, f64), which are fundamental to Wasm's type system. Additionally, it extends taint tracking capabilities to linear memory, which is crucial for monitoring data flows in applications that heavily utilize memory operations. Furthermore, TaintAssembly introduces a probabilistic variant of taint tracking, which employs statistical methods to infer potential taint propagation paths. This probabilistic approach enhances the detection of complex vulnerabilities that may not be easily identifiable through deterministic methods alone.

A notable difference between TaintAssembly and Szanto et al.'s approach lies in the handling of WebAssembly module structures.

TaintAssembly requires modifications to the Wasm module before taint labels can be assigned to variables. This preprocessing step involves analyzing and restructuring the Wasm binary to insert taint labels appropriately, ensuring that all relevant variables are accurately tracked during execution. While this introduces an additional preprocessing phase, it enables more precise taint propagation and reduces the likelihood of false positives in vulnerability detection.

One of the most significant advantages of TaintAssembly is its superior runtime performance. Through its integration with the V8 engine and optimized taint–tracking algorithms, TaintAssembly achieves a runtime overhead of merely 5–12%. This is a stark contrast to the approach proposed by Szanto et al., which incurs an overhead of up to 100%. The reduced overhead makes TaintAssembly more viable for real–world applications, where performance constraints are a critical consideration. The efficiency gains are primarily attributed to the tight integration with V8, which allows for more direct and less resource–intensive taint tracking compared to running a separate VM.

Moreover, by leveraging the V8 engine's optimizations and just–in–time (JIT) compilation capabilities, TaintAssembly can maintain high execution speeds while performing taint analysis. This integration ensures that taint tracking does not become a bottleneck, thereby supporting the deployment of security mechanisms in performance–sensitive environments such as web browsers and server–side applications. However, the requirement to modify the V8 engine introduces certain limitations. Maintaining compatibility with future updates of V8 can be challenging, as engine modifications may need to be reapplied or adjusted with each new release. Additionally, the preprocessing step to modify Wasm modules adds complexity to the deployment pipeline, potentially increasing the effort required to integrate TaintAssembly into existing workflows.

Despite these challenges, TaintAssembly represents a significant advancement in the realm of WebAssembly security. Its ability to provide efficient and accurate taint tracking within widely adopted platforms like Google Chrome and Node.js underscores its practical applicability. By enabling developers to detect and mitigate vulnerabilities such as buffer overflows, code injection, and information leakage in Wasm binaries, TaintAssembly contributes to the robustness and reliability of web applications.

- Wasabi. Wasabi [23] represents a versatile and robust framework designed for the dynamic analysis of WebAssembly binaries. Wasabi addresses this need by employing binary instrumentation techniques that enable comprehensive runtime analysis without necessitating modifications to the original Wasm binaries.

At its core, Wasabi performs binary instrumentation by injecting calls to analysis functions written in JavaScript directly into the WebAssembly binary. This approach leverages the seamless interoperability between WebAssembly and JavaScript within web environments, facilitating the integration of sophisticated analysis capabilities. The instrumentation process involves identifying relevant points within the Wasm binary where analysis functions should be inserted, thereby enabling real–time monitoring and data collection during the execution of the binary.

By embedding these analysis hooks, Wasabi can perform a variety of analyses, including instruction counting, call graph extraction, memory access tracing, and taint analysis. Instruction counting in Wasabi allows developers and security analysts to monitor the execution frequency of specific instructions, providing insights into performance bottlenecks and potential optimization opportunities. Call graph extraction is another critical feature, enabling the construction of a detailed map of function calls within the Wasm binary. This facilitates the identification of complex interdependencies and the detection of anomalous or unauthorized function invocations that may indicate malicious behavior or software defects. Memory access tracing is particularly important for uncovering vulnerabilities related to memory safety, such as buffer overflows and use–after–free errors. By tracking how memory is accessed and manipulated during execution, Wasabi can identify patterns that may lead to security breaches or data corruption.

Taint analysis, one of Wasabi's most powerful features, involves tracking the flow of sensitive or untrusted data through the program. This enables the detection of potential information leaks, injection attacks, and other forms of data misuse by ensuring that tainted data does not reach critical execution points without proper validation. A significant innovation of Wasabi is its

support for selective instruction instrumentation. Instead of indiscriminately instrumenting every instruction in the Wasm binary, Wasabi allows users to specify which instructions are relevant for a particular analysis.

This targeted approach reduces the overhead associated with instrumentation, as only the necessary parts of the binary are instrumented. By focusing on specific instructions, Wasabi can provide more precise and efficient analysis, tailored to the unique requirements of different applications and security contexts. Despite its advantages, the implementation of Wasabi introduces runtime overhead, which varies significantly depending on the application and the specific instructions being analyzed. The authors of Wasabi reported a runtime overhead ranging from 2% to 163% [23].

This variability is attributed to several factors, including the complexity of the instrumentation, the frequency of instrumented instructions, and the nature of the analyzed workload. While a 2% overhead is relatively minimal and acceptable for many applications, a 163% overhead can be prohibitive for performance–critical environments.

Consequently, the selective instrumentation feature of Wasabi plays a crucial role in balancing the trade–off between analysis comprehensiveness and runtime efficiency. Wasabi's ability to perform multiple types of analysis within a single framework enhances its utility for developers and security professionals. By providing a unified platform for instruction counting, call graph extraction, memory access tracing, and taint analysis, Wasabi simplifies the process of conducting thorough security assessments and performance evaluations of WebAssembly binaries. This multi–faceted analysis capability is particularly valuable in complex applications where understanding the interplay between different components is essential for ensuring both performance and security.

- Fuzzm. Fuzzm [24] represents a specialized fuzzer for WebAssembly (Wasm) binaries, leveraging the widely adopted American Fuzzy Lop (AFL) framework to perform fuzz testing on binary–only applications.

Fuzz testing is a critical technique in software security, where random or semi–random inputs are supplied to a program to uncover vulnerabilities such as crashes, memory corruption, or unexpected behavior. Fuzzm extends this principle to WebAssembly, enabling the security analysis of Wasm binaries even in the absence of source code, which is often a challenge in the context of proprietary or third–party applications. The AFL framework, which forms the foundation of Fuzzm, is traditionally used to fuzz applications by compiling them from source code and inserting instrumentation at compile time. This instrumentation tracks path coverage, a critical metric in fuzzing that indicates how thoroughly the fuzzer explores different execution paths within the application.

Path coverage helps guide the fuzzer toward unexplored code paths, improving the chances of discovering bugs or security flaws. However, Fuzzm departs from this source–code–centric approach by operating directly on Wasm binaries. Since Fuzzm does not have access to the source code, it cannot leverage AFL's compile–time instrumentation techniques. Instead, it employs static binary instrumentation to achieve similar functionality. Specifically, Fuzzm inserts code at all branches within the Wasm binary, ensuring that coverage information is collected in a way that is compatible with AFL's feedback–driven fuzzing mechanism. This static binary instrumentation is crucial for enabling effective fuzzing in the absence of source code, allowing Fuzzm to monitor and report the execution paths taken by the WebAssembly binary during fuzz testing.

One of the significant advantages of Fuzzm is its ability to provide detailed coverage information while maintaining a low runtime overhead. Binary instrumentation can often introduce performance penalties due to the insertion of additional code at various points in the program's control flow. However, the authors of Fuzzm demonstrated that the overhead imposed by their static binary instrumentation is minimal, making the tool practical for extensive fuzz testing campaigns without excessively slowing down execution. This low runtime overhead is essential for achieving high throughput in fuzzing, as it allows more inputs to be tested in a shorter period, thereby increasing the likelihood of discovering vulnerabilities.

Furthermore, Fuzzm's design is not tied to a specific WebAssembly runtime environment, enhancing its versatility. This flexibility means that Fuzzm can be used across different Wasm execution environments, including both web–based runtimes (such as those in browsers) and standalone Wasm runtimes (such as Wasmtime or Wasmer). By decoupling the fuzzer from any particular runtime, Fuzzm allows security

researchers to apply it to a wide range of Wasm applications and execution contexts, broadening its applicability. In addition to its core fuzzing capabilities, Fuzzm also incorporates a canary–based protection mechanism to guard against memory corruption vulnerabilities. Memory corruption is a common and serious security issue in low–level programming languages that WebAssembly often interacts with, such as C and C++. Canary–based protection works by placing special "canary" values in memory regions that are vulnerable to overflow, such as function stack frames. If a buffer overflow or similar vulnerability attempts to overwrite the memory, the canary value is altered, signaling the presence of a vulnerability before it can be exploited. This proactive detection mechanism adds an additional layer of defense, enabling Fuzzm not only to identify crashes but also to flag potential memory safety issues before they lead to severe security breaches. Fuzzm's approach to fuzz testing has several implications for the future of WebAssembly security. Given the increasing adoption of WebAssembly in areas such as web development, blockchain smart contracts, and serverless computing, the ability to fuzz test Wasm binaries without access to source code is of paramount importance. Proprietary Wasm binaries deployed in production environments often do not come with readily available source code, making tools like Fuzzm indispensable for ensuring the security of such applications. Moreover, Fuzzm's low overhead and broad runtime compatibility make it an ideal candidate for integration into continuous integration (CI) pipelines, where frequent security testing of binaries is crucial.

- WAFL. WAFL [25] is a cutting–edge binary–only fuzzer designed specifically for WebAssembly (Wasm) binaries, leveraging the robust capabilities of the AFL++ [26]] framework, a community–driven extension of the original American Fuzzy Lop (AFL) fuzzer.

Unlike traditional fuzzers that require access to source code for instrumentation, WAFL operates directly on Wasm binaries, making it particularly valuable for testing proprietary or third–party applications where source code may be unavailable. A key component of WAFL's architecture is its integration with the WAVM [27] runtime, an Ahead–of–Time (AOT) compiler for WebAssembly. WAVM translates Wasm binaries into optimized native machine code prior to execution, which significantly enhances performance.

WAFL extends WAVM by applying a series of patches that enable the generation of coverage information essential for AFL++'s feedback–driven fuzzing approach. These patches modify the WAVM runtime to insert instrumentation hooks at all branch points within the Wasm binary, facilitating precise tracking of execution paths without altering the original binary structure. WAFL employs AOT compilation to minimize runtime overhead, as Wasm binaries are precompiled into native code, reducing the need for Just–In–Time (JIT) compilation during fuzzing. Additionally, WAFL introduces lightweight Virtual Machine (VM) snapshots, allowing the fuzzer to quickly save and restore the VM state between fuzzing iterations. This optimization significantly accelerates the fuzzing process by minimizing setup and teardown times, thereby increasing the overall throughput of fuzzing campaigns.

Empirical evaluations have demonstrated that WAFL can achieve impressive performance, sometimes even outperforming native AFL x86–64 harnesses compiled from source code. This superior performance is attributed to the efficient integration with WAVM and the effective use of VM snapshots, which collectively reduce the overhead typically associated with binary instrumentation. To generate AFL++–compatible coverage information, WAFL implements static binary instrumentation within the WAVM runtime. This process involves inserting instrumentation code at all branch instructions within the Wasm binary, ensuring comprehensive coverage data collection. By capturing detailed execution paths, WAFL enhances AFL++'s ability to guide the fuzzing process towards unexplored and potentially vulnerable areas of the binary. This meticulous coverage generation is crucial for maximizing the effectiveness of the fuzzing efforts, enabling WAFL to uncover a wide range of vulnerabilities, including buffer overflows, memory corruption, and code injection flaws.

In addition to its core fuzzing functionalities, WAFL incorporates a canary–based protection mechanism to detect and prevent memory corruption vulnerabilities. Canary values are strategically placed in memory regions susceptible to overflow attacks. During execution, any attempt to overwrite these canaries triggers an immediate detection of the anomaly, allowing WAFL to flag potential security breaches before they can be exploited. This

proactive defense mechanism not only aids in identifying crashes but also enhances the overall security assurance provided by the fuzzer. Despite its strengths, WAFL is inherently tied to the WAVM runtime, which limits its applicability to environments that utilize WAVM for executing Wasm binaries [28]. This dependency restricts WAFL's use in scenarios where alternative Wasm runtimes, such as Wasmtime or Wasmer, are preferred.

Dynamic analysis techniques have the following advantages: runtime context, reduced false positives, and detection of complex vulnerabilities. Their limitations include limited coverage, performance overhead, and environmental dependencies.

Research on hybrid analysis methods

Recent studies have demonstrated the complementary nature of these approaches, with static analysis offering early detection of code vulnerabilities, and dynamic analysis capturing issues that manifest during execution. Researchers have explored combining both techniques into hybrid models to enhance vulnerability detection in WebAssembly binaries. These combined approaches provide a more comprehensive security assessment by leveraging the strengths of both static and dynamic methods.

WASP2 [29] presents a sophisticated framework for detecting vulnerabilities in WebAssembly binaries by leveraging both static and dynamic analysis techniques informed by known vulnerability patterns. A core component of WASP2 is its deep learning–based vulnerability classification model. The model is trained to identify vulnerabilities by mapping static features from known vulnerable binaries in architectures such as x86 and ARM to their corresponding WebAssembly binary representations. This mapping process involves several steps:

- Feature Extraction – WASP2 extracts a comprehensive set of static features from both the source architectures (x86/ARM) and the WebAssembly binaries. These features include opcode sequences, control flow patterns, data flow characteristics, and other relevant code attributes that are indicative of vulnerabilities.
- Model Training – The extracted features from known vulnerable and benign binaries are used to train a deep neural network. The architecture of the model typically includes multiple layers, such as convolutional layers for feature extraction and fully connected layers for classification. Techniques such as dropout, batch normalization, and regularization are employed to prevent overfitting and enhance the model's generalization capabilities.
- Cross–Architecture Mapping – By mapping features across different architectures, WASP2 ensures that the model can generalize vulnerability patterns from traditional binary formats (x86/ARM) to WebAssembly binaries. This cross–architecture approach is crucial for leveraging the extensive body of knowledge and datasets available for x86 and ARM vulnerabilities, thereby enhancing the model's robustness and accuracy. The authors of WASP2 conducted extensive evaluations to assess the framework's effectiveness in detecting known vulnerabilities within WebAssembly binaries.

The evaluation process involved the following steps:

- Dataset Construction: A diverse dataset comprising WebAssembly binaries with known vulnerabilities, derived from real–world applications and benchmark suites, was assembled. This dataset included various types of vulnerabilities such as buffer overflows, use–after–free errors, integer overflows, and code injection flaws.
- Model Performance – The deep learning model achieved high accuracy in identifying vulnerable subroutines, demonstrating its capability to generalize vulnerability patterns from x86 and ARM architectures to WebAssembly. Precision, recall, and F1–score metrics were used to quantify the model's performance, with WASP2 attaining precision and recall rates exceeding 90% in most categories.
- Runtime Overhead – The integration of static and dynamic analysis introduced minimal runtime overhead, primarily attributable to the efficient feature extraction and model inference processes. The dynamic analysis phase with Wasabi added an additional layer of verification without significantly impacting overall performance. WASP2 offers several key advantages such as:
- High Accuracy: By leveraging deep learning and cross–architecture feature mapping, WASP2 achieves high accuracy in detecting known vulnerabilities, reducing the rate of false positives and negatives.

— Comprehensive Analysis – The combination of static and dynamic analysis provides a holistic view of potential vulnerabilities, enabling the detection of both structural weaknesses and runtime behaviors that could lead to security breaches.
— Automation and Scalability – WASP2 automates the vulnerability detection process, making it scalable for large codebases and suitable for integration into continuous integration/continuous deployment (CI/CD) pipelines.
— Adaptability: The framework can be adapted to incorporate new vulnerability patterns and support additional architectures, enhancing its long–term viability and relevance. Despite its strengths, WASP2 exhibits certain limitations: dependence on known vulnerabilities, runtime environment constraints, and resource intensive.

Hybrid analysis techniques have the following advantages: enhanced coverage, improved accuracy, and contextual awareness. Their limitations include increased complexity, higher overhead, and coordination challenges.

Research on comparative analysis of the static, dynamic, and hybrid detection techniques

Vulnerability detection in Wasm binaries can be approached through various methodologies, primarily categorized into static analysis, dynamic analysis, and hybrid techniques. Each of these approaches offers distinct advantages and faces unique challenges, making a comparative understanding essential for selecting the appropriate strategy in various security contexts (Table 1).

In the context of WebAssembly, the choice between static, dynamic, and hybrid analysis techniques depends on several factors, including the availability of source code, the performance requirements of the application, and the nature of potential vulnerabilities. Static analysis is particularly useful for preliminary security assessments and ensuring code integrity before deployment. Dynamic analysis excels in environments where real–time monitoring and runtime behavior are critical, such as in web browsers and server–side applications running Wasm modules. Hybrid approaches are ideal for scenarios demanding thorough security evaluations, where both code structure and runtime behavior must be scrutinized to uncover a wide array of vulnerabilities. Recent work by M. Țălu [30] discusses advanced data protection techniques in WebAssembly, contributing to the security landscape.

Table 1. Comparative analysis of the static, dynamic, and hybrid detection techniques

Aspect	Static Analysis	Dynamic Analysis	Hybrid Analysis
Coverage	Comprehensive across all possible paths	Limited to executed paths	Comprehensive by combining both static and dynamic coverage
False Positives/Negatives	Higher potential for false positives and negatives	Lower false positives, but may miss some vulnerabilities	Reduced false positives and negatives through cross–validation
Performance Overhead	Generally low as no execution is required	Higher due to instrumentation and monitoring	Higher, combining overheads of both approaches
Contextual Information	Limited, no runtime context	Rich, with runtime context	Enhanced by leveraging both static and dynamic contexts
Complexity	Moderate, depends on the analysis depth	High, due to the need for controlled execution	High, due to the integration of multiple methodologies
Scalability	High, suitable for large codebases	Limited, especially for performance–critical applications	Moderate, balancing thoroughness with resource demands
Detection Capability	Good for structural and syntax–based vulnerabilities	Excellent for runtime and context–dependent vulnerabilities	Superior, covering a wide range of vulnerabilities

CONCLUSIONS

In conclusion, the security landscape of WebAssembly binaries is evolving rapidly as this technology gains prominence in modern web applications and server–side environments. This research has highlighted the critical need for effective vulnerability discovery techniques tailored to the unique characteristics of Wasm. By examining static, dynamic, and hybrid analysis methods, we have provided insights into the strengths and limitations of each approach. Static analysis techniques are valuable for their ability to perform comprehensive code evaluations and early detection of vulnerabilities without execution, yet they often struggle with false positives and a lack of contextual understanding. In contrast, dynamic analysis offers deeper insights into runtime behavior, enabling the identification of context–dependent vulnerabilities. However, it is constrained by the execution paths that are actually traversed during testing, which can limit its overall coverage. Hybrid analysis methods emerge as a promising solution, combining the thoroughness of static analysis with the contextual richness of dynamic analysis. By integrating these approaches, hybrid techniques

can enhance vulnerability detection while mitigating the weaknesses inherent in each individual method. The effective deployment of these techniques in the WebAssembly ecosystem is crucial to ensure the security and reliability of applications utilizing Wasm.

References

[1] WebAssembly official documentation. Available at: https://webassembly.org/ (accessed September 30, 2024).
[2] A. Rossberg, B.L. Titzer, A. Haas, D.L. Schuff, D. Gohman, L. Wagner, A. Zakai, J.F. Bastien, M. Holman. Bringing the Web Up to Speed with WebAssembly. Communications of the ACM, 61(12): 107–115, 2018
[3] P. Mendki. Evaluating Webassembly Enabled Serverless Approach for Edge Computing, 2020 IEEE Cloud Summit, Harrisburg, PA, USA, 2020, pp. 161–166
[4] M.N. Hoque, K.A. Harras. WebAssembly for Edge Computing: Potential and Challenges. IEEE Commun. Stand. Mag. 2022, 6, 68–73.
[5] P.P. Ray. An Overview of WebAssembly for IoT: Background, Tools, State–of–the–Art, Challenges, and Future Directions. Future Internet, 15(8): 275, 2023
[6] D. Lehmann, J. Kinder, M. Pradel. Everything old is new again: Binary security of WebAssembly. In Proceedings of the 29th USENIX Security Symposium (USENIX Security 20), Boston, MA, USA, 2020; pp. 217–234.
[7] Y. Yan, T. Tu, L. Zhao, Y. Zhou, W. Wang. Understanding the performance of webassembly applications. In Proceedings of the 21st ACM Internet Measurement Conference, Virtual Event, 2021; pp. 533–549.
[8] J. Dejaeghere, B. Gbadamosi, T. Pulls, F. Rochet. Comparing Security in eBPF and WebAssembly. In Proceedings of the ACM SIGCOMM 1st Workshop on eBPF and Kernel Extensions, New York City, NY, USA, 10 September 2023.
[9] M. Kim, H. Jang Y. Shin. Avengers, Assemble! Survey of WebAssembly Security Solutions, 2022 IEEE 15th International Conference on Cloud Computing (CLOUD), Barcelona, Spain, 2022, pp. 543–553
[10] J. Sun, D.Y. Cao, X.M. Liu, Z. Zhao, W.W. Wang, X.L. Gong. SELWasm: A Code Protection Mechanism for WebAssembly, 2019 IEEE Intl Conf on Parallel & Distributed Processing with Applications, Big Data & Cloud Computing, Sustainable Computing & Communications, Social Computing & Networking (ISPA/BDCloud/SocialCom/SustainCom), Xiamen, China, 2019, pp. 1099–1106
[11] H. Lei, Z. Zhang, S. Zhang, P. Jiang, Z. Zhong, N. He, D. Li, Y. Guo, X. Chen. Put Your Memory in Order: Efficient Domain–based Memory Isolation for WASM Applications. CCS '23: Proceedings of the 2023 ACM SIGSAC Conference on Computer and Communications Security, pp. 904 – 918
[12] H. Harnes, D. Morrison. SoK: Analysis Techniques for WebAssembly. Future Internet., 16(3): 84, 2024
[13] J. Shortt, Master thesis of Computer Science: A System for Bounding the Execution Cost of WebAssembly Functions. Carleton University, Ottawa, Ontario, 2023
[14] Q. Stiévenart, D.W. Binkley, C. De Roover. W: a WebAssembly Static Analysis Library (Extended Presentation Abstract). https://soft.vub.ac.be/Publications/2021/vub–tr–soft–21–04.pdf.
[15] Q. Stiévenart, D.W. Binkley, C. De Roover. Static stackpreserving intra–procedural slicing of Webassembly binaries. In Proceedings of the 44th International Conference on Software Engineering, pp. 2031–2042, 2022.
[16] Q. Stiévenart, C. De Roover. Compositional information flow analysis for Webassembly programs. In Proceedings of the 2020 IEEE 20th InternationalWorking Conference on Source Code Analysis and Manipulation (SCAM), Adelaide, SA, Australia, 28 September–2 October 2020; IEEE: Piscataway, NJ, USA, 2020; pp. 13–24. WASSAIL.
[17] P.D.R. Lopes. Master's Thesis: Discovering Vulnerabilities in Webassembly with Code Property Graphs. Instituto Superior Técnico, Lisbon, Portugal. 2021.
[18] T. Brito, P. Lopes, N. Santos, J.F. Santos. Wasmati: An efficient static vulnerability scanner for WebAssembly, Computers & Security, 118, 102745, 2022
[19] F. Marques, J. Fragoso Santos, N. Santos, P. Adão. Concolic Execution for WebAssembly. In Proceedings of the 36th European Conference on Object–Oriented Programming (ECOOP 2022), Berlin, Germany, 2022; Ali, K., Vitek, J. (eds.); Leibniz International Proceedings in Informatics (LIPIcs); vol. 222, pp. 11:1–11:29.
[20] A. Szanto, T. Tamm, A. Pagnoni. Taint tracking for WebAssembly. arXiv 2018. arXiv:1807.08349.
[21] W. Fu, R. Lin, D. Inge, TaintAssembly: Taint–Based Information Flow Control Tracking for WebAssembly, arXiv 2018. arXiv:1802.01050.
[22] Node.js. Node.js. 2022. Available online: https://nodejs.org/en (accessed on 5 October 2024).
[23] D. Lehmann, M. Pradel. Wasabi: A framework for dynamically analyzing webassembly. In Proceedings of the 24th International Conference on Architectural Support for Programming Languages and Operating Systems, Providence, RI, USA, 13–17 April 2019; pp. 1045–1058.
[24] D. Lehmann, M.T. Torp, M. Pradel. Fuzzm: Finding Memory Bugs through Binary–Only Instrumentation and Fuzzing of WebAssembly. arXiv 2021, arXiv: 2110.15433.
[25] K. Haßler, D. Maier. WAFL: Binary–Only WebAssembly Fuzzing with Fast Snapshots. In Proceedings of the Reversing and Offensive–oriented Trends Symposium, Vienna, Austria, 18–19 November 2021; pp. 23–30.
[26] A. Fioraldi, D. Maier, H. Eißfeldt, M. Heuse. AFL++: Combining Incremental Steps of Fuzzing Research. In Proceedings of the 14th USENIX Workshop on Offensive Technologies (WOOT 20), Boston, MA, USA, 2020.
[27] WAVM. 2021. Available online: https://wavm.github.io (accessed on 5 October 2024).
[28] K. Haßler, D. Maier. WAFL: Binary–Only WebAssembly Fuzzing with Fast Snapshots. ROOTS'21: Reversing and Offensive–oriented Trends Symposium. 2022, pp. 23–30
[29] P. Sun, L. Garcia, Y. Han, S. Zonouz, Y. Zhao. Poster: Known vulnerability detection for WebAssembly binaries. 2021
[30] M. Țălu, A Review of Advanced Techniques for Data Protection in WebAssembly, Acta Technica Corviniensis – Bulletin of Engineering, Hunedoara, Romania, 2024, In press.

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COST OPTIMIZATION OF A REINFORCED CONCRETE WATER TANK

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Abstract: The research aims to investigate the cost optimization of a reinforced concrete water tank design under Eurocode 2 guidelines. Water tanks are essential for domestic, industrial, and agricultural use, but their substantial construction and maintenance costs necessitate cost optimization strategies. This study utilizes Eurocode 2, to develop a cost optimization framework for reinforced concrete water tanks. The research employs a multi-objective optimization approach to balance the conflicting objectives of minimizing construction costs while ensuring structural safety and serviceability. A comprehensive cost model, incorporating material costs is developed to assess the total cost of the water tank. To evaluate the performance of the cost optimization framework, a case study is conducted using multiple hypothetical water tank projects. The results demonstrate the effectiveness of the proposed approach in achieving significant cost savings of 37.07%, 33.48% and 10.03% for concrete water tanks of 8000, 12000 and 18000 liters respectively, while meeting the necessary structural requirements. The findings of this research contribute to the field of structural engineering and provide guidance for engineers and designers involved in water tank projects. The cost optimization framework presented in this study can aid decision-making processes, enabling the selection of cost-effective designs that meet Eurocode 2 requirements.

Keywords: concrete, cost optimization, Eurocode 2, serviceability, water tank

INTRODUCTION

Reinforced concrete water tanks are critical infrastructure components that enable water storage in a variety of settings, including residential, commercial, and industrial settings. They are influenced by a wide range of external elements, including seismic stresses, wind loads, and material restrictions (Manning, 1973). Furthermore, economic issues are critical, particularly in locations with low financial resources (Salam and Badaruzzaman, 2011). As a result, the design of reinforced concrete water tanks must be based on a thorough understanding of structural engineering concepts.

However, the building and maintenance expenses connected with these structures can be significant, necessitating the use of cost-cutting techniques. In the construction of reinforced concrete water tanks, cost optimization entails striking an ideal balance between structural integrity and associated costs. It necessitates taking into account a variety of aspects, such as material amounts and design parameters, while also guaranteeing compliance with essential design norms and standards. Eurocode 2, also known as EN 1992-1-1, is a set of recommendations for the design of concrete structures, including water tanks.

The creation of a detailed optimization framework in which the cost of the reinforced concrete water tank is the objective function and the constraints are derived from Eurocode 2 is appropriate for investigating the structure's cost optimization. Cost optimization entails determining the best tank dimensions, wall thickness, reinforcement details, and concrete strength parameters. The crack width was taken into account to ensure the tank's serviceability and functionality (Eurocode 2, 2004). Furthermore, Eurocode 2's practical constraints and design limitations are incorporated into the optimization framework.

Hasan (2011) conducted a notable study on the application of optimization methods to the structural design of concrete rectangular and circular water tanks. The total cost of the tank was considered as an objective function, with tank capacity, width and length of tank in rectangular, water depth in circular, unit weight of water, and tank floor slab thickness as design variables. A computer program has been created to solve numerical examples using equations from the Indian IS: 456-2000 Code. According to the findings, the minimum total cost of a rectangular tank is more sensitive to changes in tank capacity and floor slab thickness, whereas the minimum total cost of a circular tank is more sensitive to all variables.

Increases in tank capacity, width, length, floor slab thickness, and water depth affect the cost.

Saxena et al. (1987) used the heuristic flexible tolerance method to present the minimum cost design of reinforced concrete water tanks based on the Indian and ACI ("building" 1969) codes. The cost function factored in the costs of concrete, steel, and formwork. They came to the

conclusion that large capacity water tanks can save a significant amount of money.

Tan (1993) used a direct search method and the (SUMT) to present the minimum cost design of reinforced concrete cylindrical water tanks based on the British Code for water tanks. Only the material costs of concrete and steel were included in the cost function. The thickness of the tank wall was idealized using piecewise linear slopes, with the maximum thickness at the base.

Another relevant study by Martnez-Martn et al. (2022) proposed an adaptive threshold acceptance method with a neighborhood move based on the mutation operator from genetic algorithms as an optimization framework for water tank design. Their research sought to examine the design of elevated tanks in relation to the full prescriptions of Eurocode 2, Eurocode 8, and the Spanish Structural Code of Practice. This includes variable loads such as seismicity, wind, and snow, as well as the action of self-weight and dead loads. The analysis revealed significant nonlinearity as a result of seismic forces and column rigidity. The study also discovered that for seismic zones of high degrees, steel reinforcement and concrete volume per unit height remained relatively constant with height.

Salam and Badaruzzaman (2011) investigated the cost optimization of a water tank model 9 m long, 6 m wide, and 24 m high with a capacity of 28530.6 gallon. The model was created for twelve different cases using the Staad Pro.2007 computer program, which is based on the American code (ACI) and the Euro code (EU2 and EU3). Case 7 was the best case for water tank design because it was designed using Euro 2 code and the model was a full concrete structure. A comparison of the ACI and Euro codes revealed that the Euro code is 6% more optimum in design than the ACI code, so it is recommended that the Euro code be used in the design of concrete water tank structures.

Furthermore, flexural cracking was investigated because it is important in the structural behavior of reinforced concrete tanks. Jelušic (2022) used a mixed-integer nonlinear programming (MINLP) algorithm and the Eurocode standard. The case study demonstrates the value of the optimization approach by proposing two different economic designs of reinforced concrete sections. A previously unseen direct comparison of different methods for modeling cracking in reinforced concrete cross-sections is also presented.

While previous research has primarily concentrated on optimizing water tank design parameters, few studies have investigated the comprehensive cost estimation of reinforced concrete water tanks. Eurocode 2 provides design and analysis guidance, but specific cost estimation methods are frequently lacking. As a result, the purpose of this study is to bridge that gap by developing a comprehensive cost model that includes material costs, labor costs, and construction time, allowing for a more accurate assessment of the total project cost.

The study focuses on creating a comprehensive cost model that estimates the total cost of building the water tank. This model takes into account the various material costs. The cost optimization framework seeks to identify the most cost-effective design alternatives while maintaining structural performance by taking these factors into account. A case study is conducted using a hypothetical water tank project to evaluate the effectiveness of the proposed cost optimization framework. Furthermore, the study analyzes and compares the costs and performance of three different tank designs, each of which increases capacity, demonstrating the potential cost savings achievable through optimization.

This study advances structural engineering by presenting a systematic approach to cost optimization in the design of reinforced concrete water tanks. The findings provide engineers and designers involved in water tank projects with practical guidance, allowing them to make informed decisions and choose cost-effective designs that meet Eurocode 2 requirements. This research promotes resource efficiency and sustainability in infrastructure development by optimizing the costs associated with water tank construction. The goal of this study was to create a cost-optimization framework for the design of reinforced concrete water tanks using Eurocode 2. The study used a multi-objective optimization approach to reduce construction costs while ensuring the structural safety and serviceability of the water tank.

MATERIALS AND METHODS

Materials

Eurocode 2 (2004) was used to create a mathematical model of a concrete structure. The model was created using an Excel spreadsheet, and the optimization process was carried out using Excel's Solver Tool.

Methods

— Formulation of the Optimization Problem

The water retaining structure is shown in Figure 1, 2 and 3. The assigned dimensions and the derived material quantities of concrete, reinforcement steel and formwork were used to develop a cost objective function with constraints for water retaining structures under Eurocode 2.

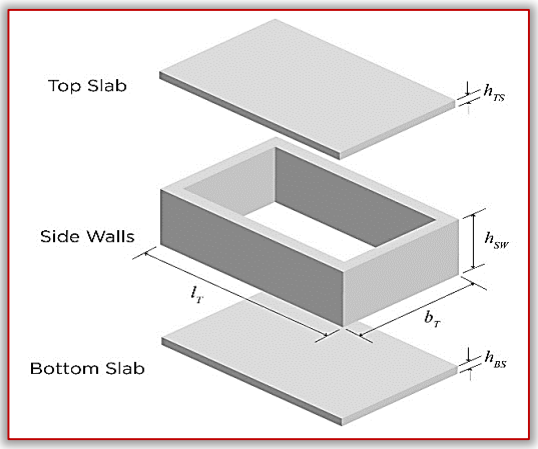

Figure 1: External dimensions of the reinforced concrete water tank.

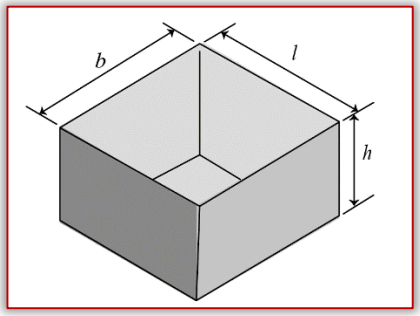

Figure 2: Interior dimensions of the reinforced concrete water tank.

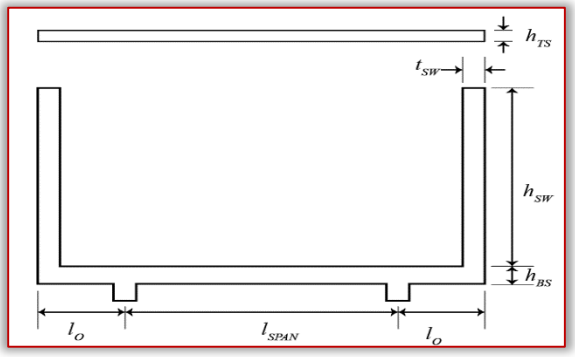

Figure 3: Cross-section of the reinforced concrete water tank.

— Development of the Objective Function

The cost of the water tank is the sum of the cost of concrete, steel and formwork components. The quantity of each of these components depends mostly on the dimensions of the tank.

The cost objective function can be defined as:

Total Cost, C = (cost of concrete) + (cost of steel) + (cost of formwork)

Which can be rewritten in full as:

$$C = [C_c \times V_c \times u_c] + [C_s \times \sum A_s] + [C_f \times F_a] \quad (1)$$

where:

C = Total cost of manufacturing the water tank.

C_c = Cost coefficient of concrete in cost per mass (naira per kg).

C_s = Cost coefficient of reinforcement steel, in cost per cross-sectional area (naira per mm²).

C_f = Cost coefficient of formwork, in cost per area (naira per m²).

u_c = Unit weight of concrete (kg/m³).

V_c = Volume of concrete (m³).

F_a = Total formwork area (m²).

$\sum A_s$= Total area of steel reinforcement (mm²).

— Inputted and Computed Parameters

Given that the cost of manufacturing the reinforced concrete water tank is related to the various parameters listed in the previous section above, further derivations were used to calculate the variables necessary for the calculation of the parameters present in the objective function.

Input parameters were classified into those that could be directly imputed and used in the objective function; those which were needed to compute values of parameters to be used in the objective function; and finally those that would be adjusted in the optimization process to produce an optimal cost of manufacturing the water tank. These parameters that needed additional calculations before being used were separated in the Excel spreadsheet as computed parameters.

The cost coefficients were each calculated based on their necessary dimensions and underlying real-world market prices as follows:

- Cost Coefficient of Concrete (C_c): This is the total cost per mass of concrete (naira per kg). It was found by calculating the total cost of manufacturing a given mass of concrete and dividing that cost by the mass of concrete manufactured.
- Cost Coefficient of Steel (C_s): This is the cost per cross-sectional area of reinforcement steel (naira per mm²). It was found by dividing the cost of specific sizes of steel bars by their areas. Given that reinforcement bars are manufactured and sold based on their diameter sizes, the bar diameters were used to derive the cross-sectional areas.
- Cost Coefficient of Formwork (C_f): Here, the cost coefficient of formwork is the cost per area of the formwork material used (commonly wood). Its dimensions are in naira per m².

The material properties of both the concrete and the steel, which were used to compute values in

the objective function and in the derivation of some constraints, are:

- Characteristic Strength of Concrete (f_{ck}): This is the compressive strength of 150 mm sized cubes tested at 28 days at which not more than 5% of the test results are expected to fail. It is taken in Eurocode 2 as 25 N/mm^2.
- Characteristic Strength of Steel (f_{yk}): This is the minimum yield stress, at which not over 5% of the test outcomes should fail. Taken as 500 N/mm^2 according to Eurocode 2.
- Unit weight of Concrete (u_c): This is the ratio of the mass of concrete per unit volume. Taken as 2400 kg/m^3.

The inputs for the geometric dimensions of the beam (as shown in Figure 1, 2 and 3):

- Total length of the tank (l_T)
- Total width of the tank (b_T)
- Total height of the tank (h_T)
- Thickness of the sidewalls of the tank (t_{SW})
- Thickness of the top slab (h_{TS})
- Height of tank side walls (h_{SW})
- Thickness of the bottom slab of tank (h_{BS})
- Span distance between the tank support (l_{span})
- Distance of overhang from tank support (l_o)
- Capacity of tank (C)

The computed parameters included the internal dimensions of the concrete tank, the volume of the tank and water within it, area of reinforcements and the required formwork area.

The internal dimensions of the tank are derived from:

$$l = l_T - 2t_{SW} \quad (2)$$

$$b = b_T - 2t_{SW} \quad (3)$$

$$h = h_{SW} \quad (4)$$

Volume of the tank (V_T), maximum volume of water (V_W) and concrete (V_C) were derived from:

$$V_W = l \times b \times h \quad (5)$$

$$V_T = l_T \times b_T \times h_T \quad (6)$$

$$V_C = V_T - V_W \quad (7)$$

Area for reinforcements are derived based on the part of the tank they were to be placed and the resulting load acting on such sections.

Area for the top slab was derived from:

$$A_{s(TS)} = 0.002bh_{TS} \quad (8)$$

Therefore, the total area of reinforcement at the top slab was give as:

$$A_{(TS)} = A_{s(TS)} \times b_T \quad (9)$$

Area for each of the side wall was derived from:

Main reinforcement:

$$A_{s(SW)} = \frac{M_{ult(SW)}}{0.87f_{yk}(0.95(t_{SW} - 50))} \quad (10)$$

where:

$$M_{ult(SW)} = 1.2 \times M_{ser(SW)} \quad (11)$$

$$M_{ser(SW)} = \frac{1}{2}(9.81 \times h_{SW}) \times h_{SW} \times \left(\frac{h_{SW}}{3} + \frac{h_{BS}}{4}\right) \quad (12)$$

Distribution reinforcement:

$$A_{d(SW)} = 0.002bt_{SW} \quad (13)$$

Therefore, the total area of reinforcement within the sidewalls was given as:

$$A_{(SW)} = 4\,(A_{s(SW)} \times h_{SW} + A_{d(SW)} \times l_T) \quad (14)$$

Area for each of the bottom slab was derived from:

Main reinforcement:

$$A_{s(BS)} = \frac{M_{ult(BS)}}{0.87f_{yk}(0.95(h_{BS} - 50))} \quad (15)$$

Where:

$$M_{ult(BS)} = \Big((\text{weight of slab} \times 1.35) + (\text{weight of water} \times 1.2) \times \frac{l_{span}^{\,2}}{8}\Big) - M_{ult(support)} \quad (16)$$

$$M_{ult(support)} = M_{ult(SW)} + \Big(\text{weight of sidewall} \times \Big(l_o - \frac{t_{SW}}{2}\Big) \times 1.35\Big) + \Big((\text{weight of slab} \times 1.35 + \text{weight of water} \times 1.2) \times \frac{(l_o - t_{SW})^2}{2}\Big) \quad (17)$$

$$\text{weight of sidewall} = (h_{SW} + h_{BS}) \times t_{SW} \times 25 \quad (18)$$

$$\text{weight of slab} = h_{BS} \times 25 \quad (19)$$

$$\text{weight of water} = 9.81 \times h \quad (20)$$

Distribution reinforcement:

$$A_{d(BS)} = 0.002bh_{BS} \quad (21)$$

Therefore, the total area of reinforcement at the bottom slab was give as:

$$A_{(BS)} = A_{s(BS)} \times l_T + A_{d(BS)} \times b_T \quad (22)$$

The total area of reinforcement along the entire tank was given as:

$$\sum A_s = A_{(SW)} + A_{(TS)} + A_{(BS)} \quad (23)$$

The total area of formwork used F_a was found using:

$$F_a = (l_T \times b_T) + ((h_{SW} + h_{BS}) \times b_T) + 4(b \times h) + (b \times h) \quad (24)$$

— Development of Constraints

The constraints used were of two types: behavioral and geometric.

The behavioral constraint was concerned with the permissible crack width on the water tank. This was not to exceed 0.3 mm, according to Eurocode 2. This was stated mathematically as:

$$\text{Crack width}, w_K \leq 0.3 \quad (25)$$

where:

$$w_K = s_{r,max} \times \varepsilon_{cr} \quad (26)$$

$$s_{r,max} = 3.4c + 0.425(k_1 k_2 \emptyset / \rho_{\rho,eff}) \quad (27)$$

$$\varepsilon_{cr} = \frac{\sigma_s - k_t\left(\frac{f_{ct,eff}}{\rho_{p,eff}}\right)(1+\alpha_e \rho_{p.eff})}{E_s} \quad (28)$$

where:

c = concrete cover.

$K_1 = 0.8$
$K_2 = 0.5$ for bending.
ø = bar diameter.
$\rho_{\rho,eff} = \frac{A_{s,min}}{A_{c,eff}}$
$A_{s,min} = k_c k f_{ct,eff} A_{ct} / f_{yk}$
$K_c = 1.0$, for pure tension
K = 1, when h = 300 mm
$f_{ct,eff} = 0.3 f_{ck}^{\left(\frac{2}{3}\right)}$, for concrete grades ≤ C50/60.
σ_s = serviceability level stress in the reinforcement.
$A_{c,eff} = (h - x)/3$
$\alpha_e = \frac{E_s}{E_{cm}}$
E_s = 200, 000 MN/mm^2
$E_{cm} = 22\left(\frac{f_{ck}+8}{10}\right)^{0.3}$
The geometric constraints include the permissible extents possible for the dimensions of the water tank and its reinforcements. In addition to these, the expected tank capacity must also be considered, if the tank's cost is to be minimized.
Behavioral constraint:

$$w_K \leq 0.3 \quad (30)$$

Geometric constraint:

$$C = V_W \quad (31)$$
$$h_T = h_{BS} + h_{SW} + h_{TS} \quad (32)$$
$$1800 \leq l_T \leq 8000 \quad (33)$$
$$1000 \leq b_T \leq 3000 \quad (34)$$
$$1000 \leq h_T \leq 3500 \quad (35)$$
$$150 \leq t_{SW} \leq 300 \quad (36)$$
$$100 \leq h_{TS} \leq 150 \quad (37)$$
$$1200 \leq h_{SW} \leq 2600 \quad (38)$$
$$150 \leq h_{BS} \leq 400 \quad (39)$$
$$300 \leq A_{TS} \leq 500 \quad (40)$$
$$5000 \leq A_{SW} \leq 20000 \quad (41)$$
$$500 \leq A_{BS} \leq 5000 \quad (42)$$

Optimization Model and Outputs

The optimization model consists of the objective function and its related constraints. These have been described in the previous sections in detail. It can be summarized as:
Minimize:

$$C = [C_c \times V_c \times u_c] + [C_s \times \sum A_s] + [C_f \times F_a] \quad (43)$$

Subject to:

$$w_K \leq 0.3 \quad (44)$$
$$C = V_W \quad (45)$$
$$h_T = h_{BS} + h_{SW} + h_{TS} \quad (46)$$
$$1800 \leq l_T \leq 8000 \quad (47)$$
$$1000 \leq b_T \leq 3000 \quad (48)$$
$$1000 \leq h_T \leq 3500 \quad (49)$$
$$150 \leq t_{SW} \leq 300 \quad (50)$$
$$100 \leq h_{TS} \leq 150 \quad (51)$$
$$1200 \leq h_{SW} \leq 2600 \quad (52)$$
$$150 \leq h_{BS} \leq 400 \quad (53)$$
$$300 \leq A_{TS} \leq 500 \quad (54)$$
$$5000 \leq A_{SW} \leq 20000 \quad (55)$$
$$500 \leq A_{BS} \leq 5000 \quad (56)$$

The design variables and the cost of manufacturing the tank were the outputs of the optimization model. The design variables included the geometric dimensions of the water tank and the total area of reinforcements.

MODEL OPTIMIZATION

The optimization model and its related formulas were replicated in Microsoft Excel were optimization of the model was performed using its Solver feature.

Development of Excel Spreadsheet

The objective function, input parameters, design parameters, computed values, constraints and their aforementioned formulas were appropriately placed in the Excel spreadsheet.

Use of Excel Solver

Once the spreadsheet was created, the Solver button was selected from the Data tab on the Excel interface. The Solver dialogue box displayed was then filled with pertinent data from the spreadsheet. The constraints were added individually, by clicking the "Add" button shown in Figure 4.

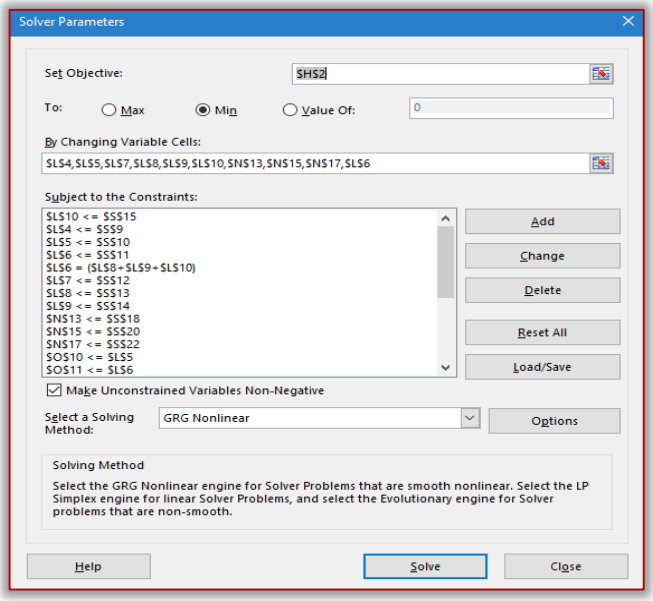

Figure 4: Excel's Solver Add-in, with objective function, design variables and constraints fully imputed.

Clicking the "Solve" button at the end of the dialogue box led to the software processing the optimization problem. After a few minutes, the new values of the cost objective function and design variables were obtained and recorded.

RESULTS AND DISCUSSION

This consisted of the cost optimization of a reinforced concrete tank with known dimensions. The cost, dimensions and reinforcement areas of the tank and their resulting values after cost optimization are shown in Table 1.

Table 1: Design case study of a RC water tank under cost optimization.

Parameters	Initial Values	Optimized Values
l_T	5000	2322.39
b_T	1000	1689.21
h_T	1850	1528.869
t_{SW}	200	100
h_{TS}	100	100
h_{SW}	1500	1265.549
h_{BS}	250	163.320
A_{TS}	200	100
A_{SW}	10721.1	10000
A_{BS}	1679.84	1500
Capacity (litres)	4000	
V_W (m^3)	4.14	3.999
Cost	489128.302	393536.265
Gain	95592.037	
Gain (%)	19.543	

A cost savings of 95592.037 naira (19.543%) was made through the cost optimization process. Whilst there was an overall reduction in all the tank's parameters, the width of the tank (b_T) was increased from 1000 mm to 1689.21 mm. The volume of water present in the tank after optimization approximately equals the design capacity of the tank.

Comparison of Select Model Reinforced Concrete Tanks

Three tanks of increasing capacities: 8000, 12000 and 18000 liters were designed and set up for cost optimization. The results are shown on Table 2, 3 and 4.

From the below tables, there is a steady decline in the gains from cost optimization of the tanks as the capacity increases. As the tank capacity rises from 8000 to 12000 to 18000 liters, the gain (%) reduces from 37.07 to 33.48 to 10.03% respectively.

Table 2: Cost optimization results for Tank A (8000 liters).

Tank A		
Parameters	Initial Values	Optimized Values
l_T	5000	3107.029
b_T	1500	2485.748
h_T	1800	1575.892
t_{SW}	150	150
h_{TS}	100	100
h_{SW}	1500	1303.896
h_{BS}	200	171.996
A_{TS}	300	497.15
A_{SW}	9057.56	5890.54
A_{BS}	2101.88	1776.45
Capacity (litres)	8000	
V_W (m^3)	8.46	7.999
Cost	487144.937	306556.647
Gain	180588.29	
Gain (%)	37.071	

Table 3: Cost optimization results for Tank B (12000 liters).

Tank B		
Parameters	Initial Values	Optimized Values
l_T	5000	3462.435
b_T	2000	2756.325
h_T	1800	1834.298
t_{SW}	150	150
h_{TS}	100	100
h_{SW}	1500	1544.806
h_{BS}	200	189.492
A_{TS}	400	551.265
A_{SW}	9057.56	6629.04
A_{BS}	2301.88	2181.04
Capacity (litres)	12000	
V_W (m^3)	11.985	12
Cost	530000.36	352534.926
Gain	177465.434	
Gain (%)	33.484	

Table 4: Cost optimization results for Tank C (18000 liters).

Tank C		
Parameters	Initial Values	Optimized Values
l_T	5000	4367.874
b_T	2300	3000
h_T	2350	1888.858
t_{SW}	150	150
h_{TS}	100	100
h_{SW}	2000	1638.858
h_{BS}	250	150
A_{TS}	460	600
A_{SW}	13323.4	11459
A_{BS}	2159.95	2088.83
Capacity (litres)	18000	
V_W (m^3)	18.8	18.000
Cost	439580.867	395467.817
Gain	44113.05	
Gain (%)	10.035	

Another trend is the consistent increase in cost that was also matched by an increase in the optimized cost as well.

The width of the tank (b_T) (as shown in Figure 1) consistently increases for all tanks after cost optimization as the other geometric parameters of the tank reduce.

CONCLUSIONS

The design case study was carried out in order to improve the cost-efficiency of a reinforced concrete tank with predefined dimensions. Following the cost optimization process, a significant cost reduction of 95,592.037 naira was achieved, representing a significant 19.54% decrease in overall expenditure.

Various parameters governing the tank's design were reduced during the optimization process, with the exception of the tank's width (referred to as b_T), which increased from 1000 mm to 1689.21 mm. As expected, the volume of water

contained within the tank after optimization closely matched the tank's original design capacity.

The investigation was expanded to three reinforced concrete tanks, each with a capacity of 8000, 12000, and 18000 liters, respectively. These tanks went through the same cost-cutting procedure.

A significant cost reduction of 37.07% was achieved for Tank A (8000 liters), resulting in a significant financial gain of 180,588.29 naira. Similarly, the cost of Tank B (12000 liters) was reduced by 33.48%, resulting in a significant gain of 177,465.434 naira. Tank C (18000 liters) achieved a less significant cost reduction of 10.03%, resulting in a gain of 44,113.05 naira.

As tank capacity increases, this data shows a trend of diminishing returns in cost optimization. It was consistently observed that as tank capacity increased, so did the cost of tank construction. Furthermore, the width of the tank (b_T) increased consistently across all tanks during the cost optimization process, while other geometric parameters decreased.

In summary, the study's findings show that cost optimization resulted in significant cost savings in all cases, albeit with diminishing returns as tank capacity increased. Furthermore, during the optimization process, the expansion of the tank's width emerged as a consistent design trend.

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References

[1] EuroCode 2. (2004). "Design of concrete structures - Part 1-1: General rules and rules for buildings."

[2] Hasan, J. M. (2011). Economical Design of Water Concrete Tanks. European Journal of Scientific Research, Vol.49 No.4 (2011), pp. 510-520.

[3] Jeluši˘c, P. (2022). Cost Optimization of Reinforced Concrete Section According to Flexural Cracking. Modelling, volume 3, pages 243–254

[4] Manning, G. P. (1973). Reinforced Concrete Reservoirs and Tanks, 1st ed. London.

[5] Martínez-Martín, F. J., Yepes, V., González-Vidosa, F., Hospitaler, A., Alcalá, J. (2022). Optimization Design of RC Elevated Water Tanks under Seismic Loads. Applied Sciences, 12, 5635

[6] Salam, J. H. and Badaruzzama, W. H. W. (2011). Cost Optimisation of Water Tanks Designed According to the ACI And Euro Codes. Proceedings of the Engineering Postgraduate Conference

[7] Saxena, K. C. and Adeli, H. (1987). Cost Optimization of Intze Tanks on Shafts Using Nonlinear Programming. Engineering. Optimization, Vol.10, No.4.

[8] Tan, G. H. (1993). Design of Reinforced Concrete Cylindrical Water Tanks for Minimum Materials Cost. Computers and Structures, Vol.48, No.5.

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IMPACT OF AVIATION NOISE ON HEALTH

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Abstract: Noise has always been a significant issue in airport areas, affecting residential dwellings, or even wildlife and ecosystems in areas surrounding airports. Aircraft noise in airport areas refers to aircraft generated noise during various phases of flight, including take-off and landing. The aim of this article is to highlight the impact of aviation noise on public health. The basics of aviation noise, the noise perception and context for the noise annoyance are presented, as simply as possible in this research article. This study also includes the aviation noise source that imply annoyance, as well as the relationships between physical mechanisms of noise and noise perception in order to describe and highlight aviation noise issues.

Keywords: noise, noise perception, annoyance, aviation noise source, health risks

INTRODUCTION

Acoustics is a scientific branch that studies sound, how it propagates and how it interacts with the environment. These include aspects such as the production, transmission and reception of sound, as well as phenomena associated with it, such as resonance, absorption and diffusion of sound. Sound is the result of the vibration of a solid, liquid or gaseous body. These vibrations locally induce a variation in atmospheric air pressure, which propagates and which the ear mechanism converts into information that is analyzed by the brain and perceived as sounds [1].

As a result, acoustics combines the description of mechanical phenomena with the physiological aspects related to the auditory sensation. Therefore, the mechanics and physiology of the auditory apparatus are inseparable for understanding and interpreting noise-induced auditory perception [1] [2].

Noise is defined as an unpleasant sound and excessive or prolonged exposure can lead to negative effects on human health, such as hearing damage, stress or sleep disturbances [1]. An important characteristic of noise is its intensity, which refers to the loudness of noise and is measured in dB (decibels) [3]. A louder noise corresponds to a higher intensity level of noise. Another property is spatial distribution [3]. Noise can be produced from various sources, e.g.: industrial machinery, construction, electronic devices, traffic and environmental factors such as wind or rain, that can damage the environment. This article deals only with air traffic – generated noise.

MECHANISM OF PRODUCTION OF AVIATION NOISE

Noise has always been a significant issue in airport areas, affecting residential dwellings, or even wildlife and ecosystems in areas surrounding airports. Aircraft noise in airport areas refers to aircraft generated noise during various phases of flight, including take-off and landing [4] [5].

Some of the important aviation noise sources include:

- Engine noise: The engines of an aircraft produce significant amounts of noise during all phases of flight, particularly during takeoff. This noise is generated by the combustion of fuel within the engine, as well as the interaction of the engine's moving parts, such as turbine blades and compressor fans, with the surrounding air. Jet engines, in particular, produce a characteristic high-pitched noise known as "jet noise." Each engine sub-component that contributes to engine noise is highlighted in Figure 1.
- Aerodynamic noise: As an aircraft moves through the air, it generates aerodynamic noise due to turbulence and airflow disruptions around the airframe, wings, control surfaces, and other components. This noise can be particularly pronounced during takeoff and landing, as well as at high speeds during cruise.
- Airframe noise: Various components of the aircraft's structure, such as landing gear, or detached high-lift devices (Figure 2), can also contribute to overall noise levels. For example, the extension and retraction of landing gear

and flaps produce noise, especially during approach and landing phases.

— Auxiliary systems: Other aircraft systems, such as air conditioning, hydraulic pumps, and auxiliary power units (APUs), can also generate noise. Even though these sources may be less significant than engine and aerodynamic noise, they can still have an important contribution to overall noise levels, especially on the ground.

The interaction of these sources of noise can result in complex acoustic characteristic of different aircraft types and operating conditions.

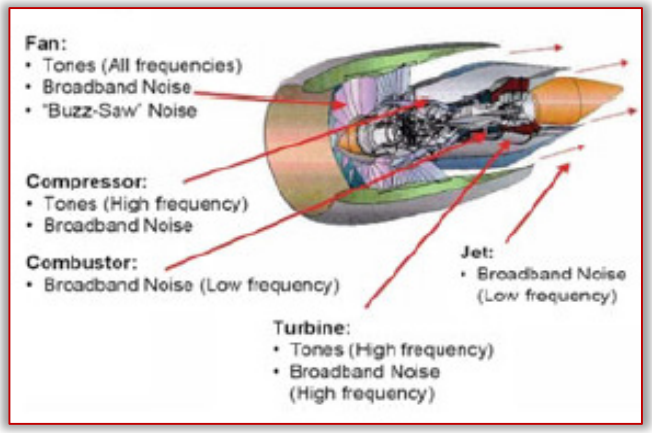


Figure 1. Engine noise source identification [5]

Figure 2. Airframe component noise contributions to total aircraft noise [5]

CONSEQUENCES OF AVIATION NOISE ON PUBLIC HEALTH IN EUROPE

According to the Environmental noise guidelines for the European region excessive noise exposure above noise levels of 45 dB Lden and 40 dB Lnight is an important environmental issue causing various health risks [6]. The relationship between health outcomes and aviation noise exposure has been evaluated by European Environment Agency (EEA), using exposure-response functions illustrated in Environmental noise guidelines for the European region [6]. According to World Health Organization (WHO) health statistics, aviation noise prolonged exposure can lead to:

— Hearing Loss: Prolonged exposure to high levels of noise, such as those generated by aircraft engines, can lead to hearing loss.

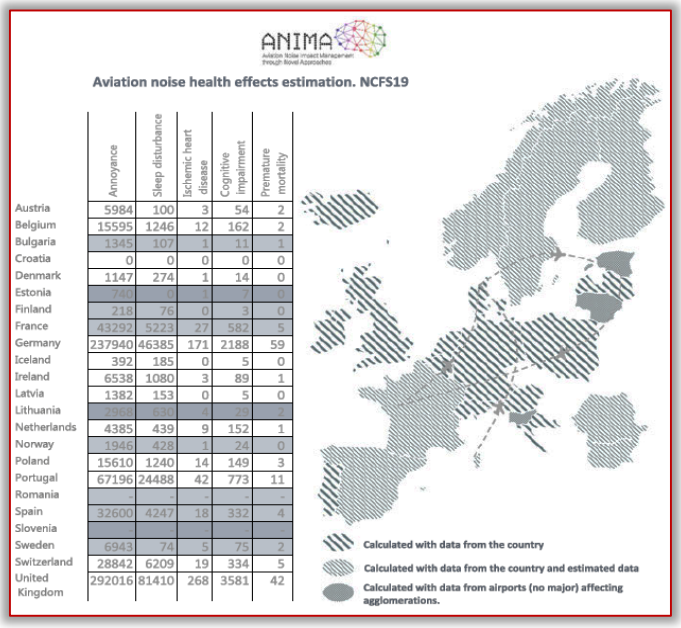
— Annoyance: Aviation noise can cause annoyance and dissatisfaction with the living environment, leading to reduced quality of life for individuals living in affected areas. Chronic exposure to noise-related annoyance can have detrimental effects on mental and emotional well-being [7].

— Sleep disturbance: Aviation noise, particularly during nighttime operations, can disrupt sleep patterns and lead to sleep disturbances such as difficulty falling asleep, frequent awakenings, and decreased sleep quality [7].

— Ischaemic heart disease (IHD), known as coronary artery disease (CAD) or coronary heart disease (CHD): Exposure to chronic noise, including aviation noise, has been associated with an increased risk of cardiovascular problems such as hypertension (high blood pressure), ischaemic heart disease, stroke and heart attacks. The stress response triggered by loud noise can rise blood pressure and heart rate, contributing to cardiovascular strain over time [7].

— Reading and oral comprehension issues for children: Living in noisy environments, including those affected by aviation noise, can contribute to increased levels of stress, anxiety, and depression. Persistent exposure to loud noise may also impair cognitive function and interfere with concentration and productivity, such as reading and oral comprehension for children [7] [8].

— Premature mortality due to IHD [7] [8].



	Annoyance	Sleep disturbance	Ischemic heart disease	Cognitive impairment	Premature mortality
Austria	5984	100	3	54	2
Belgium	15595	1246	12	162	2
Bulgaria	1345	107	1	11	1
Croatia	0	0	0	0	0
Denmark	1147	274	1	14	0
Estonia	74	6	1	2	0
Finland	218	76	0	3	0
France	43292	5223	27	582	5
Germany	237940	46385	171	2188	59
Iceland	392	185	0	5	0
Ireland	6538	1080	3	89	1
Latvia	1382	153	0	5	0
Lithuania	2968	636	4	29	2
Netherlands	4385	439	9	152	1
Norway	1946	428	1	24	0
Poland	15610	1240	14	149	3
Portugal	67196	24488	42	773	11
Romania	-	-	-	-	-
Spain	32600	4247	18	332	4
Slovenia					
Sweden	6943	74	5	75	2
Switzerland	28842	6209	19	334	5
United Kingdom	292016	81410	268	3581	42

Figure 3. People affected by aviation noise in Europe [6]

All these consequences of aviation noise on public health in Europe are highlighted in Figure 3, which shows the estimated number of people affected by aviation noise across several European countries, based on calculations with data from the country, with data from the country and estimated data, or with data from airports affecting agglomerations.
These data are available in EEA 2019 Noise country fact sheets (NCFS).

ATTEMPTS AND REGULATIONS TO REDUCE AVIATION NOISE

Since the beginning of aviation, noise has been a major environmental problem that mostly affects the residential areas that surround airports. In general, environmental noise is a clear illustration of the unintended social and technological consequences of ongoing human growth, with clear negative behavioral and health effects on those who are exposed.
In Europe in particular, urban areas account for one-third of reported noise exposure problems (14–51% in EU States), which are primarily related to noise-related annoyance among the population [5].
A comprehensive and systematic approach developed by the International Civil Aviation Organization (ICAO) to address aircraft noise issues around airports is ICAO Balanced Approach [9]. Its main goal is to achieve an equitable balance between the need for aviation services and the desire to minimize the impact of aircraft noise on communities surrounding airports [9].
The ICAO Balanced Approach consists of four main components:

- Noise Reduction at Source (focuses on reducing aircraft noise emissions through technological advancements in aircraft design, engine technology, and operational procedures),
- Land Use Planning and Management (which involves land use planning and zoning regulations to minimize the exposure of communities to aircraft noise),
- Noise Abatement Operational Procedures (focuses on the implementation of operational measures to minimize aircraft noise during takeoff, landing, and taxiing) and
- Operating Restrictions (involves the establishment of operating restrictions and limitations on aircraft operations to manage aircraft noise impacts effectively) [5] [9].

The ICAO Balanced Approach highlights the importance of cooperation among national governments, aviation authorities, airport operators, airlines, local communities, and industry stakeholders, to develop and implement effective noise management strategies.
It recognizes that no single measure can fully address aircraft noise issues and that a balanced combination of measures is necessary to achieve meaningful noise reduction while maintaining the viability and growth of the aviation industry [10] [11].

CONCLUSIONS

Aviation noise is an unpleasant sound produced by aircraft during various phases of flight, including take-off and landing. It is a significant source of environmental noise pollution, particularly in areas surrounding airports and along flight paths.
Aviation noise can have several adverse effects on communities and environment, including health impact and environmental concerns. Efforts to mitigate aviation noise include implementing reducing noise procedures, by using quieter aircraft and engine technologies, optimizing flight paths, and implementing land use planning measures to minimize noise impacts on surrounding communities.
Overall, reducing aviation noise is essential for protecting public health, improving quality of life, mitigating environmental impacts, promoting social equity, and ensuring regulatory compliance.

References

[1] Asady H. (2023). PSYCHOACOUSTIC PARAMETERS AND EAR CANAL ROLE. Canadian Acoustics - Acoustique Canadienne. 51 (3).
[2] Gély D., Márki F. (2022). Understanding the Basics of Aviation Noise. In L. Laykaylian, A. Covrig and A. Maximova (Eds.), Aviation Noise Impact Management, (p. 1-9). Springer.
[3] Fletcher H., Munson W.A. (1933). Loudness, its definition, measurement and calculation. The Journal of the Acoustical Society of America, 5, pp. 82–108
[4] Knobloch K. et al. (2022). Future Aircraft and the Future of Aircraft Noise. In L. Laykaylian, A. Covrig and A. Maximova (Eds.), Aviation Noise Impact Management, (p.117-140). Springer.
[5] Zaporozhets O. (2022). Balanced Approach to Aircraft Noise Management. In L. Laykaylian, A. Covrig and A. Maximova (Eds.), Aviation Noise Impact Management, (pp. 29-56). Springer.
[6] Sainz Pardo A. G. (2022). Noise Burden in Europe. In L. Laykaylian, A. Covrig and A. Maximova (Eds.), Aviation Noise Impact Management, (pp. 11-28). Springer.
[7] WHO Europe (2018) Environmental noise guidelines for the European region. World Health Organization Regional Office for Europe, Copenhagen, Accessed 25 February 2024.
[8] van Kamp I et al. (2018) Study on methodology to perform environmental noise and health assessment, RIVM Report No 2018–0121. National Institute for Public Health and the Environment (Netherlands)

[9] ICAO (2004) Guidance on the balanced approach to aircraft noise management. ICAO Doc. 9829, AN/451, Montreal
[10] Woodward JM, Lassman Briscoe L, Dunholter P (2009) Aircraft noise: a toolkit for managing community expectations. ACRP report 15, Washington, DC
[11] ICAO Circular 351 (2016) Community engagement for aviation environmental management. ICAO Cir. 351-AT/194, 2017

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OPTIMIZATION IN LOGISTICS: INCREASING EFFICIENCY WITH METAHEURISTICS

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Abstract: The wide application of metaheuristics and the continuous development of algorithms is currently one of the most researched areas in the field of optimization. Hundreds of algorithms already exist and their number is constantly increasing. There is almost no area where intelligent methods are not used. Numerous metaheuristic algorithms help optimization in the field of logistics as well. Despite the popularity of metaheuristic algorithms, they are rarely used in industrial practice. A wide range of different procedures is available to perform optimization tasks, traditional, e.g. from gradient–based algorithms to metaheuristics. The authors of the paper give suggestions to facilitate this.

Keywords: Logistics, metaheuristics, optimization, efficiency

INTRODUCTION

Optimization is very important in many fields: from engineering, to business, to medicine, different techniques are used to find the best solution. The goal of optimization can be essentially anything: minimizing costs, waste, scrap, travel time, energy consumption or maximizing efficiency, performance, profit. In practice, however, we always find limiting conditions when solving problems, which can be time, money, available resources, and other complex constraints. In addition to these, different techniques must find the optimal solution when solving a task [1].

During optimization, the definition of the objective function is one of the most important tasks, since the problem can be solved by minimizing or maximizing this function. Different algorithms and optimization techniques help this, especially intelligent methods, since most real problems are non–linear and multi–constrained. A wide range of different procedures is available to perform optimization tasks, traditional, e.g. from gradient–based algorithms to metaheuristics. Nondeterministic polynomial–time difficult (NP–hard) problems are usually not efficiently solved by traditional, exact algorithms, so approximate heuristic methods are the appropriate way to deal with the challenges in this case [1].

We can distinguish two common meanings of the term metaheuristics. One is a set of high–level frameworks, concepts and strategies that provide a basis for developing optimization algorithms. The other means the concrete implementation of an algorithm based on such a framework [2]. Metaheuristics arrive at the final solution iteratively, but they do not guarantee the best optimal solution. Therefore, the aim of the developments is to find a "good enough" solution in a short calculation time. This eliminates the "combinatorial explosion" (the computation time required to optimally find NP–hard problems increases exponentially depending on the size of the problem). Metaheuristics therefore represent a good compromise between the quality of the solutions and the calculation time, especially when a very complex problem with a large number of instances has to be solved. This has already been proven by the scientific community, and it can be said that metaheuristics can be effectively applied in the field of optimization. In many cases, it is an excellent alternative where exact methods (e.g. linear or dynamic programming) are no longer able to find a solution within an acceptable time. Another advantage of metaheuristics is that they do not impose specific requirements when formulating an optimization problem. Thus, the ability to obtain acceptably good solutions where other methods cannot guarantee this has made metaheuristics the choice for solving the majority of real–world multifactorial optimization problems in both academic research and practical applications [3].

The rapid growth rate of new–generation metaheuristic algorithms and new proposals, continuous developments, has induced the publication of thousands of studies in recent years. In many cases, these algorithms are not evaluated based on their usefulness or their performance values, but they emphasize the novelty of modeling a given problem or task. Due to this, similar new methods can appear at the

same time [4] and "double discoveries" [5] can be made.

Another problem is that, contrary to the hypotheses, countless algorithms do not provide the appropriate efficiency and do not bring the expected results in solving real tasks [6]. Although metaheuristic algorithms are clearly considered the pioneering method for solving complex and real–world problems, most of the publications present the techniques at a theoretical level and there are few depictions of specific engineering solutions in real–world situations. Of course, the number of successful and efficient algorithms is also large and several metaheuristics have become popular in optimization research.

The paper contributes to getting a comprehensive picture of the latest results of metaheuristic publications and applied methods in the field of logistics. The authors propose a technique to assign an algorithm to a given problem. In this way, the practical application of metaheuristics and the appearance of these techniques on real problems can be facilitated.

The paper is structured as follows: in part 2, with the literature review, the authors present the latest scientific works thematically. In the third section, a group of metaheuristic algorithms already used in the field of logistics is reviewed, and then the increase/facilitation of their use/application can be found in the fourth section. In the 5th part, the authors present the effectiveness of the implementation of the algorithms with the help of an examination. In the 6th section, the conclusion and further research directions are formulated.

LITERATURE REVIEW

Hundreds of metaheuristic algorithms have already been developed, but their number is constantly increasing. On the one hand, by continuously creating new methods, and on the other hand, by improving, existing algorithms and crossing different techniques (hybridization).

The authors have divided the literature dealing with metaheuristics into 3 large areas and based on these, they present the current state of research in the following groups:

a. comprehensive analyzes of the area,
b. possible classification of metaheuristics and
c. other research materials that are considered good practice in the field.

Comprehensive analyzes

Tens of thousands of scientific works have been published in the field of metaheuristics in the last few years and decades. In many cases, a detailed (or less detailed) presentation of special tasks or an algorithm was made in a given publication. Searching through research materials is very difficult. If, for example, we want to propose a heuristic solution to a problem, it is not easy to find previous works, ideas, and suggestions due to the variety and huge amount of articles. Therefore, several useful and at the same time well–usable, comprehensive analytical works on metaheuristics have already been prepared.

Hussain et al. [7], for example, conducted a survey by analyzing 1222 studies (research works published between 1983 and 2016) to determine the amount of research conducted in the field of science and to present the current state of the field. Critical questions related to the concerns of the field were also formulated, which could also be potential research topics.

Ma et al. [8] collected more than 500 metaheuristics and presented some of them in detail from two main aspects: the source of inspiration and the basic operators needed to generate solutions. They also examined the publication numbers of some very popular algorithms, and the metaheuristics were placed in ascending order according to the year of their publication. The latter is rare because in most comprehensive studies the algorithms are arranged in ABC order based on their names.

Rajwar et al. [9] examined 540 algorithms and provided statistical information. Several possible classification structures were presented, as well as the areas of application and most important parameters of the most popular metaheuristics were collected. Based on the number of algorithms examined, the study is outstanding and unique, as it currently contains perhaps the most examined and collected metaheuristics.

The work of Ezugwu et al. [4] is also outstanding from the point of view of the analysis of metaheuristics: they listed nearly 300 algorithms with the following most important data: author, source of inspiration, class, field of application. Perhaps there is no other summary study at the moment that presents the application areas of nearly 300 different algorithms in broad outlines, but in such detail. The advantages and disadvantages of some algorithms have been examined before, which can also contribute to the success of further research and practical applications [6]. It would also be worthwhile to extend this kind of comparative analysis to many more metaheuristics.

Mohammadi and Sheikholeslam [10] presented in detail the field of intelligent optimization and

published a comprehensive analysis containing more than 320 algorithms, which was described as follows: the algorithms were grouped according to classes taking into account numerous specifications: author, year of publication, source of inspiration, most important regulatory parameters, areas of application. Various analyzes and publication measurements are included in their work.

Systematic classification of metaheuristic algorithms

Presenting a systematic classification of all metaheuristic algorithms available in the literature is an extremely difficult task and a great challenge [4]. Fister et al [11] gave a brief overview of nature–inspired algorithms and listed the following classes: algorithms based on swarm intelligence, biologically inspired algorithms that are not based on swarm intelligence, algorithms inspired by physical and chemical processes and mentioned another category that may include all other algorithms that do not fit into the previous categories.

Ma et al. [8] describe that the most popular taxonomy is based on sources of inspiration. They describe a rough classification "in which metaheuristics are divided into population–based optimization algorithms and single–solution–based optimization algorithms according to the number of solutions generated during each iteration" [8]. In their article, they primarily deal with population–based algorithms, so this class was further divided into evolutionary algorithms, algorithms based on swarm intelligence, and algorithms based on physical or chemical processes.

In their article, Rajwar et al. [9] present several classification techniques: according to source of inspiration, according to the number/size of elements (population) of the search space, according to the movement/operation of the population, according to the number of parameters. The latter – excluding the source of inspiration – are considered a new type of classification structure in the scientific field of metaheuristics.

Molina et al. [12] also classified algorithms based on the sources of inspiration. They proposed a comprehensive taxonomy for nature–inspired optimization algorithms in a new, different approach.

Brownlee analyzed metaheuristic algorithms inspired by nature and collected a lot of parameters and important information about the individual metaheuristics, which can be of great help primarily for programming [13].

A new classification of metaheuristic algorithms was introduced by Abdel–Basset et al., which focuses on the type of inspiration. According to this, the techniques were classified into metaphor and non–metaphor based algorithms. The metaphor–based class was further divided into different subcategories: biology–based, physics–based, swarm intelligence–based, social behavior–based, music–based, chemistry–based, sports–based and mathematics–based metaheuristics are distinguished. The non–metaphor–based class was not broken down into further subcategories. All but one of the subcategories of metaphor–based algorithms (mathematical–based) belong to the additional class inspired by nature, while the non–metaphor–based class and the metaphor–based–mathematical–based algorithms are metaheuristics not inspired by nature [14].

Since most algorithms imitate processes and patterns inspired by nature, this is the category that researchers in the field deal with the most. The majority of classification techniques classify these algorithms into different categories. Currently, one of the newest taxonomies with the most subcategories is represented by the work of Darvishpoor et al. Nature–based algorithms were classified according to the source of inspiration and actually, Abdel–Basset et al. can be interpreted as an extended version of his classification. Nine main categories are distinguished: bio–based, ecosystem–based, social–based, physics–based, chemistry–based, music–based, sport–based, hybrid and math–based. The bio–based category is further divided into 10 subcategories: evolution–based, organ–based, behavior–based, disease–based, microorganism–based, insect–based, avian–based, aquatic–based, terrestrial animal–based, and plant–based [15].

The largest group of different metaheuristic algorithms are algorithms inspired by nature. This is primarily due to their excellent performance and relatively simple structure. Hundreds of animals, plants, natural formations and phenomena were used as a source of inspiration to develop an algorithm. Natural phenomena and behavioral patterns serve as the basis for algorithms, such as: food–seeking behavior of certain species, the water cycle, movement characteristics of animals, behavioral patterns of team sports, etc. There are at least – approximately – 400 algorithms that belong to

the group of algorithms inspired by nature [15]. Table 1 shows some algorithms and their sources of inspiration [16].

Table 1: Some metaheuristics and their sources of inspiration

Metaheuristics	Sources of inspiration
Particle Swarm Optimization (PSO)	Intelligent social behavior of a flock of birds
Monkey Search (MS)	The process of monkeys climbing trees while searching for food
Mine Blast Algorithm (MBA)	Mine bomb explosion
Artificial Algae Algorithm (AAA)	The lifestyle of microalgae
Shark Smell Optimization (SSO)	A shark's ability to find its prey by smell
Dolphin Swarm Optimization Algorithm (DSOA)	Mechanisms of dolphins in detecting, chasing and preying on schools of sardines
Virus Colony Search (VCS)	Viral infection and dissemination strategies
Crow Search Algorithm (CSA)	Intelligent food hiding behavior of crows
Grasshopper Optimization Algorithm (GOA)	Swarming behavior of grasshoppers
Electro–Search Algorithm (ESA)	The orbital motion of electrons around the nucleus
Spotted Hyena Optimizer (SHO)	Social behavior of spotted hyenas
Butterfly–inspired Algorithm (BA)	The mating mechanism of the butterfly
Squirrel Search Algorithm (SSA)	Dynamic foraging behavior and efficient locomotion of southern flying squirrels
Red Deer Algorithm (RDA)	Imitating the behavior of the Scottish red deer
Simulated Annealing (SA)	Annealing process in metallurgy

Research materials

When we want to optimize, depending on the size of the problem and the number of parameters and constrained conditions, there are many methods available to solve a task efficiently. Among the exact and heuristic techniques, the former is effective for problems with a smaller number of instances, while the latter can also handle large data sets, but can "only" provide a good enough solution. At what point is it worth investing time and money in developing an intelligent algorithm and is it worth using? The general comparison of exact methods and metaheuristic solutions is discussed in few scientific works, each example is typical for the solution of a specific problem. For example, Chandra et al.'s paper [17] compares the Branch and Bound (B&B) method with the Fruit Fly Optimization Algorithm (FOA) and the Artificial Atom Algorithm (A^3) metaheuristics. In terms of processing time, the difference between the two methods is more than 12 days, however, if certain conditions are met, B&B performed better. It should therefore be considered to carry out comparative analyzes in this direction during the practical application of a new metaheuristic method.

Another strong contribution to the scientific field of metaheuristics is the collection of solution proposals collected and thematically arranged for individual specific problems in one work. A good example of this is the article by Golab et al. [18], in which metaheuristic approaches applied to resource–constrained project scheduling problems were presented. This also provides a good basis for further research and can contribute to the identification of the most suitable solution method for the task.

In the scientific field of metaheuristics, several problems have already been formulated in the research community, for example, that there are no uniformly accepted standards in the field of operations research. This fact also damages the credibility of the results dealing with metaheuristics. To eliminate this, several researcher have already suggested that the optimization research community should adopt certain standards. Kendall et al. [19] formulate a specific proposal and draft for the unification of many areas, including the presentation of algorithms, solutions, calculation speed, software features, etc. By doing so, they hope to further improve the quality of research by adhering to the same minimum standards. This can contribute to and improve the reproducibility and comparability of results, as well as the efficiency of individual researchers and research groups.

Another good practice is the complete analysis of each algorithm: the basics of metaheuristics, general presentation, hybrids, application possibilities, etc. A good example of this is Neshat et al.'s article [20], in which the Artificial Fish Swarm algorithm is presented, or Teodorović's work [21] with the analysis of Bee Colony Optimization, but the work of Zebari et al. [22] with a complete overview of the Bat Algorithm can also be classified here.

Another area for improvement in studies and research on metaheuristics is that relatively few concrete engineering problems are presented at an adequate level, if at all. Even in the case of the presented problems, it often happens that the problem is not represented properly, with few parameters and an incomplete mathematical description. In their article [23], Zhao et al. describe the engineering solutions, decision variables, limiting conditions, etc. of the Artificial Hummingbird Algorithm: they examine the effectiveness of the algorithm for 10 specific small engineering tasks, comparing it with other algorithms. In the study by Agárdi et al. [24], the specific engineering problem is properly formulated and described.

Tens of thousands of studies related to metaheuristics are available in scientific databases. Research, results, and developments are continuous, but there is a need to improve the quality of the field, to provide accessible, uniform summary and comparative works in order to make the field of science more clearly understandable and unambiguous for future researchers.

METAHEURISTICS IN LOGISTICS

Metaheuristics perform well for complex, complicated problems. In the field of logistics and supply chains, the processes are extremely complex and their proper coordination and global optimization is also necessary in addition to the optimization of the individual sub–processes. Therefore, metaheuristic algorithms are also used in these areas and there are many procedures for solving complex tasks (e.g. [25], [26], [27]). There is a wealth of research and results to effectively solve a logistics or supply chain problem. However, due to the variety and quantity of articles, it is difficult to find the best solution for a specific problem and the details and reasons for the method used.

Few scientific works have been published that focus on a particular problem, and optimization techniques suitable for the problem have been systematically collected. From this approach, the authors focus on the problems.

Ezugwu et al. determined in the case of almost [4] 300 algorithms, in which area the given algorithm has already been applied. With the help of this, already used metaheuristics for some logistics problems could be easily identified, here are some examples:

- **Travelling salesman problem:** African Buffalo Optimization, Ant colony optimization, Artificial bee colony algorithm, Artificial Ecosystem Algorithm, Bean Optimization Algorithm, Bumble Bees Mating Optimization, Chicken swarm optimization, Clonal Selection Algorithm, Consultant–Guided search, Crystal Energy Optimization Algorithm, Egyptian Vulture Optimization, Elephant Search Algorithm, Firefly algorithm, Fish swarm algorithm, Genetic algorithm, Golden ball, Harmony Search Algorithm, Honey–bees mating optimization algorithm, Hunting search algorithm, Hydrological cycle algorithm, Intelligent Water Drops Algorithm, Invasive Weed Optimization, Memetic Algorithm, Penguins Search Optimization Algorithm, Photosynthetic Learning Algorithm, River Formation Dynamics, Shuffled Frog Leaping Algorithm, Simulated annealing, Swallow Swarm Optimization Algorithm, Tabu Search algorithm, The scientific algorithms, Variable Neighborhood Descent Algorithm, Water Wave Optimization, Water–flow Algorithm
- **Knapsack problem:** Artificial Algae Algorithm, Artificial Chemical Reaction Optimization Algorithm, Cuckoo search, Egyptian Vulture Optimization, Fruit Fly Optimization Algorithm, Glowworm swarm optimization, Intelligent Water Drops Algorithm, Migrating Birds Optimization, Monarch Butterfly Optimization Algorithm, Monkey search algorithm, Multi–verse Optimizer, Viral systems
- **Transportation problem:** Keshtel Algorithm, Sheep Flocks Heredity Model, Viral systems
- **Scheduling:** African Buffalo Optimization, Ant colony optimization, Ant Lion optimization, Artificial bee colony algorithm, Bat Algorithm, Biogeography Based Optimization, Bird mating optimizer, Brain Storm Optimization, Bumble Bees Mating Optimization, Cat swarm optimization, Earthworm Optimization Algorithm, Firefly algorithm, Fruit Fly Optimization Algorithm, Gases Brownian motion Optimization, Genetic algorithm, Imperialist Competitive Algorithm, Intelligent Water Drops Algorithm, Invasive Weed Optimization, League championship algorithm, Migrating Birds Optimization and Monkey search algorithm, Particle swarm optimization, Raven Roosting Optimization Algorithm, Saplings Growing Up Algorithm, Sheep Flocks Heredity Model, Shuffled Frog Leaping Algorithm, Symbiotic Organisms Search, Virus Optimization Algorithm, Water Wave Optimization, Water–flow Algorithm, Whale Optimization Algorithm, Wind Driven Optimization
- **Job scheduling:** Artificial Chemical Reaction Optimization Algorithm, Artificial Fish Swarm Algorithm, Fish swarm algorithm, Harmony Search Algorithm, Particle swarm optimization, Tabu Search algorithm, Variable Neighborhood Descent Algorithm
- **Flowshop scheduling problem:** African Wild Dog Algorithm, Anarchic Society Optimization, Artificial Immune System, Golden ball, Memetic Algorithm, Monkey search algorithm
- **Job–shop scheduling problem:** Anarchic Society Optimization
- **Flexible job scheduling problems:** Camel herd Algorithm
- **Production scheduling problem:** The Bees Algorithm

- **Routing problem:** Cultural algorithm, Genetic algorithm, POPMUSIC: Partial Optimization Metaheuristic Under Special Intensification Conditions, Simulated annealing, Variable Neighborhood Descent Algorithm
- **Multicast routing problem:** Animal Migration Optimization Algorithm, Bumble Bees Mating Optimization
- **Vehicle routing problems:** Ant colony optimization, Bumble Bees Mating Optimization, Egyptian Vulture Optimization, Golden ball, Honey–bees mating optimization algorithm, Intelligent Water Drops Algorithm, Monarch Butterfly Optimization Algorithm, Saplings Growing Up Algorithm, Simulated annealing, Tabu Search algorithm, Variable Neighborhood Descent Algorithm, Water Wave Optimization

Of course, this does not mean that only these algorithms were used to effectively solve the listed problems, since the number of metaheuristics and scientific works is growing exponentially every year. However, the question can legitimately arise, why is there little reuse of algorithms in a field that develops so quickly? Why are there few actual applications of these algorithms in practice? There are critical elements that have already been formulated by other researchers, for example, Swan et al summarized some problems that can hinder development in the field of metaheuristics. They also formulated the shortcomings of the published works (for example: the description of the algorithms in the articles dealing with metaheuristics is not precise enough and this hinders independent re–implementation, or that the main processes of algorithm design are rarely documented), the improvement of which could increase the practical application of metaheuristics [5].

INCREASING THE PRACTICAL APPLICATION OF METAHEURISTICS

Metaheuristic algorithms perform well in solving complex, complicated, high–volume tasks. Nowadays, their application in the field of optimization is significant, but at the same time, the practical use and reuse of algorithms is less realized. The primary goal of theoretical research and scientific work should be to make metaheuristics more widespread in practice and appear as a real technique. Both the work of the specialist and the solution of the tasks must be promoted in the field of optimization. Scientific works can provide a suitable basis for this, but an important research question is how can this really be implemented? What does it take a method to work effectively in practice? What are the possibilities of integrating these techniques into the field of logistics?

After reading hundreds of scientific papers, the authors make the following conclusions – especially regarding the pseudocodes of metaheuristics:

- In order to increase the reuse of metaheuristic algorithms, it is necessary to define the basic properties and most important elements that are necessary for the proper application of an optimization technique or the implementation of the basics.
- Based on the pseudocodes of the metaheuristics, the framework of the algorithm can be translated into a chosen programming language so that it is syntactically correct. Of course, this does not mean that the program will work and is able to provide a solution to a specific problem. However, it is already a big help for programmers if the framework of a metaheuristic is easier to implement. Metaheuristic algorithms and their transfer to different programming languages are extremely complicated without a basic concept. Only a few programming mathematicians have the appropriate knowledge for this. This also proves that it is not easy to apply a metaheuristic optimization procedure in practice, although due to the complexity of real engineering problems, general use would be necessary in many cases.
- If the program runs in the selected programming language written from the pseudocode, it can be said that it is syntactically correct, but it cannot output a result. The reason for this is that this code only provides the framework of the metaheuristics, however, exact parameters and the mechanisms of the behaviors need to be clarified in order to demonstrate a solution.

The example below clearly illustrates what data a randomly selected algorithm needs to function properly.

In order for the Artificial Fish Swarm Algorithm (AFSA) [28] program to function effectively and efficiently, the following data, parameters and operations are generally required:

- Definition of problem–specific data: the problem to be solved, special requirements, decision variables, objective function and constraints.

- Determination of the size and dimensions of the solution space.
- Determination of population size (number of artificial fish) for each iteration.
- Determination of the maximum number of iterations.
- Defining the preying, the swarming and the following behavior: defining the logic of the behavior based on the characteristics of the problem.
- Definition of initialization method (random, problem–specific approach).
- Determination and adjustment of crowd factor (how neighboring artificial fish interact with each other).
- Determination of stop conditions.
- Additional parameters: there are other dependent problem–specific and algorithm–specific parameters that must be taken into account (e.g. exploration–exploitation trade–off).
- Selecting appropriate data structures for displaying information.
- Testing with different parameters to determine the performance indicators, efficiency, and robustness of the algorithm to achieve the optimal configuration.

— In programming, semantics includes questions of content. Essentially, it is a set of rules for the operation of the program. A program is semantically correct if it runs and produces results. Of course, this does not mean that it works correctly for a specific problem, since it is necessary to check the final result and if it is not correct or does not give the expected result, then some parameter setting or operating mechanism is incorrect and must be corrected. Specialists in the given field are able to provide appropriate assistance for the latter.

— If a detailed and correctly formulated pseudocode of an algorithm is given, as well as a description of the mechanisms that basically determine the operation of the algorithm and the most important data, then we can obtain executable, syntactically and semantically correct program codes in different programming languages. However, it is extremely important to precisely define the task to be solved with strictly defined data, information and parameters, as well as to take into account the special properties of the chosen algorithm. The performance of an algorithm can be further improved by evaluating the results and by fine–tuning the settings and parameters related to the particularities of metaheuristics. Based on these, it is likely that an optimization procedure using metaheuristics can be carried out with the help of the above. However, this also requires the knowledge of specialists in the specific field.

It can be seen that a lot of data and mechanism definition are needed for the actual application and efficient operation of a metaheuristic procedure. In the case of complex problem solving, a high level of theoretical and practical knowledge and the serious expertise of a programming mathematician are required to solve the task. However, if the variables, the objective function, the operating mechanisms, and all other parameters and information are properly defined, then the use of the algorithm and its practical applicability are easier with their help.

PROMOTING IMPLEMENTABILITY AND EXTENDING PRACTICAL APPLICATIONS

In the fields of logistics, there are countless complex problems and optimization tasks for which the application of these algorithms provides and could provide an optimal solution within an appropriate calculation time. In practice, however, it is not an easy task to choose which metaheuristic to choose for a given problem. The reasons for this are essentially the same as those described earlier: there are many different metaheuristic algorithms for countless problems, and in the absence of few practical, real–world examples, it is difficult to say which method to choose for a given problem. Furthermore, metaheuristics have not been grouped so far based on their components and structural elements, which are responsible for the basic optimization performance of the given method, and it has not been revealed why the method works well, or what is the relationship between the properties/components of the metaheuristic and the structure of the problem to be solved.

The adaptation of an algorithm is based on close cooperation between the programmer and the logistician. So far, it has been presented which data help the programmer to implement an algorithm, but all this is not enough to properly solve a problem without the professional knowledge of the logistician. The task of the logistician is to tell the specifications of the problem, the exact parameter settings, their modification if necessary, and the real

operational efficiency of the algorithm based on the accuracy of the results.

In terms of variables, optimization problems can basically be divided into two broad categories: discrete and continuous. Many logistic problems are combinatorial optimization problems, which can usually be traced back to discrete sets, but this does not mean that all combinatorial optimization problems have discrete variables. In light of these, the authors classified logistics problems according to these three categories: combinatorial, discrete and continuous. Metaheuristics were also classified into the same categories in light of the types of problems they have already effectively solved based on the literature. Of course, an algorithm can efficiently solve both continuous, discrete and combinatorial problems, but the authors believe that if an algorithm is able to solve the largest number of combinatorial problems, it is likely that it can be used to solve several other types of combinatorial problems. Some examples are presented below according to the described classification principle.

Problems:

- Continuous Capacity Planning (CLP) – continuous
- Discrete Facility Location Problem (DFLP) – discrete
- Economic Order Quantity (EOQ) – continuous
- Job Scheduling (JS) – combinatorial
- Knapsack Problem (KP) – combinatorial
- Traveling Salesman Problem (TSP) – combinatorial
- Vehicle Routing Problem (VRP) – combinatorial
- Metaheuristics:
- African Buffalo Optimization (ABO): combinatorial [29]
- African Vultures Optimization Algorithm (AVOA): continuous [30], [31], [32], [33]
- Ant Colony Optimization (ACO): combinatorial [34], [35], [36], [37]
- Artificial Bee Colony (ABC): combinatorial [38], [39]
- Artificial Fish Swarm Algorithm (AFSA): continuous, combinatorial [40], [41]

The authors assume that more emphasis should be placed on the nature of the problem when connecting the optimization technique and the problem. This can provide a starting point and help you find the right way to solve the problem. According to their assumption, if an algorithm worked effectively in solving combinatorial problems based on the literature, it is likely that it will also be suitable for solving logistic combinatorial problems. The goal is to determine which of the metaheuristics chosen at random can be suitable for solving a chosen logistics problem. The method is suitable for promoting the industrial use of metaheuristics, because the goal here is not to prove the efficiency and capabilities of an algorithm against other algorithms. The (most) suitable solution method must be found for a given problem.

EFFICACY STUDY

If we compare the problems and metaheuristics presented in the previous chapter, then a possible matching can be the following (Hypothesis 1): Continuous Capacity Planning problem (Eq. 1) can be efficiently solved by the African Vultures Optimization Algorithm (AVOA).

Objective function:

$$\text{Minimize} \int_0^T [k_1 (P(t) - P(t-1))^2 + k_2 I(t)^2] \, dt$$

where T is is the planning horizon, k_1 and k_2 are cost coefficients, $P(t)$ is the production rate and $I(t)$ is the inventory level at time t.

In the first step, the previously described technique must be used, i.e. a method capable of solving a Continuous Capacity Planning problem can be adapted based on the information found in scientific works, expert knowledge and the pseudocode and most important operating mechanisms of the selected algorithm.

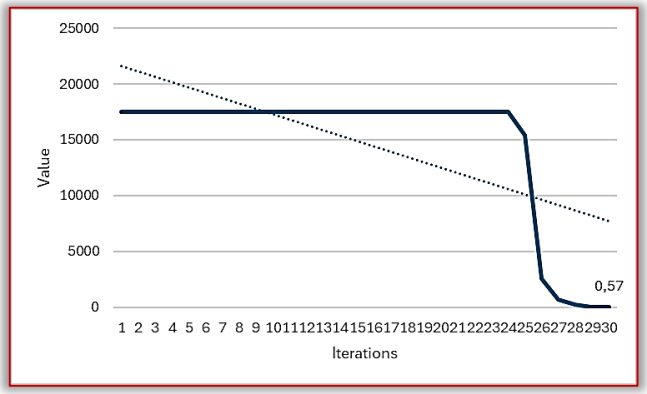

Figure 1: Results of an AVOA–based procedure

A characteristic of metaheuristic procedures is that it is necessary to experiment with the appropriate setting of parameters and different mechanisms. Even in the case examined by the authors, several modifications were needed to obtain acceptable values. Initially, the algorithm did not improve the fitness value above the initial value found in the first iteration. After the modified parameters and mechanisms, the algorithm significantly reduces the fitness value in the first few iterations. However, it converges quickly, suggesting that it is trapped in a local minimum and is not looking any further to find a

potentially better global minimum. Further fixes and modifications proved to be successful. Fig. 1 shows that the adaptation was successful. The metaheuristic approach achieved an extremely good result in the 30th iteration. The following can be said about the previous iterations: In the beginning, the algorithm converged quickly, but it successfully got out of the trap of the local minimum and effectively reduced the fitness value in later iterations. This indicates that the parameter modification and the diversity mechanism performed effectively.

CONCLUSION AND FUTURE WORK

Nowadays, the development, usefulness and success of metaheuristic optimization procedures are unquestionable. Hundreds of algorithms have already been developed and demonstrated their success based on various efficiency tests. However, the number of metaheuristics applied to specific, real–world problems and the scientifically acceptable, detailed presentation of solving a real engineering task with metaheuristics are still few. This would require the provision of data and parameters that actually promote practical applicability and adaptability to problems in other areas. The primary goal of the paper was to show how the results of scientific works and industrial practice can be brought closer together.

The authors examined metaheuristic optimization procedures and the possibilities of how they can be adapted and implemented to solve various logistics tasks and problems. It was determined how important it is to have the detailed pseudocode of a metaheuristic and other important parameters and operating mechanisms available in a given paper. With the expert knowledge that can be obtained from scientific works, an optimization procedure can be created, which is able to effectively solve the problem while retaining the special properties of a chosen metaheuristic. It can be concluded that a program written based on AVOA's pseudocode and other parameters performed well in a continuous optimization problem. Of course, there are parameters that can be fine–tuned to achieve even better performance and results, and the efficiency of the algorithm can be gradually improved.

Another result is that a working optimization method can be implemented in practice and is suitable for solving real logistics tasks. With a similar novel classification of logistics tasks and metaheuristics, the authors facilitated the assignment of an optimization technique to a given task. In relation to the parameter settings of the algorithms, it was pointed out how important the contribution of the logistician is during the adaptation of an optimization procedure into practice. With the help of all these, the practical usefulness of the paper contributes to a great degree of promotion of the logistical applicability of metaheuristic algorithms, as well as to bringing empirical theory and industrial practice closer to each other. With the help of the presented techniques, the implementability of an algorithm was facilitated not only in the field of logistics, since the method can be adapted to other fields as well.

Based on the paper, it is clear that there are countless possibilities for further research in the area. Further development and expansion of the methods presented in this work is a primary task for the future. In addition to these, adding additional information to the organization of pseudocodes can contribute to even more effective implementability. A database supplemented with mathematical formulas can also be a defining task of a further research direction.

References

[1] Yang, X.–S., & Karamanoglu, M. (2020). Nature–inspired computation and swarm intelligence: a state–of–the–art overview. Nature–Inspired Computation and Swarm Intelligence, 3–18

[2] Sörensen, Kenneth & Sevaux Marc & Glover, Fred. (2013). A History of Metaheuristics. in R. Martí, P. Pardalos, and M. Resende, Handbook of Heuristics, Springer, 2016. (https://www.researchgate.net/)

[3] Kenneth Sörensen, Fred Glover: Metaheuristcs, Encyclopedia of Operations Research andManagement Science (3e) Springer, New York. (https://www.researchgate.net/publication/237009172_Metaheuristics)

[4] Ezugwu, A.E., Shukla, A.K., Nath, R. et al. Metaheuristics: a comprehensive overview and classification along with bibliometric analysis. Artif Intell Rev 54, 4237–4316 (2021)

[5] Jerry Swan, Steven Adriaensen, Alexander E.I. Brownlee, Kevin Hammond, Colin G. Johnson, Ahmed Kheiri, Faustyna Krawiec, J.J. Merelo, Leandro L. Minku, Ender Özcan, Gisele L. Pappa, Pablo García–Sánchez, Kenneth Sörensen, Stefan Voß, Markus Wagner, David R. White: Metaheuristics "In the Large", European Journal of Operational Research, Volume 297, Issue 2, 2022, Pages 393–406

[6] Ezugwu, Absalom & Adeleke, Olawale & Akinyelu, Ayo & Viriri, Serestina. (2019). A conceptual comparison of several metaheuristic algorithms on continuous optimization problems. Neural Computing and Applications. 32

[7] Hussain, K., Mohd Salleh, M.N., Cheng, S. et al. Metaheuristic research: a comprehensive survey. Artif Intell Rev 52, 2191–2233 (2019)

[8] Zhongqiang Ma, Guohua Wu, Ponnuthurai Nagaratnam Suganthan, Aijuan Song, Qizhang Luo: Performance assessment and exhaustive listing of 500+ nature–inspired metaheuristic algorithms, Swarm and Evolutionary Computation, Volume 77, 2023, 101248.

[9] Rajwar, K., Deep, K. & Das, S. An exhaustive review of the metaheuristic algorithms for search and optimization: taxonomy, applications, and open challenges. Artif Intell Rev 56, 13187–13257 (2023)

[10] Ali Mohammadi, Farid Sheikholeslam, Intelligent optimization: Literature review and state–of–the–art algorithms (1965–2022), Engineering Applications of Artificial Intelligence, Volume 126, Part D, 2023, 106959

[11] Fister Jr, Iztok & Yang, Xin–She & Fister, Iztok & Brest, Janez & Fister, Dušan. (2013). A Brief Review of Nature–Inspired Algorithms for Optimization. Elektrotehniski Vestnik/Electrotechnical Review. 80(3): 1–7.
[12] Molina, D., Poyatos, J., Ser, J. D., García, S., Hussain, A., & Herrera, F. (2020). Comprehensive Taxonomies of Nature– and Bio–inspired Optimization: Inspiration Versus Algorithmic Behavior, Critical Analysis Recommendations. Cognitive Computation
[13] Brownlee, J. (2011). Clever algorithms: nature–inspired programming recipes. Jason Brownlee
[14] Abdel–Basset, M., Abdel–Fatah, L., & Sangaiah, A. K. (2018). Metaheuristic Algorithms: A Comprehensive Review. Computational Intelligence for Multimedia Big Data on the Cloud with Engineering Applications, 185–231
[15] Darvishpoor S, Darvishpour A, Escarcega M, Hassanalian M. Nature–Inspired Algorithms from Oceans to Space: A Comprehensive Review of Heuristic and Meta–Heuristic Optimization Algorithms and Their Potential Applications in Drones. Drones. 2023; 7(7):427
[16] Kumar, Neetesh & Singh, Navjot & Vidyarthi, Deo. (2021). Artificial lizard search optimization (ALSO): a novel nature–inspired meta–heuristic algorithm. Soft Computing. 25. 1–23
[17] A. Chandra, C. Natalia and A. Naro "Comparative Solutions of Exact and Approximate Methods for Traveling Salesman Problem", Lámpsakos, no. 25, pp. 1–12., 2021
[18] Golab, Amir & Sedgh Gooya, Ehsan & Falou, Ayman & Cabon, Mikael. (2022). Review of conventional metaheuristic techniques for resource–constrained project scheduling problem. Journal of Project Management. 7. 95–110. 10.5267/j.jpm.2021.10.002.
[19] Kendall, Graham & Bai, Ruibin & Blazewicz, Jacek & De Causmaecker, Patrick & Gendreau, Michel & John, Robert & Li, Jiawei & Mccollum, Barry & Pesch, Erwin & Qu, Rong & Sabar, Nasser & Vanden Berghe, Greet & Yee, Angelina. (2015). Good Laboratory Practice for Optimization Research. Journal of the Operational Research Society. 67. 10.1057/jors.2015.77.
[20] Neshat, M., Sepidnam, G., Sargolzaei, M. et al. Artificial fish swarm algorithm: a survey of the state–of–the–art, hybridization, combinatorial and indicative applications. Artif Intell Rev 42, 965–997 (2014)
[21] Teodorović, D. (2009). Bee Colony Optimization (BCO). Studies in Computational Intelligence, 39–60
[22] Zebari, Amar & Almufti, Saman & Abdulrahman, Chyavan. (2020). Bat algorithm (BA): review, applications and modifications. International Journal of Scientific World. 8. 1
[23] Weiguo Zhao, Liying Wang, Seyedali Mirjalili: Artificial hummingbird algorithm: A new bio–inspired optimizer with its engineering applications, Computer Methods in Applied Mechanics and Engineering, Volume 388, 2022, 114194.
[24] Agárdi, A.; Nehéz, K.; Hornyák, O.; Kóczy, L.T. A Hybrid Discrete Bacterial Memetic Algorithm with Simulated Annealing for Optimization of the Flow Shop Scheduling Problem. Symmetry 2021, 13, 1131
[25] Pedro Coelho, Cristovão Silva: Parallel Metaheuristics for Shop Scheduling: enabling Industry 4.0 Procedia Computer Science 180 (2021) 778–786
[26] Farshid Keivanian, Raymond Chiong: A Novel Hybrid Fuzzy–Metaheuristic Approach for Multimodal Single and Multi–Objective Optimization Problems Expert Systems with Applications Available online 16 November 2021, 116199
[27] Robert Pellerin, Nathalie Perrier, François Berthaut: A survey of hybrid metaheuristics for the resource–constrained project scheduling problem European Journal of Operational Research 280 (2020) 395–416
[28] Faeq, I.F. & Duaimi, Mehdi & Sadiq, Ahmed. (2018). An efficient artificial fish swarm algorithm with harmony search for scheduling in flexible job–shop problem. Journal of Theoretical and Applied Information Technology. 96. 2287–2297.
[29] Julius Beneoluchi Odili, Mohd Nizam Mohmad Kahar, Shahid Anwar: African Buffalo Optimization: A Swarm–Intelligence Technique, Procedia Computer Science, Volume 76, 2015, Pages 443–448
[30] Benyamin Abdollahzadeh, Farhad Soleimanian Gharehchopogh, Seyedali Mirjalili: African vultures optimization algorithm: A new nature–inspired metaheuristic algorithm for global optimization problems, Computers & Industrial Engineering, Volume 158, 2021, 107408
[31] R. Ghafari, N. Mansouri: E–AVOA–TS: Enhanced African vultures optimization algorithm–based task scheduling strategy for fog–cloud computing, Sustainable Computing: Informatics and Systems, Volume 40, 2023, 100918
[32] V Rajaguru, K Iyswarya Annapoorani: Virtual synchronous generator based superconducting magnetic energy storage unit for load frequency control of micro–grid using African vulture optimization algorithm, Journal of Energy Storage, Volume 65, 2023, 107343
[33] Ahmed A. Zaki Diab, Mohamed A. Tolba, Ali M. El–Rifaie, Kotin A. Denis: Photovoltaic parameter estimation using honey badger algorithm and African vulture optimization algorithm, Energy Reports, Volume 8, Supplement 10, 2022, Pages 384–393
[34] S.K. Chaharsooghi, Amir H. Meimand Kermani: An effective ant colony optimization algorithm (ACO) for multi–objective resource allocation problem (MORAP), Applied Mathematics and Computation, Volume 200, Issue 1, 2008, Pages 167–177
[35] Junguo Cui, Lei Wu, Xiaodong Huang, Dengpan Xu, Chao Liu, Wensheng Xiao: Multi–strategy adaptable ant colony optimization algorithm and its application in robot path planning, Knowledge–Based Systems, Volume 288, 2024, 111459
[36] Hongguang Wu, Yuelin Gao: An ant colony optimization based on local search for the vehicle routing problem with simultaneous pickup–delivery and time window, Applied Soft Computing, Volume 139, 2023, 110203
[37] Rafał Skinderowicz: Improving Ant Colony Optimization efficiency for solving large TSP instances, Applied Soft Computing, Volume 120, 2022, 108653
[38] Syed Fawad Hussain, Adeel Pervez, Masroor Hussain: Co–clustering optimization using Artificial Bee Colony (ABC) algorithm, Applied Soft Computing, Volume 97, Part B, 2020, 106725
[39] Dervis Karaboga, Celal Ozturk: A novel clustering approach: Artificial Bee Colony (ABC) algorithm, Applied Soft Computing, Volume 11, Issue 1, 2011, Pages 652–657, ISSN 1568–4946
[40] Bin Sun, Tong Guo: A physics–informed artificial fish swarm algorithm for multiple tunnel fire source locations prediction, International Journal of Thermal Sciences, Volume 199, 2024, 108939
[41] Genrang Zheng, ZhengChun Lin: A Winner Determination Algorithm for Combinatorial Auctions Based on Hybrid Artificial Fish Swarm Algorithm, Physics Procedia, Volume 25, 2012, Pages 1666–1670

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AN ANALYTICAL ASSESSMENT FOR COMPARING GENERALIZED LEAST SQUARES – QUANTILE REGRESSION AND GENERALIZED LEAST SQUARES

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Abstract: This article presents a comparative analysis of the Generalized Least Squares–Quantile Regression (GLS–QR) and Generalized Least Squares (GLS) models using macroeconomic data from the Central Bank of Nigeria (1981–2020). Focusing on poverty reduction (PR) as the dependent variable and incorporating independent variables such as money supply (MS), government expenditure, government revenue, and financial inclusion, the study evaluates the predictive performance of both models. Results indicate that GLS–QR outperforms GLS, with adjusted coefficients of determination revealing a stark contrast: GLS at 3.8% versus GLS–QR at 46%, 45%, and 47% for the 25th, 50th, and 75th percentiles respectively. These findings clearly shows the superiority of GLS–QR in providing more accurate estimations of poverty reduction dynamics, suggesting its potential utility for policymakers and economists in formulating effective poverty alleviation strategies in Nigeria.

Keywords: Generalized Least Squares–Quantile Regression (GLS–QR), Generalized Least Squares (GLS), poverty reduction (PR), money supply (MS), strategies in Nigeria

INTRODUCTION

Generalized least squares (GLS) regression was introduced by [1], it is a statistical technique that accommodates heteroscedasticity and correlation in the error terms, making it versatile for regression analysis, it minimizes the weighted sum of squared residuals, with weights drawn from the inverse of the residual's estimated covariance matrix. GLS is widely used in various fields including econometrics, biology, finance, where data often exhibit heteroscedasticity and correlated errors.

Considering the research of [2] on the adaption of akaike information criterion under least squares frameworks for comparison of stochastic models demonstrated using simulated data. [3] addressed the parameter identification challenge in a bilinear state–space system with colored noise by eliminating the state variables from the model. They developed an input–output representation of the bilinear state–space system for parameter identification and introduced a recursive generalized extended least squares method for estimating the parameters of the resulting model.

Additionally, they proposed a computationally efficient three–stage recursive generalized extended least squares technique. [4] proposed a few preconditioned generalized AOR (denoted by GAOR) approaches. A comparison was also made between the original and suggested preconditioned approaches' spectral radii for the iteration matrices. In this study, the estimator of the GLS and Quantile regression was combined to give GLS–QR for the regression parameters of the multiple regression model and subsequently subjected to the real–life data and compare the performance of GLS and GLS–QR model.

MATERIALS AND METHOD

The macroeconomic variables employs poverty reduction as the dependent variable and Money Supply, Government Expenditure, Government Revenue, and Financial Inclusion are the explanatory variables and R program was used for the analysis.

Generalized Least Squares

Generalized least squares is a statistical method used to analyze data and estimate the parameters of a linear regression model when the assumptions of ordinary least squares are violated, particularly when the errors in the data are correlated or have unequal variances.

OLS is given as:

$$g_i = \beta_0 + \beta_i s_i + u_i \quad (1)$$

Equation (1) can be reformulated as:

$$g_i = \beta_0 s_{0i} + \beta_i s_i + u_i \quad (2)$$

where $s_{0i} = 1$ for each value of i.

Assuming heteroscedastic variances σ_i^2 are known, equation (3) becomes:

$$\frac{g_i}{\sigma_i} = \beta_0 \left(\frac{s_{0i}}{\sigma_i}\right) + \beta_1 \left(\frac{s_i}{\sigma_i}\right) + \frac{u_i}{\sigma_i} \quad (3)$$

Thus,

$$g_i^* = \beta_0^* s_{0i}^* + \beta_1^* s_i^* + u_i^* \quad (4)$$

In order to minimize the GLS estimators. Equation (4) becomes

$$\sum u_i^{2*} = \sum (g_i^* - \beta_0^* s_{0i}^* - \beta_1^* s_i^*)^2 \quad (5)$$

Thus,

$$\sum \left(\frac{u_i}{\sigma_i}\right)^2 = \sum \left[\left(\frac{g_i}{\sigma_i}\right) - \hat{\beta}_0^* \left(\frac{s_{0i}}{\sigma_i}\right) - \beta_1^* \left(\frac{s_i}{\sigma_i}\right)\right]^2 \quad (6)$$

Then,

$$\beta_1 = \frac{(\sum z_i)\sum(z_i x_i g_i) - (\sum z_i s_i)(\sum z_i g_i)}{(\sum z_i)(\sum z_i s_i^2) - \sum(z_i s_i)^2} \quad (7)$$

where $z_i = \frac{1}{\sigma_i}$

Quantile Regression

$$g_t = s\beta_q + u_t \quad (8)$$

$$\sum q u_t + \sum(1-q)u_t \quad (9)$$

Minimize equation (9), then it becomes

$$\sum u_t^2 = \sum(g_t - s_t'\beta_q)^2 \quad (10)$$

Thus,

$$\beta_q = \frac{\delta Q_q(g/s)}{\delta s_k} \quad (11)$$

Substituting $u_t = g_t - s_t'\beta_q$ in to equation (9), equation (12) becomes

$$q\sum(g_t - s_t'\beta_q) + 1 - q(g_t - s_t'\beta_q) \quad (12)$$

where $0 < q < 1$

Combining equation (8) and (11), gives β_{GLSQ_0} and β_{GLSQ_p}

The Proposed regression model can be written as:

$$\hat{g} = \hat{\beta}_{GLS-Q_0} + \hat{\beta}_{GLS-Q_1}s_1 + \hat{\beta}_{GLS-Q_2}s_2 + \hat{\beta}_{GLS-Q_3}s_3 + \cdots + \hat{\beta}_{GLS-Q_{p-1}}s_{p-1} \quad (13)$$

RESULTS AND DISCUSSION

GLS Regression

The association between four explanatory variables and poverty reduction was assessed using a GLS model. This equation appears in the fitted model:

$$PR = 34.025 - 0.00023\,MS - 0.00016\,GEX + 0.00032\,GRV + 3.64\,FII$$

GLS–Quantile Regression

A GLS–QR model explains the association between poverty reduction and the four explanatory factors.

The fitted models of lower, middle and upper quartiles of GLS–QR contains the equations below:

$$PR = 21.84 + 0.14\,MS - 0.009\,GEX + 0.059GRV + 0.049\,FII \text{ (Lower quartile GLS–QR)}$$

$$PR = 21.31 + 0.092\,MS - 0.011\,GEX + 0.15GRV + 0.10\,FII \text{ (Middle quartle GLS–QR)}$$

$$PR = 30.93 + 0.036\,MS - 0.012\,GEX + 0.074\,GRV + 0.304\,FII \text{ (Upper quartile GLS–QR)}$$

Comparison of GLS and GLS–QR

The GLS adjusted coefficient of determination is 3.8%, the GLS–QR (25%), GLS–QR (median), and GLS–QR (75%) all have adjusted coefficients of determination of 46%, 45%, and 47%, respectively. The adjusted coefficient of determination of GLS shows that only 3.8% of the variability in poverty reduction is collectively explained by changes in money supply, government expenditures, government revenue, and financial inclusion. The adjusted coefficient of determination of lower, median and upper quartile of GLS–QR gives a better explanatory power than GLS.

CONCLUSION

This study highlights the comparative efficacy of the GLS–QR model against the conventional Generalized Least Squares (GLS) model in analyzing the relationship between macroeconomic variables and poverty reduction in Nigeria. By utilizing extensive macroeconomic data from the Central Bank of Nigeria spanning nearly four decades, the research provides valuable insights into the predictive capabilities of these models.

The findings reveal that GLS–QR significantly outperforms GLS in estimating the dynamics of poverty reduction, as evidenced by substantially higher adjusted coefficients of determination across various percentiles. Specifically, while GLS demonstrates a modest adjusted R–squared value of 3.8%, GLS–QR yields markedly superior results, with values ranging from 46% to 47% across the lower, middle and upper quartiles

These results shows the importance of incorporating quantile regression techniques alongside traditional least squares methods in analyzing complex socio–economic phenomena like poverty reduction. The superiority of GLS–QR suggests its potential utility for policymakers and economists in devising more targeted and effective poverty alleviation strategies tailored to the diverse needs of Nigeria's population. Moving forward, further research and policy implementation efforts should consider an advanced econometric methodologies like GLS–QR to address the persistent challenge of poverty in Nigeria comprehensively.

References

[1] C. Rao, "Linear Statistical Inference and its Applications". 2nd Edition, wiley, New York, 1973.

[2] H.–T. Bank and M.–L Joyner, "AIC under the Frame Work of Least Squares Estimation," Applied Mathematics Letter, vol. 74, pp. 33 – 45. 2017.

[3] L. Wang., Y. Ji., L. Wan and N. Bu, "Hierarchical Recursive Generalized Extended Least Squares Estimation Algorithm for a Class of Nonlinear Stochastic Systems with Colured Noise". Journal of the Franklin Institute, vol.356 no.16, pp. 10102 – 10122. 2019.

[4] Y. Ke., C. Ma and H. Zhang, "The Preconditioned GAOR Methods for Generalized Least Squares Problem". Journal of Applied Analysis and Computation, Vol. 11 no. 3, pp. 1138 – 1160. 2021.

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END–OF–LIFE VEHICLES MANAGEMENT IN ROMANIA: AN OVERVIEW

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Abstract: Vehicles, which people are so dependent on, are produced all over the world in quite large number. Therefore, when they become obsolete or can no longer be repaired from various reasons, are called end–of–life vehicles (ELVs). Considering the high number resulting annually, the legislation in force, in each EU member country, obliges the insurance of treatment activities for all end–of–life vehicles, and so in this way the concept of sustainable development is supported. The main purpose of this paper is to provide an overview on end–of life vehicles treatment operations, and also an analysis regarding the quantity of ELVs generated and then reused (REU), recycled (RCY) respectively recovered (RCV). The analyzed data were obtained from Statistical office of the European Union. The study makes a comparison between Romania, the Member States of UE and the quantitative targets that are set out in the End–of–life vehicle Directive. In Romania the REU–RCV and REU–RCY percent for year 2020 was 91.60% respectively 85.40%. Therefore, Romania fulfilled the conditions related to the imposed targets only for reuse–recycling rate.
Keywords: End–of–life vehicles (ELVs), Recovery, Recycling, Reuse, Eurostat

INTRODUCTION

Considering the large number, the end of life vehicles (ELVs) can represent a major problem of the contemporary world, as an incorrect treatment can have a negative impact on the environment.

So, in 2000, the European Union issued the Directive 2000/53/EC of the European Parliament and of the Council on end–of life vehicles [1] and thereby has introduced means to promote and increase recycling [2]. At the same time, it established the minimum technical requirements for the treatment of ELVs. The EU policy on ELVs emphasizes the importance of a correct management approach as related to treatment operations of all components and materials that can be found in a vehicle. Therefore, the targets imposed by the European Commission according to Article 7 (2b) of Directive 2000/53/CE are: by "1 January 2015, for all end–of life vehicles, the reuse and recovery shall be increased to a minimum of 95 % by an average weight per vehicle and year. Within the same time limit, the reuse and recycling shall be increased to a minimum of 85 % by an average weight per vehicle and year". This directive is transposed into Romanian legislation by Law 212 of July 21, 2015, regarding the management of end–of–life vehicles. All economic agents that deal with ELVs management must comply with all the specifications of the law mentioned above.

According to the literature [3], the European Union member states apply the diagram shown in Figure 1 in the process of ELVs managing.

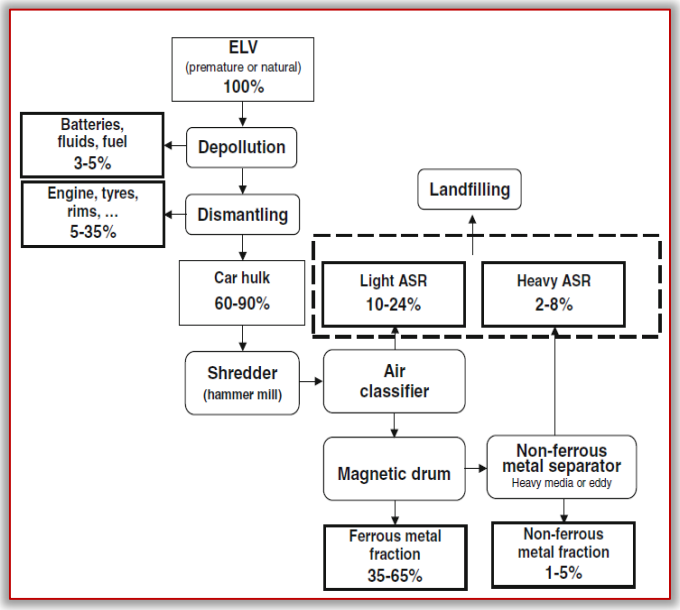

Figure 1. The treatment flow of end–of–life vehicles in the European Union [3]

Usually, in the treatment of end–of–life vehicles are followed three main stages [4,5,6]:

- *depollution*, an essential stage in which all hazardous substance, materials and components are selectively removed such as batteries, fuels, pyrotechnic components, cooling fluids, components containing mercury, oils, glass;
- *the dismantling* stage involving the removal of components that can be reused as such or can be reconditioned and then reused such as wheels, engines, plastic parts, radiators and
- *the shredding* stage where the car hulks are fed into a hammer mill. The resulting fragments are sorted into ferrous and non–ferrous metals and a residues named automotive shredder residue (ASR).

In Article 6 (3c) of Directive 2000/53/CE is specified that the dismantling stage must be carried out in such a way as to allow the reuse, recovery and, in particular, the recycling of vehicle components. *Ferrous fraction* (steel) and *non–ferrous metals* (aluminum, copper, zinc, lead, etc.) represent about 70–75%, respectively 5% of the mass of an end–of–life vehicle [6] and can be reused or recycled in proportion to about 100%. The rest of 20–25% waste that remains after shredding called automotive shredder residue (ASR) [6] is divided in two categories: *heavy fraction* which contains glass and metal fines and *light fraction* that contain plastic, rubber, textiles, etc. [7]. So, in order to reach the target of 95% for reuse–recovery must be found efficient and clean methods to improve the ASR recovery.

Economic operators involved in ELVs treatment activities can be guided by the International Dismantling Information System (IDIS). IDIS is a platform that contains information on the preliminary treatment and dismantling of end–of–life vehicles. Moreover, it provides instructions for airbag deployment and handling of high voltage batteries respectively information on parts and components with recycling potential, mentioned in the EU directive on end–of–life vehicles [8]. The platform covers over 72 vehicle brands and is available in 43 countries including Romania, and 31 languages [8].

The paper emphasize the obligatory main stages in ELVs treatment, analyze the trend concerning the rate of reuse, recovery, recycling for Romania (in period 2012–2021), and then compare the data with those of the EU member states and with the target imposed by the EU. The data used for graphical dependencies presented regarding ELVs generation, reuse (REU), recovery (RCV) and recycling (RCY) were obtained from the Statistical Office of the European Union (Eurostat) website [9].

END–OF–LIFE VEHICLES MANAGEMENT IN ROMANIA

In 2023, approximately 94 million motor vehicles [10] were produced worldwide, 10% more than the previous year, as can be seen in figure 2. Considering the large number generated, it is predictable that the number of vehicles removed from use is also high. The studies [7] indicate that every year 50 million vehicles become waste or ELVs to be treated.

Based on statistical data, in 2021 [9], only in European Union member countries approximately 5.68 million ELVs were subjected to treatment operations (Figure 3).

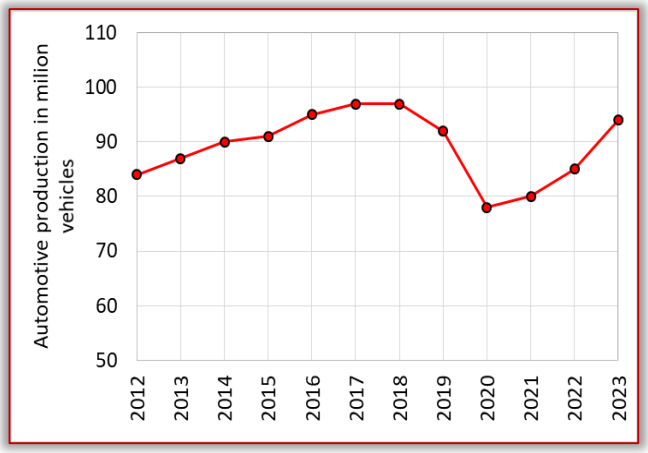

Figure 2. Estimated global motor vehicle production (reproduced from Statista 2024 [10])

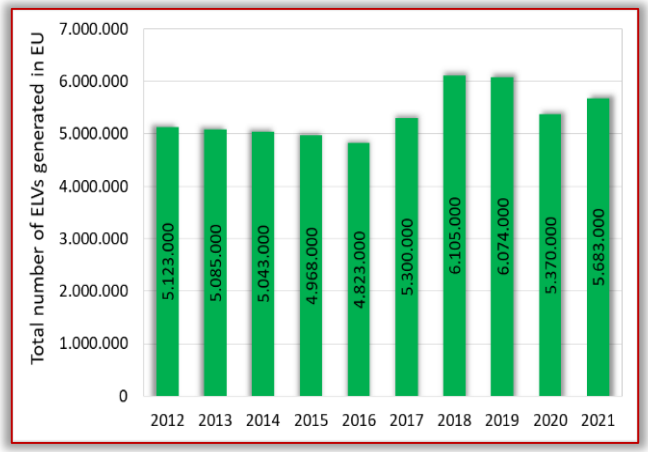

Figure 3. Total number of ELVs generated by current EU member states, in period 2012–2021

Figure 4 shows the number of ELVs generated by current EU member states over a 10–year period (2012–2021).

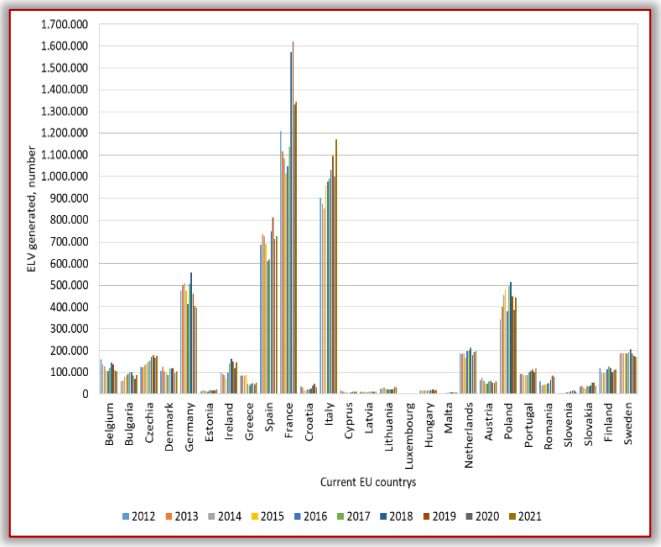

Figure 4. ELVs generated by current EU member states in period 2012–2021

Analyzing the number of ELVs for year 2021, was found that the countries that removed from use the largest and the smaller number of vehicles

more precisely 1.345.831 and 2.497, are France respectively Luxembourg.

By calculating the arithmetic mean of the ELVs number generated for each country for the last decade, it turned out that France is in the first place with a number of 1.248.299 end–of–life vehicles, followed by Italy (986.008 ELVs) and Spain (707.143 ELVs). Romania did not exceed the value of 100.000 ELVs annually, the highest number of end–of–life vehicles being 84.621 in 2019 (Figure 5).

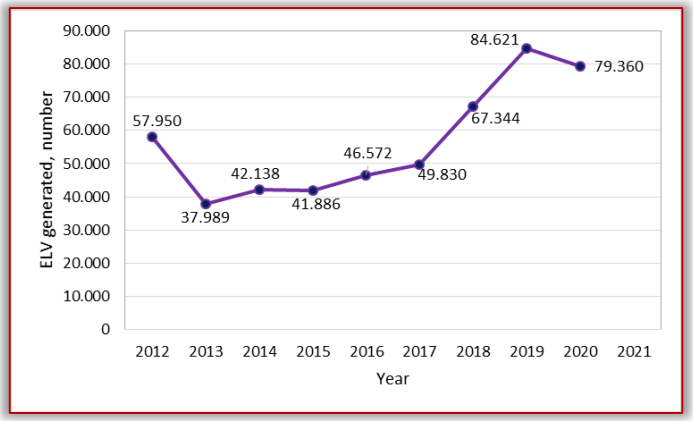

Figure 5. ELVs generated in Romania in period 2012–2020

As specified above, economic operators treating end–of–life vehicles are required to reuse (REU) and recover (RCV) at least 95% of the average mass per vehicle per year. The graph in figure 6 shows the percentage quantities obtained in Romania compared to the European Union average and the impose target. Studying the chart, we notice that Romania managed to obtain percentage values slightly below the average results obtained for EU. During the period 2016–2020 our country succeeded to exceed the reuse and recycling rate of 90%, but the target imposed was not reached.

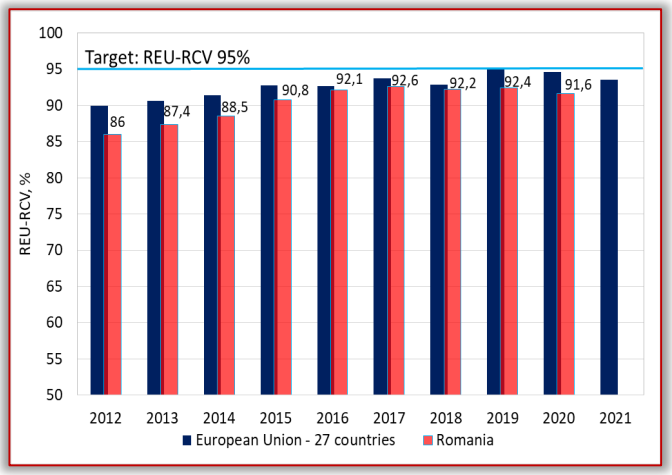

Figure 6. ELVs reused and recovered (REU–RCV) [%] in Romania compared with EU average and EU target

If we refer to the reuse and recycling rate, we can see in figure 7 that the target imposed of 85% is achieved from year 2015 until 2020.

From the data provided by EUROSTAT, it is found that that in 2020, twenty–four member states achieved the reuse–recycling target of 85%, and twenty achieved the reuse–recovery target of 95%.

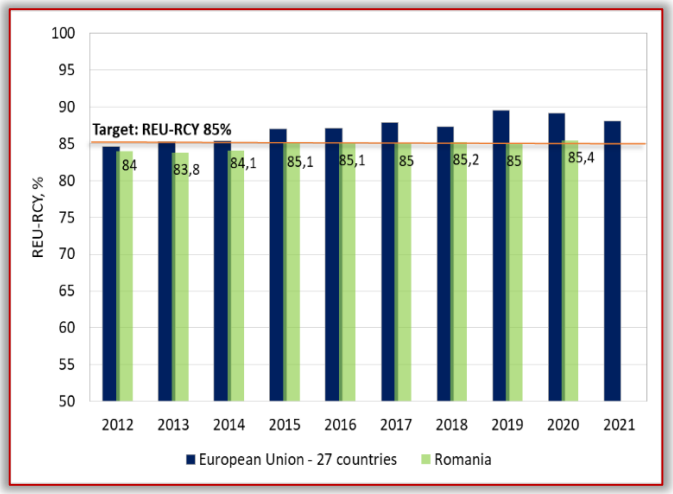

Figure 7. ELVs reused and recycled (REU–RCY) [%] in Romania compared with EU average and EU target

In Romania, the monitoring of the objectives regarding the reuse, recycling and recovery of ELVs is done according to Annex 2 of H.G. 2406/2004 [11]. The REU–RCV rate is calculated by dividing the total amount reused and recovered to the total mass of end–of–life vehicles, and the REU–RCY rate is the ratio of the total amount reused and recycled to the total mass of end–of–life vehicles. The values are reported as percentage.

Increasing the reuse and recovery rate at 95% could be achieved by finding efficient and environmentally friendly treatment methods of waste that remains after shredding called automotive shredder residue. Must be mentioned that ASR is a complicated solid waste, if we refer to its composition, since it contains different plastics, elastomers, foams, metals, glass, textiles, etc. [12] and so is hard to recycle. But, for example Santini A., et al. [13] showed that recycling of light, organic fraction of ASR through mechanical separation and pyrolysis could be a suitable recycling method if the resulted oil can be refined and used as chemical.

Another low cost, green recycling strategy elaborated Yang S. [14] called solid state shear milling technology (S^3M), applied on ultrafine fraction of ASR, is used to obtain polypropylene composites that can be used in the production of container for waste, plastic garbage bags

etc. Thus must find more efficient recovery solutions for ASR, knowing that the most unfavorable option in waste treatment is disposal.

CONCLUSIONS

End–of–life vehicles can have a negative impact on the environment if they are not treated properly by the economic agents involved in this process. Therefore, Romania, together with the rest of the EU member states, meet or trying to reach and exceed the reutilization, recycling and recovery targets set in the Directive 2000/53/CE.

For Romania, the next conclusions can be drawn:

- In year 2020 achieved the reuse – recycling target of 85% along with twenty–four other member states;
- The highest reuse – recovery rate of 92.4% was achieved in 2017, while in 2020 the obtained percentage was slightly lower (91.6%);
- In order to achieve and exceed the 95% reuse–recovery target, attention must be directed to more effective utilization of the automotive shredder residue.

References

[1] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end–of life vehicle, Official Journal of the European Union, L269, 34–43, ISSN 0378–6978

[2] Depolluting End–of–Life Vehicles (cars and light goods vehicles) Guidance for Authorised Treatment Facilities, Available online: https://www.gov.uk/government/publications/depolluting–end–of–life–vehicles–guidance–for–treatment–facilities

[3] S. Sakai et al., An international comparative study of end–of–life vehicle (ELV) recycling systems, Journal of Material Cycles and Waste Management 16:1–20 (2014)

[4] A. S. Fonseca, M. I. Nunes, M. A. Matos and A. P. Gomes, Environmental impacts of end–of–life vehicles' management: recovery versus elimination, The International Journal of Life Cycle Assessment, Vol. 18, Issue 7 (2013)

[5] LAW no. 212 of July 21, 2015 on the manner of managing vehicles and end–of–life vehicles (LEGE nr. 212 din 21 iulie 2015 privind modalitatea de gestionare a vehiculelor și a vehiculelor scoase din uz), MONITORUL OFICIAL, 554 (2015)

[6] R. Cossu, T. Lai, Automotive shredder residue (ASR) management: An overview, Waste Management 45 (2015) 143–151

[7] S. K. Vijayan, V. Sahajwalla, S. Bhattacharya, Insights into the options of energy and metal recovery from automotive shredder residue: A review, Resources, Conservation & Recycling Advances 15 (2022) 200097

[8] International Dismantling Information System, Available online: https://www.idis2.com/discover.php

[9] Statistical Office of European Union (EUROSTAT), End–of–life vehicles by waste management operations [env_waselvt], Eurostat Dissemination Database, Available online: https://ec.europa.eu/eurostat/en/data/database

[10] Statista. Estimated worldwide motor vehicle production from 2000 to 2023. Available online: https://www.statista.com/statistics/262747/worldwide–automobile–production–since–2000/

[11] HG 2406/2004, Available online: https://legislatie.just.ro/Public/DetaliiDocument/115819

[12] I. de Marco, B.M. Caballero, M.A. Cabrero, M.F. Laresgoiti, A. Torres, M.J. Chomo, Recycling of automobile shredder residues by means of pyrolysis, J. Anal. Appl. Pyrolysis 79 (2007) 403–408

[13] A. Santini et al., Auto shredder residue recycling: Mechanical separation and pyrolysis, Waste Management 32 (2012) 852–858

[14] S. Yang et al., Recycling of automotive shredder residue by solid state shear milling technology, Journal of Industrial and Engineering Chemistry 57 (2018) 143–153

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DETERMINING METHOD FOR THE PHENOLOGICAL STAGE OF SPRING ESTABLISHED CROPS OF *HORDEUM VULGARE* L., *HORDEUM DISTICHON* L. AND *AVENA SATIVA* L. BY USING ATMOSPHERIC TEMPERATURE

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Abstract: Barley, two–rowed barley and oat crops covers an area of approximately 500 thousand hectares in Romania and produce 1.3 million tons of grains. Due to thermo–hydric stress, sometimes it is necessary for these cultures to be established in the spring instead of autumn. The aim of the work is to create a decision support based on a method for determining the phenological stages of spring crops using the mathematical correlations between atmospheric temperature and biological parameters. With this method, digital simulations can be made regarding the phenological phase, plant height, water content and crop progress. The proposed method is useful for the digitization process in agriculture in order to optimize the consumption of fertilizers and pesticides

Keywords: barley, oat, spring, temperature, BBCH

INTRODUCTION

Knowledge of the phenological stages of plants is useful for determining the optimal timing of agronomic care and harvesting activities. Since plants are dependent on ambient temperature, the calendar period from sowing to harvest may exhibit variations that can lead to suboptimal crop management. For a better assessment of the biological age and phenological stages of plants, the concept of thermal time was introduced as the sum of effective temperature degrees (GDD) (Arnold *C.,1959,1960; McMaster G.S. and Wilhelm W., 1997*).

As early as 18th century, the term "heat units" (*Re'aumur, 1735*) was used in agriculture to assess the development stage or age of the plant. Using this concept, thermal constants of plants were defined. Initially, a simple calculation was used, represented by the product of the average daily temperature and the number of days corresponding to the period from sowing to the point of interest. Over time, it was observed that certain factors, such as soil temperature or extreme values of atmospheric temperature, could introduce errors in accurately determining the biological age. In the case of atmospheric temperature values lower or higher than the favorable temperatures for the species, summing the degrees can result in different accumulated values for the same phenological stage. This led to the introduction of a new parameter called biological threshold, representing the temperature value at which a species begins to have metabolic activity or accumulate biomass. Thus, the calculation formula became (1):

$$GDD = [(T_{MAX} + T_{MIN})/2] - T_{BASE} \quad (1)$$

where *GDD* is growing degree days, T_{MAX} and T_{MIN} are the maximum and minimum daily temperatures, and T_{BASE} is the threshold temperature.

By using this formula, the threshold temperature value is extracted from the atmospheric temperature, and the remaining value is taken into account when summing up the useful or effective degrees. For crops sown in the fall, the formula containing the biological threshold in the calculation mode is considered acceptable for thermal time because the temperature values in the fall–winter–spring months have a balanced weight. For crops sown in the spring, high temperature values were observed that contributed to the calculated value but did not contribute to plant biomass accumulation. These temperatures are considered supra–optimal as they slow down plant–specific metabolic processes.

To mitigate this effect, an upper temperature threshold was introduced. For corn, an upper threshold of 30 °C was introduced (*Cross H.Z. and Zuber M.S.,1972*), and one of 25 °C for wheat (*McMaster G.S. and Smika D.E., 1988*). Thus, the sum of effective temperature degrees is calculated only for those values within the temperature range limited by the minimum biological threshold and the upper threshold. This

calculation method has become the most widespread and is used by several researchers (*Nield R.E. and Seeley W.M., 1977; Davidson H.R. and Campbell C.A.,1983*). With the advent of meteorological stations capable of recording atmospheric parameter values at a sampling rate of one hour or a few minutes, the possibility of increasing the accuracy of thermal time determination was analyzed. By increasing the sampling rate, the frequent fluctuations in temperature are taken into account, which normally cannot be covered by only the minimum and maximum daily temperatures.

Considering that biochemical reactions are correlated with temperature through a polynomial function that follows a bell–shaped trend, this study proposes using a nonlinear function to calculate the sum of effective degrees.

MATERIALS AND METHODS

In the experiment, barley, triticale, and oats were sown on an area of 200 square meters each on March 14, 2023, after preparing the seedbed through fall plowing and spring disking. Weekly, biometric determinations were carried out from March 27 to July 27, including plant height, plant mass, plant moisture, and phenological stage. Ten plants from each cultivated species were analyzed at each time interval. Atmospheric temperature data were collected from the local station at an hourly sampling rate.

The average plant height was determined by measuring the highest point of the plants from the soil surface. Plant moisture was determined using a thermobalance (Partner MAC50/NH) at 115 °C after three consecutive identical readings, and the BBCH scale determination was performed according to the specific scale for cereals (*Witzenberger A. et al., 1989; Lancashire P.D. et al., 1991*).

The calculation of the sum of useful degrees was performed using the classical (linear) method (2):

$$GDD = \sum\{[(T_{MAX}+T_{MIN})/2]-T_{BASE}\} \quad (2)$$

where T_{BASE} for barley / two–rowed barley is 2°C and 5°C for oat, and the nonlinear method (3):

$$GDD = \sum[(a*T4+bT3+cT2+dT+e)\ *T/100]/24 \quad (3)$$

where *a, b, c, d,* and *e* are the coefficients of the polynomial, and *T* is the atmospheric temperature.

For barley, triticale, and oats, the polynomial equations for determining the percentage of thermal comfort of atmospheric temperature are presented in Table 1.

Table1. The polynomial equations for determining the percentage of thermal comfort of atmospheric temperature

Species	non–linear equation GDD=∑
Barley – *Hordeum vulgare* L.	[(0.00078*T⁴ – 0.05985*T³ + 1.15634*T² – 0.19557*T – 6.67968)*T/100]/24
Two–rowed barley – *Hordeum distichon* L.	[(0.00078*T⁴ – 0.05985*T³ + 1.15634*T² – 0.19557*T – 6.67968)*T/100]/24
Oat – *Avena sativa* L.	[(0.0047*T⁴ – 0.33412*T³ + 7.52267*T² – 56.67688*T + 135.4783)*T/100]/24

RESULTS

The growth of plants in height during the experimental period followed a trend similar to climatic evolution (Figure 1).

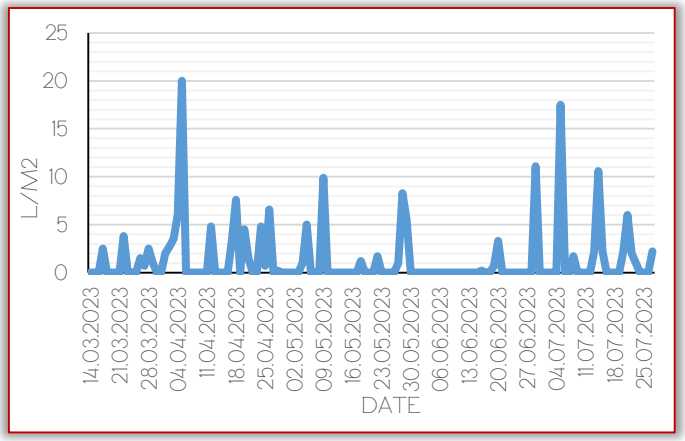

Figure 1 – Rainfall amount during the experimental period

In Figure 2 is presented the dynamics of height growth of plants where it can be observed that the majority of collected sample had increasing values, except for three determinations out of the 18. In the first month from sowing, all three species had the same height. Throughout the growth period, it was observed that two–rowed barley and oat had a more accelerated height growth compared to barley. This difference in growth may be due to genetic characteristics defining the species or adaptability to drought.

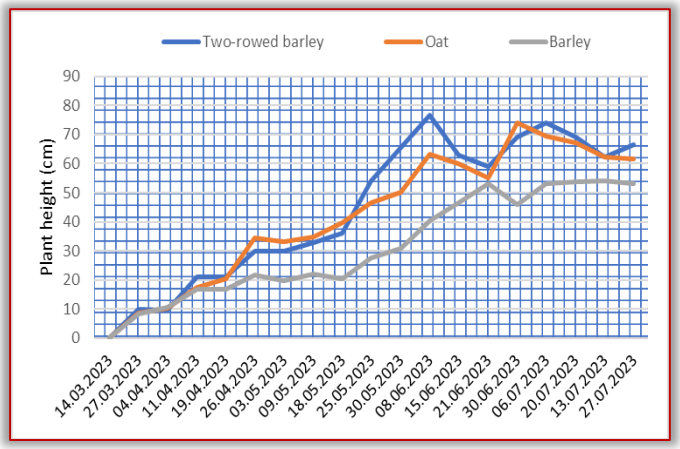

Figure 2. – The height growth dynamics of barley, oats, and two–rowed barley

Correlations between the sum of growing degrees calculated by the two methods (Figure 3 and Figure 4) and the dynamics of height

growth had regression coefficient (R^2) values ranging between 0.94 and 0.96, demonstrating that plant height can be mathematically approximated using atmospheric temperature values. Due to the very close values of the regression coefficients, it can be concluded that there are no significant differences between the two methods regarding the physico–mathematical determination of plant height.

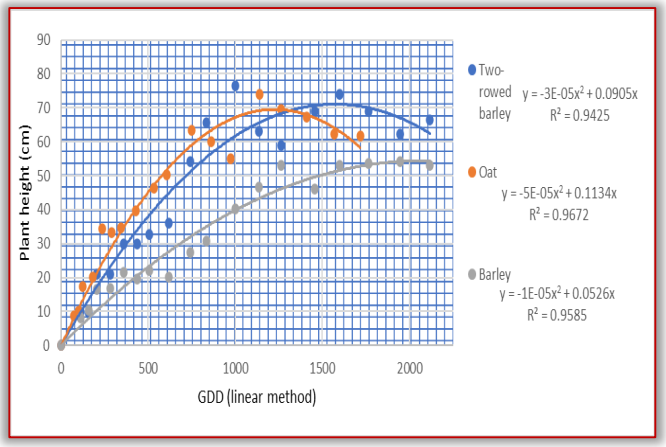

Figure 3. – The correlation between plant height and GDD (classical linear–method)

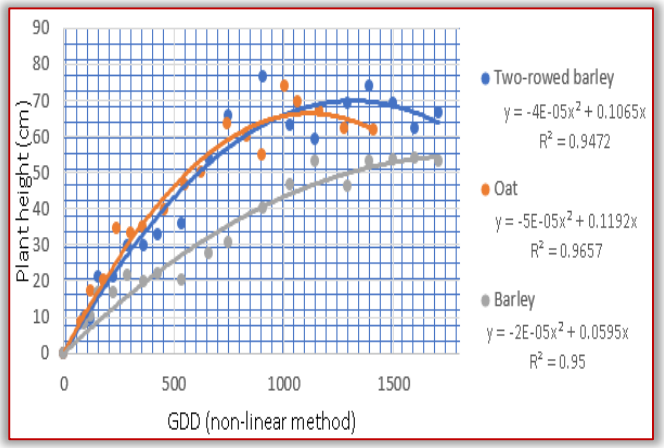

Figure 4. – The correlation between plant height and GDD (non–linear method)

The biomass accumulation of the three species followed a normal growth trend for plants, reaching values of 34.69 g per plant for two–rowed barley, 32.15 g for oats, and 28.6 g for barley. In Figure 5, the dynamics of plant biomass accumulation are presented, highlighting that the majority of collected biometric samples were useful for mathematical analysis.

Mathematical correlations between the sum of temperature degrees and plant mass (Figure 6 and Figure 7) had regression coefficient (R^2) values ranging between 0.77 and 0.83. The correlation coefficient values of plant mass and GDD are lower than those of plant height and GDD, by both methods. One possible explanation could be the lack of the uniformity of the collected samples.

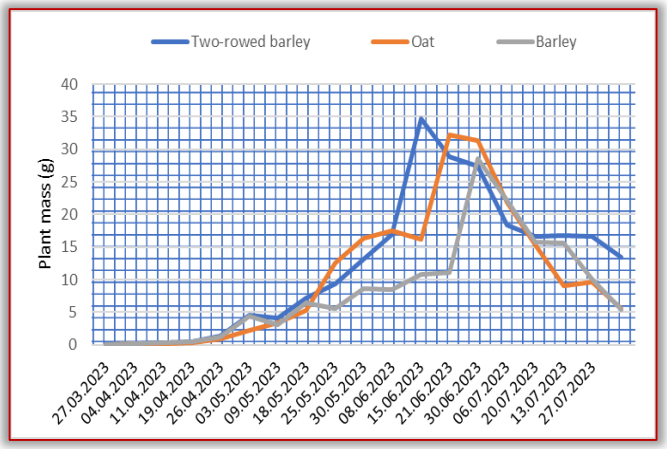

Figure 5. – Biomass accumulation dynamics of barley, oats, and two–rowed–barley

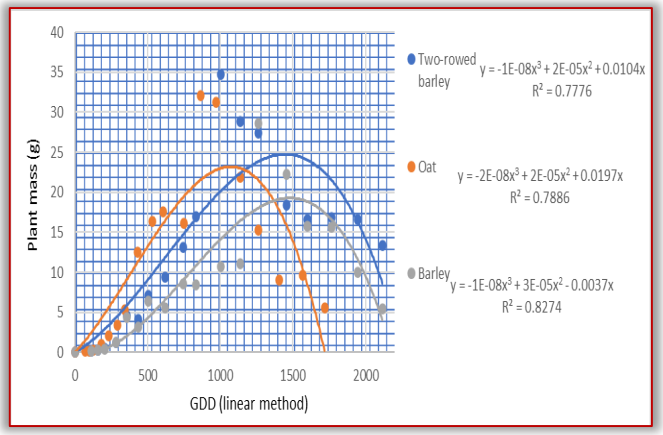

Figure 6. – The correlation between plant mass and GDD (classical linear–method)

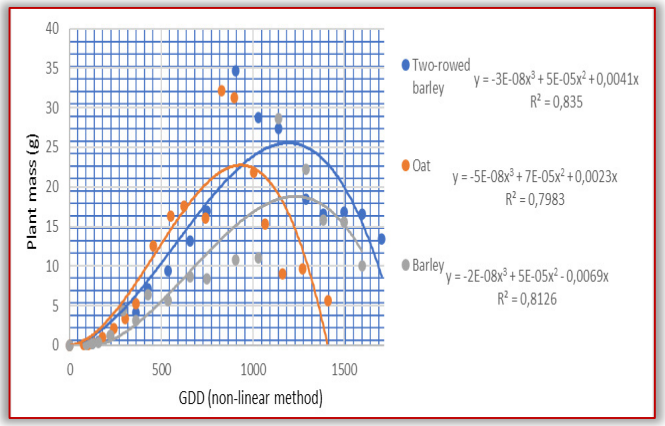

Figure 7. – The correlation between plant mass and GDD (nonlinear method)

The water content of the plants (Figure 8) reached values close to 85–90% during the period from germination to the halfway point of inflorescence emergence (BBCH 55), after which it began to decrease progressively to 10%, indicating the optimal harvest time.

The mathematical determination of water content dynamics throughout all phenological stages, according to the analysis of correlation coefficient values, can be accurately performed regardless of the method used to calculate the sum of degree days. In Figures 9 and 10, correlation coefficient values ranging between 0.90 and 0.97 are presented. The linear method

of calculating the sum of degree days had regression coefficient values higher than those of the nonlinear method, but statistically non–significant.

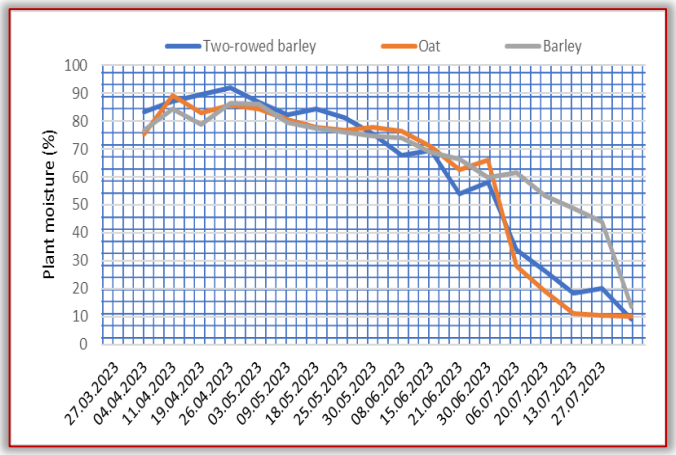

Figure 8. – The plants water content variation during the 2023 growing season

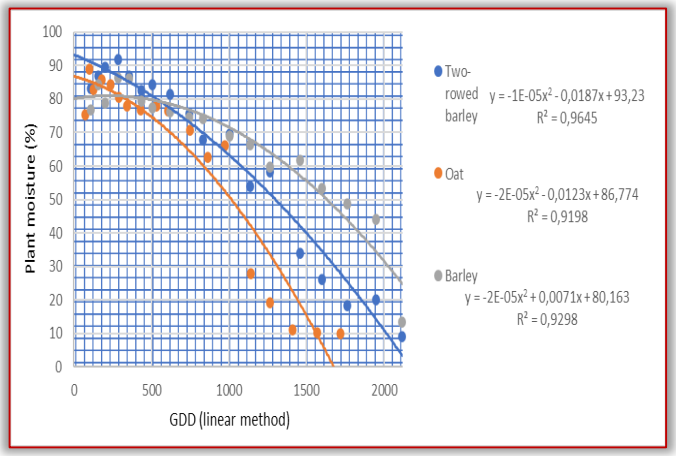

Figure 9. – Water content and GDD correlation (classical linear–method)

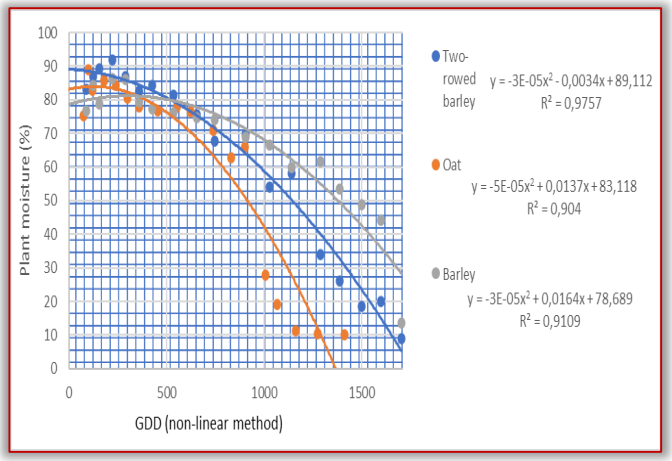

Figure 10. – Water content and GDD correlation (nonlinear method)

The analysis of the cumulative growing day degree values for the phenological ripening phase of grains highlighted that, using the linear method (Figure 11), higher accumulated heat values are obtained compared to the nonlinear method (Figure 12). Thus, barley and two–rowed barley crops reached the phenological stage of ripening at a value of 1457 degree days using the linear method and at 1290 using the nonlinear method. Both values fall within the range reported in the literature, specifying for these crops a range between 1193 and 1438 days–degree (*Miller P. et al., 2001*). The oat crop reached the phenological ripening stage at 1139 days degree using the classical calculation method and at 1007 days degree using the nonlinear method.

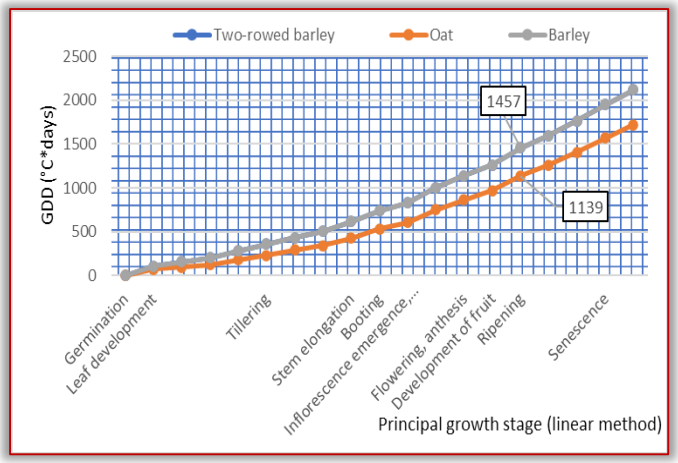

Figure 11. – The correlation between the phenological phase and GDD (classical linear–method)

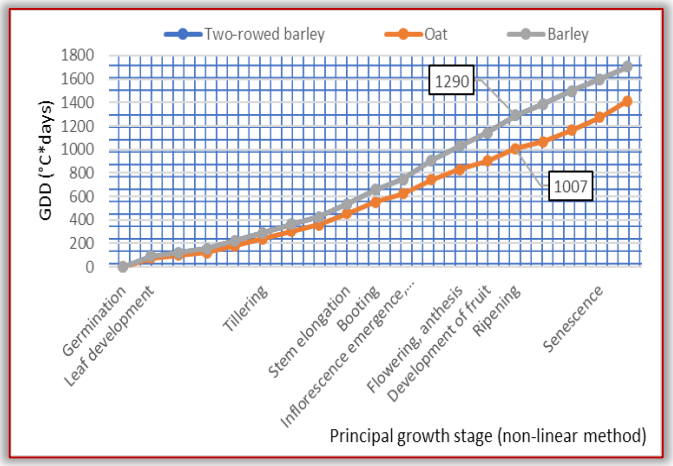

Figure 12. – The correlation between the phenological phase and GDD (nonlinear method)

Comparatively, the values obtained for the oat crop using both methods were lower than the known data range (1483–1738 degree–days) (*Miller P. et al., 2001*). One possible explanation for this could be the spring planting of crops and the low precipitation of 176 mm (Figure1) between March 14 and July 27, 2023, significantly lower than the 30–year average of 287.4 mm for the same period (*INS, 2007*).

The precipitation deficit also affected the production level, with two–rowed barley and oat crops yielding 1.5 and 1.2 tons/ha, respectively, compared to the multi–year average for fall–sown crops of 3.4 tons/ha. The precipitation deficit was more pronounced in the case of

barley, with a production of only 270 kg/ha, significantly lower than the average of 1900 kg/ha.

CONCLUSIONS

Determining thermal time is crucial for planning specific agronomic activities at the farm level. By comparing calendar time to thermal time, assessments can be made regarding the progression and duration of the crop's vegetative cycle. Precise knowledge of the thermal constants for cultivated species and the theoretical cumulative growing degree days for the spring crop season enables farmers to decide whether to establish a barley, two–rowed barley or oat crop in place of failed fall–sown crops. Since the nonlinear method of calculating cumulative growing degree days generated lower values for phenological stages compared to the classical method, it can be concluded that this method leads to a better correlation with the phenological stage of the plant because it takes into account the fact that the temperatures above the upper biological threshold do not optimally contribute to biomass accumulation.

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References

[1.] Arnold, C.Y. (1959). The determination and significance of the base temperature in a linear heat unit system. Journal of the American Society for Horticultural Science, 74(1), 430–445.

[2.] Arnold, C.Y. (1960). Maximum–minimum temperatures as a basis for computing heat units. Journal of the American Society for Horticultural Science, 76, 682–692.

[3.] Cross, HZ., Zuber, M.S. (1972). Prediction of flowering dates in maize based on different methods of estimating thermal units. Agron. J. 64, 351–355.

[4.] Davidson, H.R., Campbell. C.A. (1983). The effect of temperature, moisture and nitrogen on the rate of development of spring wheat as measured by degree days. Can. J. Plant Sci. 63, 833–846.

[5.] Lancashire P. D., Bleiholder H., Van den Boom T., Langelüddeke P., Stauss R., Weber E., Witzenberger A. (1991). A uniform decimal code for growth stages of crops and weeds, Annals of Applied Biology, 119 (3), 561–601.

[6.] McMaster, G.S., Smika, D.E., (1988). Estimation and evaluation of winter wheat phenology in the central Great Plains. Agric. For. Meteorol. 43, 1–18.

[7.] McMaster, G.S.; Wilhelm, W. (1997). Growing degree–days: One equation, two interpretations. Agric. For. Meteorol., 87, 291–300.

[8.] Miller, P., Lanier, W. and Brandt, S. (2001). Using growing degree days to predict plant stages. Montguide MT200103 AG 7/2001. Cooperative Extension Service, Montana State University, Bozeman.

[9.] National Institute of Statistics, Romanian Statistical Yearbook, 2007.

[10.] Nield R.E., Seeley M.W. (1977). Growing degree days predictions for corn and sorghum development and some applications to crop production in Nebraska. Nebr. Agric. Exp. Sm. Res. Bull. 280. Lincoln, NE.

[11.] Re'aumur, R. A. D. (1735). Temperature observations in Paris during the year 1735, and the climatic analogue studies of l'Isle de France, Algeria and some islands of America. Histoire de l'Académie Royale des Sciences année 1735, 545–584.

[12.] Witzenberger A., Van den Boom T. & Hack, H. (1989). Erläuterungen zum BBCH–Dezimal–Code für die Entwicklungsstadien des Getreides – mit Abbildungen. Gesunde Pflanzen 41, 384–388.

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ASPECTS REGARDING THE PHYSICAL CHARACTERISTICS OF BLUE MOLD CHEESE DURING RIPENING PROCESS

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Abstract: The aim of this paper is to conduct a brief study on blue mold cheeses for a deeper understanding of their ripening process, texture evolution and physical properties. Mold cheeses are a distinct category of cheeses, characterized by the presence of a specific type of mold called Penicillium roqueforti. Blue mold cheeses are recognized for their distinct taste and aroma, as well as their distinctive appearance, respectively strands of blue-green mold within the paste. There are several varieties of blue cheese, the most famous of which are Roquefort, Gorgonzola, Stilton and Danish Blue. Refrigeration and pasteurization of milk, addition of starter cultures and ripening conditions (temperature, humidity, time, air circulation, etc.) are the most important steps in the technological process to produce quality ripened cheeses. In cheese making, the most important step in the process is ripening. This involves a series of biochemical changes that determine the quality of the cheese, its texture and physical characteristics.

Keywords: cheese, ripening, physical characteristics, temperature, penicillium roqueforti

INTRODUCTION

A popular fermented food that is produced and consumed worldwide is cheese, (*Fox and McSweeney, 2017*). Cheese can be a soft, semi-hard, hard or extra hard, matured or fresh, which can be covered or not covered with wax, to which ist was added aromatic plants and for which the whey/casein protein ratio does not exceed that of milk (*Romanian Law 307/2022*). Cheeses with fungal flora are part of the category of soft cheeses. This category of soft cheeses is characterized by a high content in water, a short ripening period and a shorter shelf life. Due to the soft, fine consistency, as well as the pleasant taste, with a specific aroma to the assortment, the production of these types of cheese has recently expanded, the number of assortments being in a continuous increase worldwide, (*Catherine Donnelly, 2016)*.

Molded cheeses possess viscoelastic properties, meaning they display the characteristics of both solids (elasticity) and liquids (viscosity). Internally mold-ripened cheese was first manufactured in France, where it is still manufactured on a large scale today, under the name of Roquefort, then expanding to other countries, under different names, for example in Romania the Bucegi cheese and the Homorod cheese are manufactured, (*Costin Gh. et al. 2003*). Roquefort cheese is part of the category "Blue veined cheese" or Blue cheeses, due to the development of *Penicillium roqueforti* mold in the spaces of the cheese paste. In France, the *Penicillium roqueforti* used to make Roquefort cheese is obtained from moldy bread. The bread is kept in a humid room until it is completely covered with a blue powder, after which it is dried and ground, (*Ramón Ordoñez et al. 2019*). *Penicillium roqueforti* is recognized for its major role in ripening, but in conventional cheese made from raw milk, the secondary microflora is also essential for the formation of the specific sensory characteristics, *(Lourdes Santiago-Lopez et al., 2018)*. The technological process of obtaining cheeses includes several stages, the most important of which are reception of milk, heat treatment, standardization, coagulation, cutting and processing of curd, draining, pressing, salting and ripening, *(Ane Aldalur, María Ángeles Bustamante et al., 2019)*.

After the completion of the salting phase, the last stage of the technological manufacturing process is the ripening of the cheeses. It is a complex process that results from the action of enzymes that are present in both milk and curd, as well as enzymes secreted by microorganisms that grow naturally in milk or are seeded through the use of specific cultures (*Coelho et al., 2022*). In the ripening process, the cheese curd, initially white, crumbly and with an insipid taste, becomes yellowish-white, elastic, unctuous, with a taste and aroma specific to each variety (*Masoumeh Alinaghi et al., 2023*).

Ripening consists of three phases: pre-ripening, ripening or the main fermentation, when the production of flavoring substances begins, and final ripening, the phase during which the taste and aroma of the cheese are mainly finalized, *(Andretta, M., Almeida et al., 2019*).

In the ripening process of cheese, temperature plays an essential role, because a high temperature stimulates the proliferation and activity of microorganisms, while a low temperature slows down their development. Ripening is generally carried out at temperatures between 10-20°C (*M. E.Johnson, 2017*). To obtain quality cheeses, the precision of temperature control during the ripening stage is a key factor. In general, mold cheeses are matured in rooms with a controlled temperature of 10-12°C and a relative air humidity of 95-100%. Thus, recordings of the air temperature in the ripening room revealed slow temperature variations throughout the process, with variations between 11.4°C and 12.1°C, (*Pellegrino Conte, Luciano Cinquanta et al, 2020*). During the ripening process, it is necessary to ensure air exchange at least three times a day, with an air speed of 2.5 to 3 m/s. This air ventilation removes gases such as ammonia and carbon dioxide, which are produced during ripening, (*Thomas Bintsis, Photis Papademas, 2018*).

The ripening period is 2-4 months, and after the second month, the cheese is thoroughly cleaned of spores and packed in aluminum foil, still maintaining the temperature of 10-12˚C and the relative humidity of the air at minimum 95% until maturation is complete, (*Mariana González, Eliana Budelli et al, 2019*).

MATERIALS AND METHODS

The laboratory experiments consisted in obtaining Roquefort cheese from cow's milk, followed by its characterization. To facilitate the development of blue mold inside the cheese and to allow air circulation, the cheese is spiked with needles or other specialized tools. These perforations help to increase the ventilation of the cheese and to evenly distribute the moisture and mold inside. The Roquefort cheese, obtained in the laboratory, was analyzed during the period of 30 days of ripening.

Figure 1 - Day 1 of ripening

Figure 2 - Day 5 of ripening

Figure 3 - Day 30 of ripening

Dry matter

Determination of dry matter in the cheese samples it was performed using the SR EN ISO 5534:2004 reference method. A Memmert UN55 drying oven (Schwabach, Germany) and an analytical balance (SHIMADZU ATX224R; Kyoto, Japan) were used as equipment. Moisture content is responsible for the bitter, astringent, salty, umami taste present in mold-ripened cheeses.

Usually, reducing the fat content results in increased hardness. Küçükoner and Haque, 2003 demonstrated that high-fat ripened cheeses were characterized by softer consistency and higher elasticity than low-fat ripened cheeses throughout the ripening period.

The acidity

Determination of acidity in cheese samples was performed by titration with 0.1N NaOH and phenolphthalein. An analytical balance (SHIMADZU ATX224R; Kyoto, Japan) was used as equipment.

Figure 4 - Sample preparation

pH

Determination of pH in cheese samples was performed using a digital pH meter (WTW pH330i; London, UK).

RESULTS

The physico-chemical characteristics of Roquefort cheese are presented in table 1.

Tabel 1. Physico-chemical characteristics of Roquefort cheese during ripening

Day - ripening	Dry matter [%]	Acidity [°T]	pH
1	51.39	72.15	4.95
5	52.95	75.18	5.10
10	53.65	78.65	5.25
15	54.79	82.52	5.42
20	54.95	84.32	5.60
30	55.20	85.36	5.88

It is found that dry matter varied from 51.39% to 55.20%. In low-fat cheeses, water acts as a plasticizer and determines their final rheological properties. Reducing the fat content of cheeses increases their hardness and has a negative role on their sensory attributes.

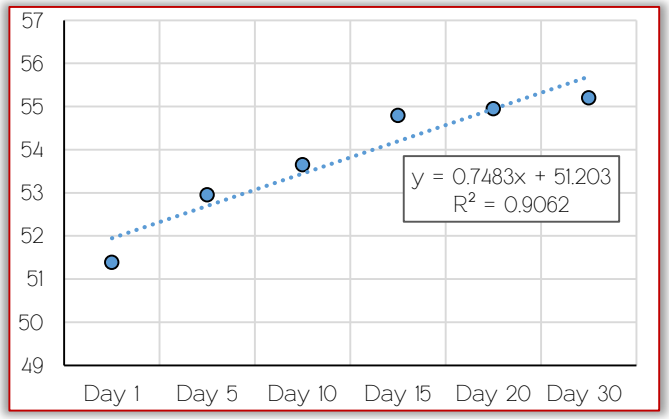

Figure 5 - Changes of dry matter during ripening

Two stages can be distinguished in the ripening process of Roquefort cheeses: a first stage is represented by the first 15 days of ripening, which are characterized by a sudden change in the ripening parameters, and the following 15 days, which are characterized by a slow increase in values of the studied parameters.

Acidity increased during the 30 days of ripening and gave the cheeses a pleasant sour taste when it is in reasonable quantity. In hard and semi-hard cheeses, the sour taste gradually disappears as the lactic acid breaks down and is replaced by a nut-like taste. A characteristic of Roquefort cheese is its moderate or slightly increased acidity, which contributes to its distinctive taste and texture.

The fermentation and ripening processes, as well as the Penicillium Roqueforti mold species used in the production process, contribute to the acidity of Roquefort cheese. Camembert cheese has a higher acidity than Roquefort cheese, and this is due to the pressing of the cheese pieces.

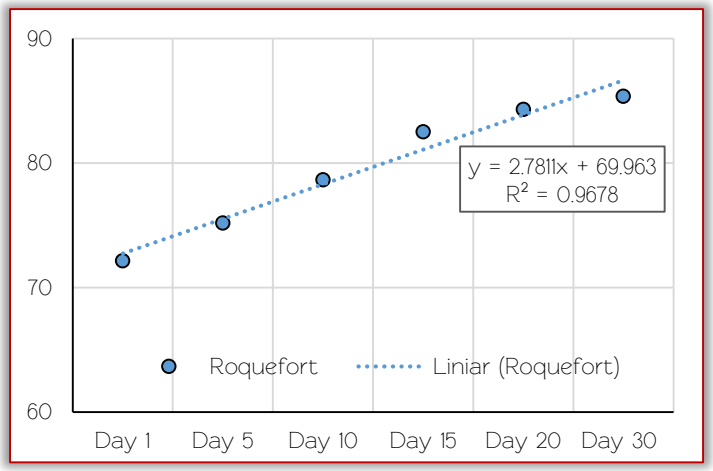

Figure 6 - Changes of acidity during ripening

As shown in Figure 7, the pH increased during the ripening of cheeses and this results from the consumption of lactic acid and the formation of non-acidic products of its degradation, as well as the release of free fatty acids and alkaline products as a result of protein degradation. The pH value in mold-ripened cheeses has an important effect on their properties, such as texture, taste and smell.

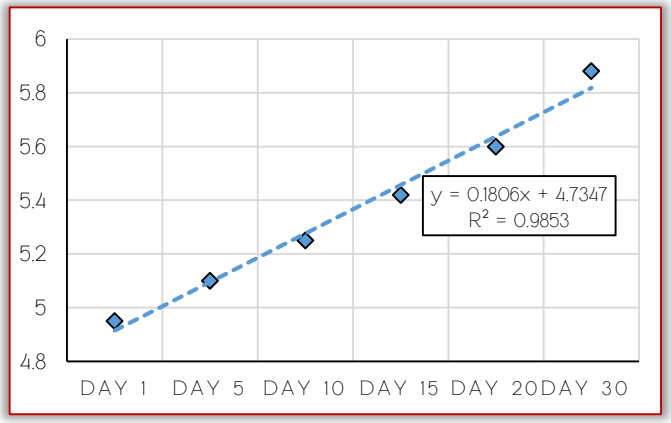

Figure 7 - Changes of pH during ripening

The pH of Roquefort cheese varies depending on the stage of ripening and other production conditions, but is usually in a slightly acidic range, around 5.0 or even lower. This is a characteristic of Roquefort cheese that contributes to its distinctive taste and the development of a unique blue mold.

CONCLUSIONS

The study of the physical characteristics of blue mold cheeses reveals significant aspects of these cheeses. These characteristics include their appearance, texture, color and structure, which are the result of a complex production and maturation process. The modification in the consistency of the cheese is the main change

during the ripening process, because the reduction of moisture depends on the duration and the temperature conditions in the ripening rooms. At the same time, the rind of the cheeses, characteristic of each variety, is finished.

Also, the study of these cheeses showed the importance of ripening room factors such as temperature, humidity and air circulation on the physical characteristics.

A careful control of these parameters is crucial for obtaining cheeses with appropriate flavors and textures. Roquefort cheese has a soft and creamy middle texture. The formation of taste and aroma substances takes place in the final phase of ripening. The texture of Roquefort cheese is a perfect combination of soft and creamy on the inside, with characteristic blue-green indentations and a denser rind on the outside. This texture is essential to its distinctive taste and makes Roquefort one of the most prized blue cheeses in the world.

Research on the physical characteristics of blue cheeses adds significant insight to understanding the production process and culinary value of these cheeses. It also provides a solid basis for the continuous development and improvement of these food products and to satisfy the tastes of cheese lovers around the world.

References

[1] Andretta, M., Almeida, T. T., Ferreira, L. R., Carvalho, A. F., Yamatogi, R. S., & Nero, Microbial safety status of Serro artisanal cheese produced in Brazil, Journal of Dairy Science, L. A. (2019).

[2] Aldalur, A., Bustamante, M.A., and Barron, L.J.R. (2019). Effects of technological settings on yield, curd, whey, and cheese composition during the cheese-making process from raw sheep milk in small rural dairies: Emphasis on cutting and cooking conditions, Journal of Dairy Science, 102(9): 7813-7825

[3] Catherine Donnelly, The Oxford companion of cheese, New York, Oxford University Press, 2016

[4] Coelho, M. C., Malcata, F. X., & Silva, C. C. (2022). Lactic acid bacteria in raw-milk cheeses: From starter cultures to probiotic functions. Foods

[5] Costin Gh. Miron, Florea T., Popa C., Rotaru G., Segal R., Știința și Ingineria Fabricării Brânzeturilor/ Science and Engineering of Cheese Manufacturing, Galați, Ed. ACADEMICA, 2003

[6] Lourdes Santiago-Lopez, Jose E. Aguilar-Toalá, Adrián Hernández-Mendoza, Invited review: Bioactive compounds produced during cheese ripening and health effects associated with aged cheese consumption, Journal of Dairy Science, Volum 101, May 2018

[7] M. E. Johnson, 2017, A 100-Year Review: Cheese production and quality, American Dairy Science Association

[8] Mariana González, Eliana Budelli, Nicolás Pérez, Patricia Lema, Acoustic techniques to detect eye formation during ripening of Emmental type cheese, Innovative Food Science and Emerging Technologies, 2019

[9] Masoumeh Alinaghi, David Nilsson, Nikita Singh, Annika Höjer, Karin Hallin Saedén, and Johan Trygg, Near-infrared hyperspectral image analysis for monitoring the cheese-ripening process, Elsevier, 2023

[10] Pellegrino Conte, Luciano Cinquanta, Paolo Lo Meo, Francesca Mazza, Anna Micalizzi, Onofrio Corona, 2020, Fast field cycling NMR relaxometry as a tool to monitor Parmigiano Reggiano cheese ripening, Food Research International;

[11] Ramón Ordoñez, Carolina Contreras, Chelo González-Martínez, Amparo Chiralt, 2019, Edible coatings controlling mass loss and Penicillium roqueforti growth during cheese ripening, Journal of Food Engineering;

[12] Riyadh Alaa, Assad Rehman, Mohsen Gavahian, 2020, Moderate electric field pasteurization of milk in a continuous flow unit: Effects of process parameter, energy consumption, and shelflife determination, Innovative Food Science and Emerging Technologies

[13] Thomas Bintsis, Photis Papademas, Global Cheesemaking Technology,Wiley, 2018

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RECENT ADVANCES ON KULFI– A POPULAR INDIAN FROZEN DESSERT

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Abstract: Numerous global communities and research institutions have expressed a strong interest in an enhanced version of kulfi, enriched with increased nutrients and bioactive compounds. Through the amalgamation of peach pulp, banana, and pistachio, along with probiotic bacteria and mango–flavoured camel milk powder, certain trials were conducted in an attempt to enhance the colour, flavour, and therapeutic attributes of kulfi. Varied proportions of banana pulp (5%, 10%, 15%) and 2% pistachio powder, mango pulp (10%, 15%, 20%), probiotic cultures, peach pulp (5%, 10%, 15%, 20%), camel milk powder, and Amaranthus:SMP ratios (25:75, 50:50, 75:25, 100:0.0, 0.0:100) were explored across different research institutions to create diverse types of kulfi. Following rigorous physico–chemical and sensory assessments, the final optimized product was determined, consisting of 15% banana pulp, 15% peach pulp, 15% mango pulp, and 3% mixed probiotic cultures (*L. acidophilus* and *L. casei* in a 50:50 proportion), with Amaranthus:SMP in a 25:75 ratio. This particular combination proved highly favorable compared to other variations. The incorporation of fortified ingredients, such as fortified kulfi with improved antioxidant activity and total phenolics, and malted quinoa–enriched kulfi with heightened polyphenol content and antioxidants, showcases a promising avenue for developing healthier frozen desserts. The resulting products demonstrated effectiveness in terms of nutritional quality, maintaining the authentic taste of locally available kulfi.

Keywords: kulfi, peach pulp, banana pulp, pistachio powder, probiotic mango kulfi, amaranthus, nutritional enhancement

INTRODUCTION

Kulfi, also known as Malai Kulfi/Malai–ka–burf is a popular Indian frozen milk product prepared from cow or buffalo milk and/or a combination thereof. It closely resembles ice cream in composition; however, it does not contain air (Nalkar, 2012; Singh *et al.,* 2017; Nizam and Rai, 2018). Traditionally, Kulfis are prepared by concentrating sweetened and flavoured milk by slow heating with continuous stirring until its volume is reduced by a half.

Figure 1. Kulfi, also known as Malai Kulfi/Malai–ka–burf

It comes in various flavours, including rose, mango, cardamom, saffron (kesar or saffron), strawberry, and pistachio; as well as supplemented with fruit pulp of mango, apple, orange, strawberry, and peanut.

In India about 0.7% of the total milk produced is converted into frozen desserts like ice–cream and kulfi. Kulfi contains approximately 8.53 % fat, 34.18 % TS, 3.43 % protein, 11.02 % SNF, 6.17 % lactose, 0.84 % ash. In the past few years, significant efforts have been dedicated for improving the quality of kulfi to align with consumer preferences.

This review paper delves into the intricacies of recent developments in the preparation of kulfi, presenting a detailed examination of the methodologies and outcomes involved in the pursuit of enriched and nutritionally enhanced kulfi varieties.

ENRICHMENT OF KULFI

In the new millennium we are witnessing the upward trend in nutritional and health awareness which has increased the consumer demand for functional foods (Singh and David, 2018). The present investigation was made with an attempt to enrich the kulfi by incorporating various flavors and supplements that not only contribute to human health but also contribute to extending the shelf life of the kulfi.

Singh and David (2018) experimented on development of pistachio flavoured banana kulfi by partial addition of different levels of banana pulp and pistachio powder and anotherworked on suitability of incorporating probiotics in mango based kulfi with different levels of Alfanso, most popular fruit (king of fruit crop) and the addition of *L. acidophilus* and *L. casei* (Nalkar*et al.*,2019). Susngi*et al.* (2019) worked on

development of kulfi supplemented with peach pulp by partial addition of different levels of peach pulp which are highly acceptable by consumers for its physico–chemical and sensory characteristics. Gupta *et al.* (2020) also studied on camel milk powder supplemented with concentrated milk and Camel milk powder which have therapeutic health benefits like antimicrobial, anti–inflammatory, anti–diabetic, anti–cancerous. Patel *et al.* (2020) researched on development of Kulfi incorporated with Amaranthus (Rajgara) with the ratio of Amaranthus: SMP.

Murthy *et al*., (2009) conducted an experiment by using sunflower brand vanaspathi (vegetable fat) as an alternative source of milk fat to prepare filled kulfi.Kaur et al., (2021) was developed kulfi by encapsulating betalains which was extracted fromred beetroot (*Beta vulgaris* L.) pomace. Fortified kulfi had high antioxidant activity and low microbial load than control sample. JI and A.P. (2024) prepared a functional kulfi with addition of malted quinoa flour to make it high protein and fibre richproduct.Quinoa has gluten free property which can be beneficial for celiac disease and digestive issues. The cereal with low glycemic index would be promising in food incorporation especially for the diabetic patients. Singh & Das (2017) was prepared coconut milk fortified kulfi with addition of different percentage.

Giri *et al.* (2014) experimented on effect of quality of kulfi by partial replacement of sugar with stevia. Stevia is 100–300 times sweeter than sucrose with many health benefits such as increase digestion, helps to prevent diabetes, decreases weight, prevent tooth decay etc. Sontakke *et al.* (2023) worked on the buffalo milk kulfi with strawberry pulp addition at different levels.

Strawberries are excellent source of manganese and vitamin C. they also met the criteria for being an excellent supply of potassium, folate, riboflavin, vitamin B5, omega–3 fatty acids, vitamin B6, vitamin K, magnesium, and copper. They were also very good source of dietary fibre and iodine.

METHOD OF PREPARATION

After collection of the ingredients, scientific procedures were employed to conduct the experiments. The preparation method for kulfi remains consistent with the traditional approach, involving processes such as heating of milk, mixing of ingredients, condensing, transferring into molds, and the hardening process.

However, several experiments were conducted by scientists from various laboratories to introduce novelty to the product. For experimental purposes, different temperatures were utilized in each experiment, as discussed below.

- **Development of pistachio flavoured banana kulfi**

Singh and David (2018) performed an experiment by partial addition of different levels of banana pulp (5%, 10%, 15%) and 2% pistachio powder. In the preparation of control kulfi samples, milk was standardized to contain 6% fat and 9% SNF in a double–jacketed vat, and then condensed to half of its initial volume. Subsequently, 14% sugar was added after the condensation process. The mix was cooled to 5˚C and frozen in molds at –20˚C overnight.

- **Suitability of incorporating probiotics in mango based kulfi**

Nalkar*et al.* (2019),while working on suitability of incorporating probiotics in mango based kulfi with mixing of different levels of Alfanso, most popular fruit (king of fruit crop) pulp viz.,10%, 15%, and 20% and probiotic cultures *L. acidophilus* and *L. casei* with different proportions. After the addition of probiotics, Kulfimix just after cooling of milk andincubated for 5h at 37°C prior to addition of mango pulp.

- **Development of kulfi supplemented with peach pulp**

Susngi *et al.* (2019) experimented with peach pulp by partial addition of different levels of peach pulp (5%, 10%, 15% and 20%) and one controlled sample was also prepared to estimated it.

- **Studies on Camel milk powder supplemented Kulfi**

Gupta *et al.* (2020) studied on camel milk powder supplemented with 95% concentrated milk and 5% Camel milk powder (95%CM + 5%CMP), 90% concentrated milk with 10% Camel milk powder (90% + 10%CMP), 85% concentrated milk with 15% Camel milk powder (85%CM + 15%CMP).

- **Development of Kulfi incorporated with Amaranthus (Rajgara)**

In the investigation conducted by Patel *et al.* (2020), the examination focused on varying proportions of Amaranthus and SMP (25:75, 50:50, 75:25, 100:0.0, and 0.0:100 ratios).

The formulated Kulfi mix was pasteurized at 80 °C for 25 seconds, followed by cooling at 4 °C. To enhance flavour, either artificial or natural Mawa flavour was introduced at a concentration of

0.3%. Subsequently, the Kulfi mix was poured into moulds, covered, and placed in a candy–making machine set at –20°C for freezing. After achieving complete freezing, the Kulfi was transferred to a deep freezer maintained at –18 ± 2°C overnight for hardening.

The frozen Kulfi was stored in the deep freezer until further use. The same process was meticulously carried out to achieve the desired results as discussed in the research.

Preparation of filled kulfi by using vegetable fat

Murthy *et al.*, (2009) was studied on kulfi on suitability of using vegetable fat over milk fat. They made control sample of kulfi for their experiment by using skim milk and fresh cream. Standardization ofkulfi mix was carried out with 5% fat and 8.5% solids not fat by using fresh skim milk, cream, and Sagar brand SMP.

Mix preheated temperature was 65°C after that two stages homogenization was performed (first stage – 2500 PSI, second stage –500 PSI). Mix was condensed to half of its original volume and the stabilizer, emulsifier, and sugar was added @ 0.25% gelatine, 0.25% GMS, 15% of the condensed product respectively in it and mixed thoroughly with slow heating.

Mix was kept for aging at below 7°C for 5 hours without fluctuation of temperature. Then colour, flavour and crashed almond was added to it and transferred to 80 ml kulfi moulds and hardened at 20 ± 2°C for 12 hrs.

Experimental (Filled) kulfi (a frozen dairy dessert) was prepared by using vegetable fats @ 60%, 70%, 80% of milk fat. Dietetic kulfi was prepared with addition of ash gourd pulp and checked the effect (David, 2014).

Development of functional kulfi fortified with microencapsulated betalains

Kaur *et al.*, (2021) extracted betalain from red beetroot pomace (Singh *et al.*, 2017) then purification of betalains were carried out by gel electrophoresis method (Caldas–Cueva *et al.*, 2016). Then betalain content was calculated and microencapsuls were prepared by using freeze drying method.

The content of betalain in microcapsules was determined by standard method (Ravichandran *et al.*, 2014). Kulfi was developed with some modification of method mentioned by Giri *et al.* (2014).

After preparing the hot kulfi mix by addition of microencapsulated betalains (0.50% and 1%), freeze dried extract (0.50% and 1%) and microencapsules without betalain (control; 0.50%) at 40°C. freezer temperature was maintained at –20°C for 24 hours.

Preparation of malted quinoa flour enriched kulfi

JI and A.P. (2024) develop kulfi on certain objectives (free of sugar, high protein and fibre rich). Experiment was carried out by adding different rate of malted quinoa @ 0%, 10%, 15%, 20%.

Coconut milk fortified kulfi preparation

Singh and Das (2017) experimented by addition of coconut milk @ 10%, 20% and 30% and the control sample (without coconut milk) had fat, sugar and total solids @ 12%, 14%, 44% respectively.

Development of kulfi by adding stevia with partial replacement of sugar

Giri *et al.* (2014) prepared kulfi in which 50%, 60%, 70% sugar was replaced with 0.05%, 0.06% and 0.07% stevia powder respectively.

Preparation of ash gourd pulp dietetic kulfi

David *et al.* (2014) developed dietetic kulfi by mixing of different levels of ash gourd pulp @ 5%, 10%, 15%. Control sample (10% milk fat, 15% sugar, 0.2% stabilizer, 0% ash gourd pulp) was made to obtain 37% total solid.

Three corresponding treatments were carried out (T1, T2, T3). Standardization of T1 (10% milk fat, 15% sugar, 0.2% stabilizer, 5% ash gourd pulp), T2 (10% milk fat, 15% sugar, 0.2% stabilizer, 10% ash gourd pulp) and T3 (10% milk fat, 15% sugar, 0.2% stabilizer, 15% ash gourd pulp) were carried out.

Production of strawberry pulp enriched kulfi

Sontakke *et al.* (2023) studied on buffalo milk kulfi to observe the sensory attributes of kulfi with different levels of strawberry pulp @ 10%, 15%, 20% and 25%.

EVALUATION OF PHYSICO–CHEMICAL, ORGANOLEPTIC AND SENSORY PROPERTIES OF KULFI

All chemical constituents including acidity, total solids (TS), protein content, and fat content were estimated as per the standard methods (AOAC, 2005). The melting time of Kulfisamples was also determined. pH was estimated by pH meter. Melting resistance was determined (Giri *et al.* 2012).

All the samples were evaluated for sensory attributes such as colour and appearance, body and texture, flavour, and overall acceptability on a nine–point hedonic scale (9 for liking extremely and 1 for disliking extremely) by the panel of discriminative and experienced expert judges was formulated (Nalkar *et al.*, 2019).

Kulfi made from vegetable fat was evaluated by 10 judges (Murthy *et al.*, 2009).

OBSERVATION AND RESULTS

In the investigation conducted by Singh and David (2018) regarding the development of pistachio–flavoured banana kulfi, it was noted that a 15% inclusion of pulp emerged as the most favourable among various combinations. This selection was based on comprehensive organoleptic and sensory evaluations, as well as the notable health benefits associated with banana and pistachio.

Additionally, the incorporation of 15% Alphonso mango pulp and 3% mixed probiotic cultures (*L. acidophilus* and *L. casei* in a 50:50 proportion) in the kulfi mix, as explored by Nalkar *et al.* (2019), resulted in a product of superior quality. This particular combination exhibited higher viability counts of probiotics (8.75 and 8.20 log cfu/g for *L .acidophilus* and *L. casei*, respectively) after storage compared to alternative treatment combinations.

Furthermore, Susngi *et al.* (2019) found that 15% peach pulp yielded highly acceptable results in kulfi formulations, based on both physico–chemical and sensory evaluations. In a separate study by Gupta *et al.* (2020), the exploration of camel milk powder supplementation in kulfi, with a composition of 95% concentrated milk and 5% camel milk powder, highlighted the potential therapeutic health benefits such as antimicrobial, anti–inflammatory, anti–diabetic, and anti–cancerous properties.

In a study by Patel *et al.* (2020) focusing on the incorporation of Amaranthus (Rajgara) in kulfi, it was observed that a ratio of 25:75 for Amaranthus and Skimmed Milk Powder (SMP) significantly enhanced flavor, body & texture, and color& appearance scores. This underscores the potential for innovative kulfi formulations that not only prioritize taste but also incorporate health–promoting ingredients.

Murthy *et al.* (2009) observed that acidity of kulfi was lowest (0.241 % LA) which was exclusively made by skim milk and cream. Acidity and pH of kulfi were increased as the level of vegetable fat increased. It was seen that before aging acidity as 0.241 – 0.255% LA and after aging acidity was determined 0.262 – 0.272%). There was no effect on color and appearance at any substitution level but significant effect was noticed on body, texture, flavor and overall acceptability when substitution level increased beyond 70%. Oily taste was noticed by the judges.

Fortified kulfi was determined with improved antioxidant activity and total phenolics and decreased level of melting rate and microbial counts (Kaur *et al.*, 2021).

Malted quinoa enriched kulfi was high in polyphenols additionally antioxidants. It was observed that kulfi had a unique color, flavor. So, no artificial coloring and flavoring agents were added. 15% malted quinoa flour added kulfi was optimized and stored for 35 days. Antioxidant activity was higher over storage and there was slight change in acidity but microbial activity was decreased significantly over time (JI & A.P., 2024).

Coconut milk fortified kulfi was evaluated by organoleptic test and 30% was found best (Total solid– 55.59%, fat– 22.73%, carbohydrate– 24.28%, protein– 7.57% and ash– 1.45%) (Singh & Das, 2017).

Giri *et al.* (2014) observed that specific gravity, melting rate, total calorie content, carbohydrate percentage were decreased with increasing sugar replacement and freezing point, hardness and fat, protein, ash and moisture percentage were increased significantly. It was observed that above 50% replacement of sugar resulted bitter taste and presence of icy texture.

David, (2014) found highest value in T3 (containing 15% ash gourd pulp) by organoleptic test, T2 showed best result in microbiological count through SPC and coliform count results. Therefore, for overall acceptability the treatment can be rated as T0> T1>T2>T3.

Sontakke *et al.* (2023) noticed that 15% strawberry pulp added kulfi was more acceptable. Organoleptic test was conducted by 9– point hedonic scale.

CONCLUSION

According to the findings of several types of experiments on improving the colour, flavour, and medicinal value of kulfi, the physico–chemical properties, sensory qualities, and microbiological properties of kulfi were highly acceptable.

It may be established that kulfi enriched with various pulps and powders is nutritionally superior to regular kulfi. As a rich source of high–quality animal protein, fat, minerals, and vitamins, kulfi has seen an increase in popularity in recent years.

Banana and pistachio offer a plethora of health benefits, according to traditional medicine and preclinical studies, and kulfi, as a widely acknowledged food, can operate as a vehicle

to transfer the bioactive components of banana pulp and pistachio.

The incorporation of fortified ingredients, such as fortified kulfi with improved antioxidant activity and total phenolics, and malted quinoa–enriched kulfi with heightened polyphenol content and antioxidants, showcases a promising avenue for developing healthier frozen desserts.

The utilization of natural sources for color and flavor in the malted quinoa kulfi is noteworthy, emphasizing a commitment to avoiding artificial additives. Thus, the diverse approaches presented in this review underscore the potential for creating innovative and health–conscious kulfi variations.

These findings not only contribute to the culinary landscape but also address the growing demand for nutritious and flavorful frozen desserts in the market.

References

[1] Patel, A. C., Pandya, A. J., Gopikrishna, G., Patel, R. A., Shendurse, A. M., & Roy, S. K. (2020). Development of kulfi incorporated with Amaranthus (Rajgara). Journal homepage: http://www. ijcmas. com, 9(5), 2020.

[2] Gupta, D. K. Studies on Camel Milk Powder Supplemented Kulfi. (2020)

[3] Susngi, S. R., Das, A., Dympep, P., Gupta, D. K., Bharti, B. K., Ranvir, S. G., & David, J. (2019). Studies on development of kulfi supplemented with peach pulp. Journal of Pharmacognosy and Phytochemistry, 8(5), 985–988.

[4] Singh, S. B., & David, J. (2018). Development of pistachio flavoured banana kulfi. Journal of Pharmacognosy and Phytochemistry, 7(2), 2089–2091.

[5] Nalkar, S. D., Patel, A. R., Chandraprakash, V. B., &Kalyankar, S. D. (2018). Studies on suitability of incorporating probiotics in mango–based Kulfi–A popular Indian frozen dessert. Annals Food Science and Technology, 19(4), 714–721.

[6] Nizam, N., Rai, S. (2018): A study on the development of probiotic diabetic Kulfi Indian Ice cream. Int. J. Food Sci. Nutri., **3**(1), 60–64

[7] Giri, A., Rao, H.G.R., Ramesh, V. (2012): Effect of partial replacement of sugar with stevia on the quality of Kulfi. J. Food Sci. Technol.10.1007/s:5–6.

[8] AOAC (2005): Official Methods of Analysis. Association of Official Analytical Chemists. 18th Edition, Washington DC.

[9] Murthy, M. R., Sharanagouda, B., Jayaprakash, H. M., &Ramanjaneyalu, G. (2009). Studies on the preparation of filled Kulfi. Mysore Journal of Agricultural Sciences, 43(3), 597–599.

[10] Kaur, N., Kaur, A., Sridhar, K., Sharma, M., Singh, T. P., & Kumar, S. (2021). Development and quality characteristics of functional Kulfi fortified with microencapsulated betalains. International Journal of Food Science & Technology, 56(10), 5362–5370.

[11] Singh, A., Ganesapillai, M., &Gnanasundaram, N. (2017, November). Optimizaton of extraction of betalain pigments from beta vulgaris peels by microwave pretreatment. In IOP Conference Series: Materials Science and Engineering (Vol. 263, No. 3, p. 032004). IOP Publishing.

[12] Caldas–Cueva, J. P., Morales, P., Ludeña, F., Betalleluz–Pallardel, I., Chirinos, R., Noratto, G. & Campos, D. (2016). Stability of betacyanin pigments and antioxidants in ayrampo (Opuntia soehrensiibritton and rose) seed extracts and as a yogurt natural colorant. International Journal of Food Science and Technology, 40, 541–549.

[13] Giri, A., Rao, H. G. & Ramesh, V. (2014). Effect of partial replacement of sugar with stevia on the quality of Kulfi. Journal of Food Science and Technology, 51, 1612–6.

[14] Ravichandran, K., Palaniraj, R., Saw, N. M. M. T., Gabr, A. M. M., Ahmed, A. R., Knorr, D. &Smetanska, I. (2014). Effects of different encapsulation agents and drying process on stability of betalains extract. Journal of Food Science and Technology, 51, 2216–2221.

[15] JI, A. P. Development and quality characteristics of functional Kulfi enriched with malted quinoa flour. Indian Journal of Dairy Science, 77(1).

[16] Shiva, S., & Anamika, D. (2017). Studies on development of coconut milk fortified kulfi. Trends in Biosciences, 10(1), 286–288.

[17] Giri, A., Rao, H. R., & V, R. (2014). Effect of partial replacement of sugar with stevia on the quality of kulfi. Journal of food science and technology, 51(8), 1612–1616.

[18] David, J. (2014). Effect of different level of ash gourd pulp for manufacturing dietetic Kulfi. Trends in Biosciences, 7(5), 339–340.

[19] Sontakke, M. M., Narwade, S. G., & Zine, P. L. (2023). Effect of Addition of Strawberry Pulp on Sensory Attributes of Kulfi. International Journal of Environment and Climate Change, 13(8), 1741–1745.

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COST OPTIMIZATION OF A T-BEAM UNDER BENDING CONSTRAINTS

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Abstract: This research paper focuses on the cost optimization of a T-beam subjected to bending constraints according to Eurocode 2. The objective of the study is to minimize the cost of the T-beam while ensuring that it meets the specified structural requirements and design limitations outlined in Eurocode 2. The optimization problem is formulated as a nonlinear constrained minimization problem,, taking into account the geometric and material properties of the T-beam, as well as the imposed loading conditions. The Eurocode 2 provisions for structural analysis and design are incorporated into the optimization process to ensure compliance with safety and serviceability requirements. This was solved using the GRG Algorithm. The optimization offered minimal cost savings, with gains reducing from 1.4% to 0.8% as the beam span increased. However, the optimal cost was found to increase with the design moment applied, with gains from 11.96% to 32.46% for a design moment ranging from 200kNm to 500kNm respectively. The results demonstrate the effectiveness of the proposed cost optimization approach, highlighting the potential for significant savings in material usage and construction costs. The findings also provide valuable insights into the trade-off between structural performance and economic considerations in the design of T-beams

Keywords: cost optimization, Eurocode 2, GRG algorithm, moment, t-beam

INTRODUCTION

Reinforced Concrete T-beams are commonly used in industrial construction, particularly in building floors, retaining walls, bridge decks, and in all reinforced concrete construction projects where an appropriate portion of the slab is associated with the resisting section of the supporting beam. Non-linear programming techniques can be used to produce a cost-effective design solution for large-scale utilization of such T-shaped beams, as may be the case for precast reinforced concrete component manufacture. The best-designed beams can be adequately fabricated in a prefabrication facility and then used for their intended purpose. This could result in significant savings in both the superstructure and the foundation elements' expensive construction materials. The overall cost to be reduced is fundamentally divided into the costs of concrete, steel, and formwork. From an economic standpoint, it is also important to include the nonlinear ultimate behavior of the concrete and reinforcing steel in compliance with current design codes throughout the design process optimization of the crucial sections.

The current study falls within this framework and is concerned with the cost-effective design of reinforced concrete T-shaped beams under ultimate stresses. The art of cost effective design entails first formulating a structural optimization model and then solving it with an appropriate mathematical programming technique (Bhalchandra and Adsul, 2012). An objective function and a set of constraints comprise the structural optimization model. The latter often contain search limits for choice variables, structural behavior restrictions, and various stress and strain circumstances and their limits. Ideally, the final design must incorporate compatibility between the geometrical dimensions of the optimized T-cross section and the ultimate loading condition, which includes the T-beam's self-weight. Some of the early investigations paid very little attention to this element. Another important feature of optimal design is the adoption of a proper optimization technique. In structural design optimization, many mathematical programming techniques have been applied (Salim et al., 2018; Bhalchandra and Adsul, 2012; Ildiko et al., 2010). This study uses a suitable mathematical programming technique to formulate and solve the nonlinear minimum cost design issue of reinforced concrete T-beams under bending constraint.

The purpose of a designer is to create an "optimal solution" for the structural design under consideration. An optimal solution typically indicates the most cost-effective construction without jeopardizing the building's intended functional functions. The total cost of the concrete structure is the sum of the costs of its constituent materials, which include at least concrete, reinforcement steel, and formwork. Some properties of reinforced concrete (RC) structures distinguish their design optimization from that of other structures. Several cost items influence the cost of RC constructions.

To address this issue, this study presents a thorough technique for T-beam cost optimization. The project will use advanced

computational tools and optimization techniques to identify configurations that minimize material consumption and construction costs while meeting Eurocode 2 safety and performance criteria (Eurocode 2, 2004). This work tries to provide a holistic solution to the problem of cost-efficient T-beam design by using an interdisciplinary approach that merges engineering concepts with economic models.

Optimization is the art of selecting the most cost-effective or highest achievable performance alternative from a set of alternatives by maximizing the desired elements and reducing the undesirable factors. Babiker et al. (2012) employed an Artificial Neural Networks-based model to optimize the cost of simply supported beams by factoring in the cost of concrete, reinforcing, and formwork. The beams were developed in accordance with the American Concrete Institute (ACI) standard ACI 318-08.

The majority of the recent literature on this topic was created utilizing the Genetic Algorithm (GA) optimization technique. Yousif and Najem (2013) presented the use of genetic algorithms (GA) for the optimum cost design of RCC continuous beams based on ACI 318-08 requirements. The solutions to the depicted example problem produced sensible, dependable, economical, and practical designs. Ismail (2017) conducted a comparison study between one of the conventional optimization approaches, Generalized Reduced Gradient (GRG), and one of the heuristic strategies, Genetic Algorithm. The comparison found that the GA outperformed the traditional GRG. Bhalchandra and Adsul (2012) demonstrated the GA technique's superiority over the GRG and Interior Point optimization techniques. The problem of optimum design of simply supported doubly reinforced beams with uniformly distributed and concentrated load has been solved by adding the beam's true self-weight.

Alex and Kottalil (2015) attempted to illustrate the use of the GA to the construction of reinforced concrete cantilever and continuous beams. The design was based on the guidelines provided by the Indian Standard, IS 456. Cost optimization was performed to obtain the most cost-effective concrete section and reinforcements at user-defined intervals. Prakash (2016) investigated the economic considerations of reinforced concrete beam design. Manual and MS-Excel programs were used to design reinforced concrete rectangular and flanged sections. IS 456-2000 code standards were used to design the singly reinforced, doubly reinforced, and flanged sections at a constant imposed load of 25 kN/m. The study also took into account different spans and depth to width ratios. The majority of the works were designed in accordance with international standards such as ACI. The design factors utilized for the optimization issues also differed amongst researchers. The purpose of this work is to determine the best design of a singly reinforced T-beam for a particular imposed load while keeping code and practical constraints in mind. The cost of the beam can be represented as a function of the amount of concrete and steel used, the grade of concrete used, the size of the form work, and so on. This function will be the problem's objective function. The beam must meet the strength and serviceability conditions specified in the EC2 design, which will serve as constraints for the optimization problem. The goal of the optimization is to minimize the total cost of the beam while keeping the limits in mind.

The scope of this project was restricted to the cost of concrete, formwork, and steel. The cost targets were also determined using the generalized reduced gradient approach in Microsoft Excel. This research is justified by its potential to significantly cut construction costs, reduce environmental effect, and improve the level of knowledge in the field of structural engineering and optimization.

The goal of this project was to find the cheapest concrete material, formwork, and steel reinforcement for a reinforced concrete T-beam. This was accomplished by altering the beam spans and the enforced design moment in order to reduce the total cost of construction of a reinforced flanged beam. The methodology used to achieve this goal was the creation of a computer software in Microsoft Excel that allows for the simple selection of design variables that will optimize the overall cost of construction of a reinforced T-Beam in bending.

MATERIALS AND METHODS

Materials

Eurocode 2 (2004) was used to develop a mathematical representation of a concrete structure. An Excel spreadsheet was used to set up the model and the optimization process was executed using Excel's Solver Tool.

Methods

— T-Beams under Bending Constraints

T-Beams are concrete structural members, which have a flange cross-section shaped like a 'T'.

Their cross-section consists of a central web and a flange on both left and right sides of the web, as shown in Figure 1.

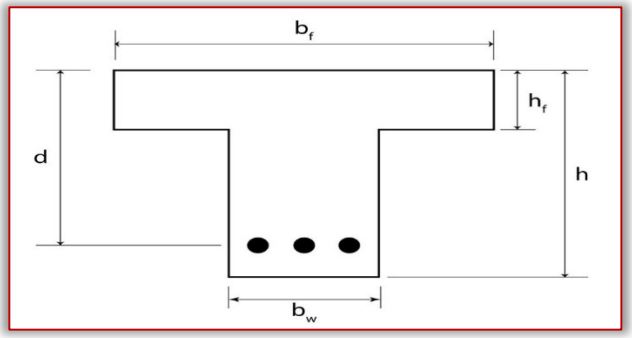

Figure 1: Cross-section of a concrete T-Beam.

The T-Beam, experiences tension at the bottom and compression at the top. However, due to the large surface area provided by the concrete (which is favorable in compression) in the flange, it is usually unnecessary to consider a case where compression reinforcement is needed.

In addition, since this research focuses on T-Beams under bending constraints, the nature of the beams cross-section under flexure was fully considered. Here, there were two cases:

- The stress block lies within the compression flange.
- The stress block extends outside the compression flange.
- Both cases are shown in Figure 2 and Figure 3, respectively.

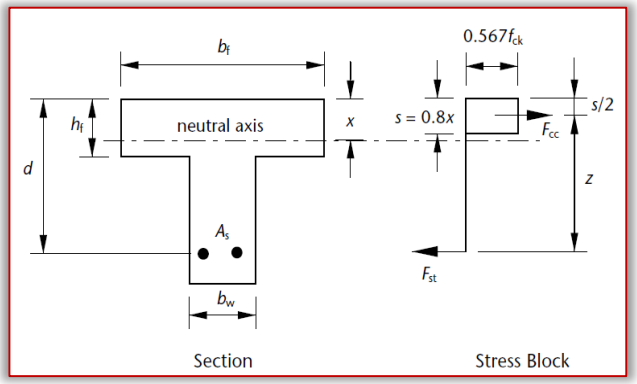

Figure 2: T-section, with stress block within the flange, $s < h_f$

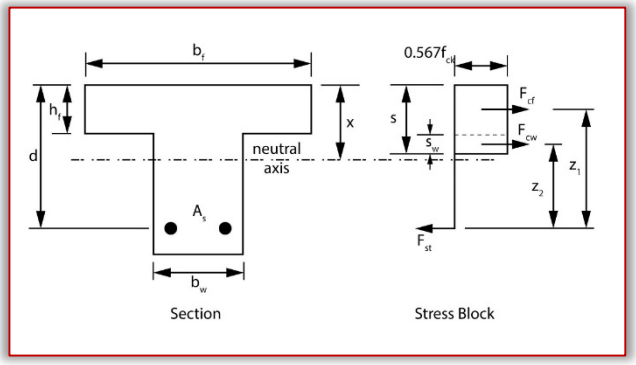

Figure 3: T-section, with stress block beyond the flange, $s > h_f$

In this research, the second case was chosen under the design constraints of Eurocode 2 as the focus of this study.

— **Optimization Technique**

Generalized reduced gradient (GRG) method was the optimization technique used to carry out the cost optimization. The objective function developed for the cost optimization was a non-linear one, with bending constraints derived from Eurocode 2. The optimization problem is a non-linear constrained optimization problem, which the generalized reduced gradient method can resolve.

Microsoft Excel was the preferred software of choice to handle the optimization problem. Being easily affordable and ubiquitous in the software market, it was also chosen for its ease and clarity of usage. An Excel spreadsheet was built to set up the model, before the optimization process was finally executed using Excel's Solver Tool, which possesses the generalized reduced gradient method for non-linear models as one of its solving methods. Values were derived from the spreadsheet and documented as results.

— **Development of Model**

An objective function was derived which related the cost of manufacturing a reinforced concrete T-Beam of specific dimensions to the materials and their sizes needed to construct the beam. This was then subjected to bending constraints under Eurocode 2.

— **Cost Objective Function**

The cost of the T-Beam is the sum of the cost of concrete, steel and formwork components. The quantity of each of these components depends not only on the dimensions of the beam, but also on some of its design properties. For example, the area of reinforced steel is dependent on the applied moment (also known as the design moment) and the dimensions of the stress block.

The cost objective function can be defined as:

Total Cost, C = (cost of concrete) + (cost of rebar) + (cost of formwork)

Which can be rewritten in full as:

$$C = \left[C_c \times \left(\left(b_f h_f + b_w(h - h_f)\right) - A_s\right) \times u_c \times L\right] + [C_s + A_s] + [C_f \times (b_f + 2h)] \quad (1)$$

where:

C = Total cost of manufacturing the T-Beam.

C_c = Cost coefficient of concrete in cost per mass (naira per kg).

C_s = Cost coefficient of reinforcement steel, in cost per cross-sectional area (naira per mm²).

C_f = Cost coefficient of formwork, in cost per length (naira per m).

b_f = Width of the flange (mm).

b_w = Width of the web (mm).
h = Total height of the beam (mm).
h_f = Height of the flange (mm).
A_s = Total area of reinforcement steel (mm^2).
L = Length of the beam (m).
u_c = Unit weight of concrete (kg/m^3).

— **Input and Design Parameters**

Given that the cost of manufacturing the T-beam is related to the various parameters listed in the previous section above, further derivations were used to calculate the variables necessary for the calculation of the parameters present in the objective function.

Input parameters were classified into those that could be directly imputed and used in the objective function; those which were needed to compute values of parameters to be used in the objective function; and finally those that would be adjusted in the optimization process to produce an optimal cost of manufacturing the T-beam.

The parameters that were to be adjusted to derive the optimized costs were classified as design variables. Those that needed additional calculations before being used were separated in the Excel spreadsheet as computed values.

The cost coefficients were each calculated based on their necessary dimensions and underlying real-world market prices as follows:

≡ Cost Coefficient of Concrete (C_c): This is the total cost per mass of concrete (naira per kg). It was found by calculating the total cost of manufacturing a given mass of concrete and dividing that cost by the mass of concrete manufactured.
≡ Cost Coefficient of Steel (C_s): This is the cost per cross-sectional area of reinforcement steel (naira per mm^2). It was found by dividing the cost of specific sizes of steel bars by their areas. Given that reinforcement bars are manufactured and sold based on their diameter sizes, the bar diameters were used to derive the cross-sectional areas.
≡ Cost Coefficient of Formwork (C_f): Here, the cost coefficient of formwork is the cost per length of the formwork material used (commonly wood). Its dimensions are in naira per meter.

The material properties of both the concrete and the steel, which were used to compute values in the objective function and in the derivation of some constraints, are:

≡ Characteristic Strength of Concrete (f_{ck}): This is the compressive strength of 150 mm sized cubes tested at 28 days at which not more than 5% of the test results are expected to fail. It is taken in Eurocode 2 as 25 N/mm^2.
≡ Characteristic Strength of Steel (f_{yk}): This is the minimum yield stress, at which not over 5% of the test outcomes should fail. Taken as 500 N/mm^2 according to Eurocode 2.
≡ Unit weight of Concrete (u_c): This is the ratio of the mass of concrete per unit volume. Taken as 2400 kg/m^3.

The inputs for the geometric dimensions of the beam (as shown in Fig 1):

≡ length of the beam (l)
≡ width of the flange (b_f)
≡ width of the web (b_w)
≡ total height of the beam (h)
≡ height of the flange (h_f)
≡ effective depth of reinforcement bar (d)

The design moment M_d, which is the resulting moment applied on the member as a result of the load conditions on the member was also imputed in the model. This moment would be used to calculate s_w, which is the depth of the stress block into the web of the beam. It would also be used in the derivation of the bending constraints, as shown in the next section.

The area of reinforcement A_s, required in the objective function was calculated from the formula:

$$A_s = \frac{0.567 f_{ck} b_f h_f + 0.567 f_{ck} b_w s_w}{0.87 f_{yk}} \quad (2)$$

Where s_w was found by deriving the roots of the equation:

$$s_w^2 \left[\frac{0.567 f_{ck} b_w}{2}\right] - [0.567 f_{ck} b_w (d - h_f)] s_w + (M_f - M_d) = 0 \quad (3)$$

Given that there are two roots to equation 3, additional constraints were developed to ensure that the value of s_w used by the model was an appropriate and mandatorily positive real number. The term M_f in the above equation represents the moment of resistance developed by the flange.

DEVELOPMENT OF CONSTRAINTS

The beam was optimized under bending constraints to Eurocode 2. Hence, the behavioral constraints were limited to only parameters related to flexure. These constraints were derived using structure illustrated in Figure 3. Here, the design moment M_d, is to be constrained by both the moment of resistance in the flange M_f and the moment of resistance of the entire section, M_R.

To ensure that the stress block extends beyond the flange, the design moment is to be greater than the moment of resistance developed by the flange alone:

$$M_f \leq M_d \quad (4)$$

In addition, to ensure that the beam does not fail in bending, the applied moment has to be exceeded by the moment of resistance of the entire section:

$$M_d \leq M_R \quad (5)$$

Mathematically, equation 4 and 5 was combined and restated as:

$$M_f \leq M_d \leq M_R \quad (6)$$

Where,

$$M_f = 0.567 f_{ck} b_f h_f \left(d - \frac{h_f}{2}\right) \quad (7)$$

$$M_R = 0.567 f_{ck} b_f h_f \left(d - \frac{h_f}{2}\right) + 0.567 f_{ck} b_w (s - h_f)\left(d - \frac{s}{2} - \frac{h_f}{2}\right) \quad (8)$$

The term s, from equation 8, is the total height of the stress block and was derived from the formula:

$$s = \frac{0.87 f_{yk} A_s - 0.567 f_{ck} b_f h_f}{0.567 f_{ck} b_w} + h_f \quad (9)$$

Given that in the model, the stress block must extend past the flange and into the web of the beam, a constraint relating s to the depth of the flange h_f was developed:

$$s > h_f \quad (10)$$

In order to ensure that there was no need for compression reinforcement, the depth of the neural axis, x, as shown in Figure 3, must not exceed forty-five percent (45%) of the depth of reinforcement d. Mathematically:

$$x < 0.45d \quad (11)$$

where,

$$x = \frac{s}{0.8} \quad (12)$$

Apart from behavioral constraints, there were geometric constraints placed on the model. These were based off the permissible and real-life dimensions of the beam's possible cross-section.

Behavioral constraints:

$$M_f \leq M_d \leq M_R \quad (13)$$

$$s > h_f \quad (14)$$

$$x < 0.45d \quad (15)$$

Geometric constraints:

$$350 \leq b_f \leq 550 \quad (16)$$

$$100 \leq h_f \leq 150 \quad (17)$$

$$200 \leq b_w \leq 300 \quad (18)$$

$$400 \leq h \leq 600 \quad (19)$$

$$1200 \leq A_s \leq 2500 \quad (20)$$

$$s_w > 0 \quad (21)$$

OPTIMIZATION MODEL

The optimization problem has been described in the previous sections in detail. It can be summarized as:

Minimize:

$$C = \left[C_c \times \left((b_f h_f + b_w(h - h_f)) - A_s\right) \times u_c \times L\right] + [C_s + A_s] + [C_f \times (b_f + 2h)] \quad (22)$$

Subject to:

$$M_f \leq M_d \leq M_R \quad (23)$$

$$s > h_f \quad (24)$$

$$x < 0.45d \quad (25)$$

$$350 \leq b_f \leq 550 \quad (26)$$

$$100 \leq h_f \leq 150 \quad (27)$$

$$200 \leq b_w \leq 300 \quad (28)$$

$$400 \leq h \leq 600 \quad (29)$$

$$1200 \leq A_s \leq 2500 \quad (30)$$

$$s_w > 0 \quad (31)$$

To find $X = [X_1 X_2 X_3 X_4 X_5]^T$ which minimizes the objective function while satisfying the constraints stated above.

Let:

$$b_f = X_1$$
$$h_f = X_2$$
$$b_w = X_3$$
$$h = X_4$$
$$A_s = X_5$$

The matrix X, contains the design variables which were to be changed from their initial values to derive an optimum cost, provided that they can satisfy the constraints. The output of the model would include both the design variable and the now optimized cost C, from the objective function.

OPTIMIZATION PROCESS

The cost optimization of T-beam was carried out by replicating the mathematical model in a Microsoft Excel spreadsheet.

Development of Excel Spreadsheet

The objective function, input parameters, design parameters, computed values, constraints and their aforementioned formulas were appropriately placed in the Excel spreadsheet shown in Figure 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Cost Optimization of a T-Beam under Bending Constraints to Eurocode 2												
2													
3		Objective Function:			54507.89								
4													
5	Input Parameters:			Design Variables:			Constraints:						
6	C_c	12.91429		b_f	400		Behaviorial Constraints:						
7	C_s	27.73323		b_w	200		$M_f <= M_d <= M_R$						
8	C_f	218.7227		h	400		$s > h_f$						
9	L	5		h_f	100		$x < 0.45d$						
10	U_c	2400		A_s	1397.1788		0.45d =		158				
11	b_f	400					Side Constraints:						
12	b_w	200		Computed values:			350	<=	b_f	<=	550		
13	h	400		s_w	14.381934		100	<=	h_f	<=	150		
14	h_f	100		A_s	1397.1788		200	<=	b_w	<=	300		
15	d	350		s	114.38193		400	<=	h	<=	600		
16	M_d	180		M_f	170.1		1200	<=	A_s	<=	2500		
17	f_{ck}	25		M_R	180								
18	f_{yk}	500		x	142.97742								
19													

Figure 4: Excel spreadsheet set up to evaluate the cost optimization of a T-beam subject to bending constraints.

Use of Excel Solver

Once the spreadsheet was created, the Solver button was selected from the Data tab on the Excel interface. The Solver dialogue box displayed was then filled with pertinent data from the spreadsheet. The constraints were added individually, by clicking the "Add" button. The solving method selected in the Solver dialogue box was the Generalized Reduced Gradient Non-linear algorithm method.

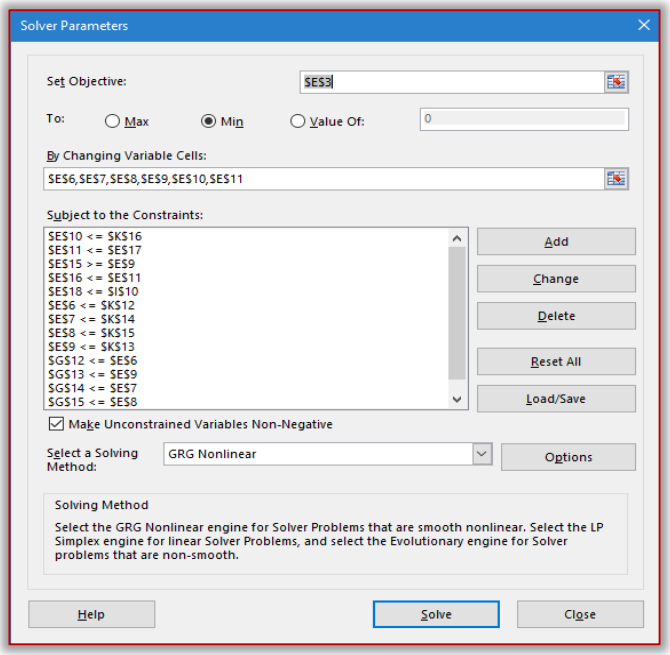

Figure 5: Solver dialogue box with relevant cells filled with information from the spreadsheet.

The "OK" button was then selected, after which a dialogue box reporting the success of the optimization process. The cells containing the design variables were changed due to the success of the operation. This also led to a corresponding change in the cost of the T-beam as represented in the objective function.

RESULTS AND DISCUSSION

Design Example

The developed Excel model was used to optimize a specific case study T-beam. The corresponding preassigned parameters are defined as follows:

Input parameters:

C_c = 12.91429 naira/kg, Cs = 27.73323 naira/mm^2, Cf = 218.7227 naira/m, L = 6 m, U_c = 2400 kg/m^3, M_d = 350 kNm, f_{ck} = 25 N/mm^2, f_{yk} = 500 N/mm^2, d = 475 mm.

Design variables:

b_f = 450 mm, b_w = 250 mm, h = 500 mm, h_f = 125 mm, A_s = 1979.6121 mm^2.

The results of the subsequent optimization is shown in Table 1. A comparison of the design variables and optimal solution is also represented. The degree of decrease in the cost of the beam is shown by the gain, which can be stated mathematically as:

$$\text{Gain } (\%) = \frac{\text{initial cost} - \text{optimal cost}}{\text{initial cost}} \times 100\% \qquad (13)$$

A cost savings of roughly 26% was observed from the design study with the model.

Table 1: Optimization of the design study, showing initial and optimal values.

Design Variables	Initial Design	Optimal Solution
b_f	450	493.8914212
b_w	250	206.3508112
h	500	577.6607185
h_f	125	143
A_s	1979.6121	1200
Cost:	83113.04	61491.88
Gain (%):	26.01416095	

Optimum Cost Due to Varying Span

The span of the beam was incrementally increased from 1 to 10 meters and its cost was optimized at each step. The results from the optimization are show in Table 2.

Table 2: Cost optimization results with varying span lengths.

Span (m)	Original Cost (naira)	Optimized Cost (naira)	Gain (%)
1	36995.14273	36475.86194	1.40365
2	39939.59987	39420.31908	1.30017
3	42884.05701	42364.77622	1.21089
4	45828.51416	45309.23337	1.1331
5	48772.9713	48253.69051	1.06469
6	51717.42844	51198.14765	1.00407
7	54661.88558	54142.6048	0.94999
8	57606.34273	57087.06194	0.90143
9	60550.79987	60031.51908	0.8576
10	63495.25701	62975.97622	0.81783

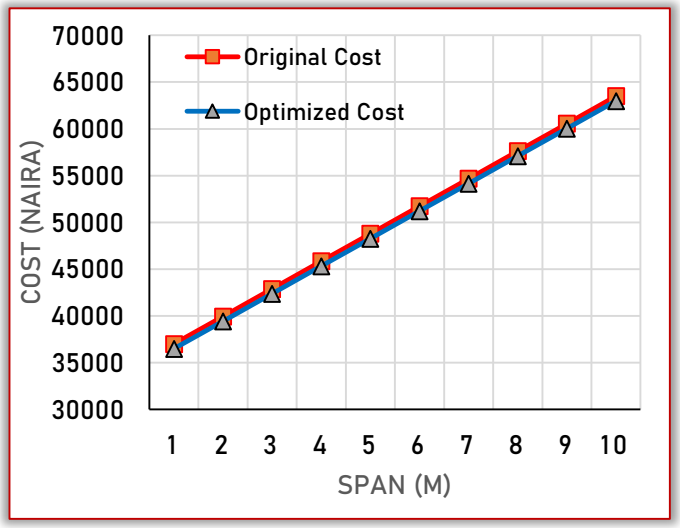

Figure 6: Comparison of costs with the span of the beam.

The resulting optimization offered only very little savings in cost as the difference in the values of the original cost and optimized cost offered maximum gains of 1.4%. From Figure 7, the gains in cost savings reduced from 1.4% to 0.8% as the length of the beams span increased from 1 to 10 meters.

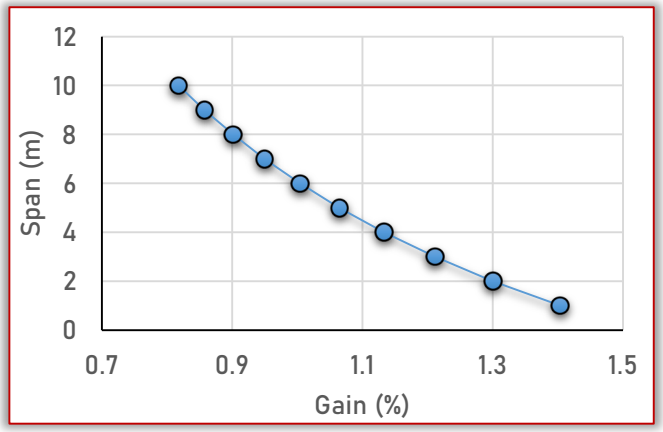

Figure 7: Comparison of beam span with gain

Optimum Cost Due to Varying Design Moment

Unlike the optimization of the beam with increasing span length, there was an increasing difference in the original and optimal costs as the design moment applied on the beam increased. However, when comparing the design moment to the cost gains directly, there is a steady increase in the gains as the imposed moment increases from 200 kNm to 400 kNm. After which the gains reduce as the moment increases to 500 kNm.

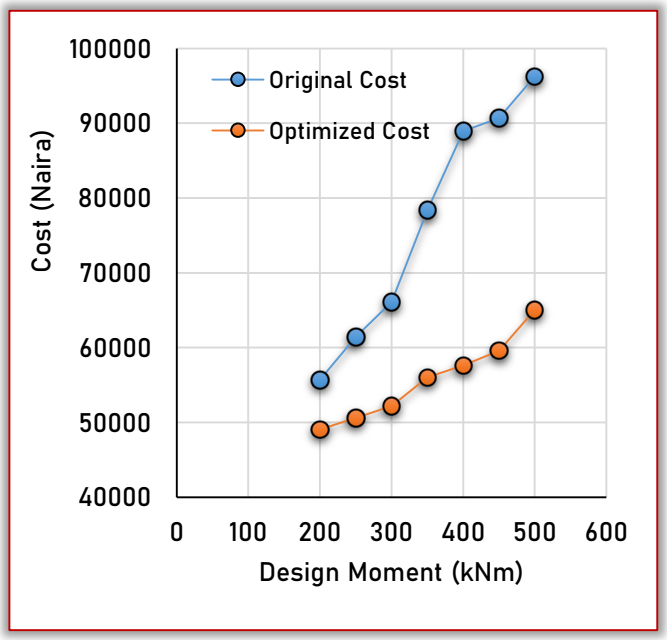

Figure 8: Comparison of costs with the design moment.

Table 3: Cost optimization results with varying design moment loads.

Design Moment (kNm)	Original Cost (naira)	Optimized Cost (naira)	Gain (%)
200	55704.065	49039.484	11.964
250	61432.767	50611.070	17.616
300	66077.004	52182.657	21.028
350	78366.828	56027.879	28.506
400	88953.750	57617.593	35.228
450	90686.835	59576.608	34.305
500	96268.265	65022.480	32.457

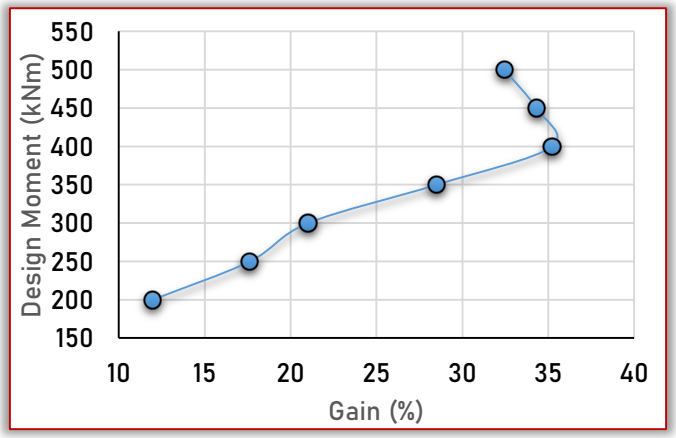

Figure 9: Comparison of design moment with gain.

CONCLUSION

From the procedures developed and results observed, the following can be concluded about the research:

- Minute savings in cost was observed when comparing the optimization of the structure with respect to increasing span. The difference in the values of the original cost and optimized cost offered maximum gains of 1.4%. The gains in cost savings reduced from 1.4% to 0.8% as the length of the beams span increased from 1 to 10 meters.
- Increase in the span of the member led to an increase in the original costs, as well as the optimized costs, even though the latter were smaller than the former.
- There was an increasing difference in the gains as the design moment applied on the beam increased. However, when comparing the design moment to the cost gains directly, there is a steady increase in the gains as the imposed moment increases from 200 kNm to 400 kNm. After which the gains reduce as the moment increases to 500 kNm.

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References

[1] Alex, D. M. and Kottalil, L. (2015). Genetic algorithm Based design of a reinforced concrete cantilever beam. International Research Journal of Engineering and Technology, vol. 2, no.7, pp. 1249 -1252.

[2] Babiker, S. A. , Adam, F. M. and Mohamed, A. E. (2012). Design optimization of reinforced concrete beams using artificial neural network. International Journal of Engineering Inventions, vol. 1, no. 8, pp. 07-13.

[3] Bhalchandra, S. A., and Adsul, P. K. (2012). Cost Optimization of Doubly Reinforced Rectangular Beam Section. International Journal of Modern Engineering Research (IJMER), Vol. 2, Issue. 5, pages 3939-3942.

[4] EuroCode 2 (2004) "Design of concrete structures - Part 1-1: General rules and rules for buildings."

[5] Ildiko, M, Kolbitsch, A., and Kravanja, S. (2010). Cost Optimization of Reinforced Concrete Beams. Proceedings of the Third International Conference on Modelling, Simulation and Applied Optimization Sharjah, U.A.E, January 20-22, 2009.
[6] Ismail, M. A. (2007). Design optimization of structural concrete beams using genetic algorithms. (Master's Thesis). Department of Civil Engineering, Islamic University of Gaza, Gaza.
[7] Salim, T. Y., Ikhlas, S. A., and Saddam, M. A. (2018). Optimum Design of Singly and Doubly Reinforced Concrete Rectangular Beam Sections: Artificial Neural Networks Application. Iraqi Journal of Civil Engineering, Vol. 6, No. 3, pp. 1-19.
[8] Yousif, S. T. and Najem, R. (2013). Optimum cost design of reinforced concrete continuous beams using genetic algorithm. International Journal of Applied Sciences and Engineering Research, vol. 2 no. 1, pp. 79-92.

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CONSIDERATIONS REGARDING CONSTRUCTIVE SOLUTIONS FOR THE REALIZATION OF INSTALLATIONS FOR OBTAINING BIOCHAR

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Abstract: Biochar is a product obtained using thermal conversion of biomass and can be a viable option for the valorization of plant resources. The technology for exploiting plant resources in the form of biochar develops significant potential for improving soil quality, reducing greenhouse gas emissions, and promoting sustainable waste management practices. There are several methods of producing biochar, including slow pyrolysis, fast pyrolysis, and gasification. The choice of technology will depend on factors such as the type and availability of raw materials, the desired end product, and the economic aspects of the process. The process of producing biochar can also generate syngas, a mixture of carbon monoxide and hydrogen that can be used as a fuel.

Keywords: biochar, plant–based resources, pyrolysis, gasification

INTRODUCTION

Biochar is a type of charcoal used for soil improvement or restoration, regardless of whether it comes from wood or unused plant residues (*https://ro.frwiki.wiki/wiki/Biochar)*.

Biochar is obtained by baking any form of organic biomass in a controlled process called gasification (limited oxygen) or pyrolysis (without oxygen) at a high temperature, often above 450 degrees in the absence of oxygen. Biochar has a high carbon content of up to 90% and binds the carbon material reliably, long–term, and without negative side effects. It is characterized by special physical and chemical properties and has a positive effect on biochemical processes. (https://anzbig.org/about/about–biochar/).

Biochar is also known as vegetal charcoal, and in general, it is produced by pyrolysis, which represents a process of chemical transformation or decomposition of organic substances at high temperatures and in the absence of air. It has been established that various biomass materials have been used to produce biochar, which involves agricultural waste, forest waste, garden waste, food waste, manure, sewage sludge, and aquatic organisms (*Woolf et al., 2010; Wu P. et al., 2021; Wu P. et al, 2023*).

Biochar has received increasing attention for its potential benefits in carbon capture, climate change mitigation, waste management, bioenergy production, soil improvement, and pollution control due to its unique properties (*Nidheesh et al., 2021; Xiao et al., 2018, Nenciu et al., 2022*). Biochar has a high content of recalcitrant carbon (C) and a strong capacity for carbon dioxide (CO2) adsorption (*Shafawi AN. et al, 2021; Ma Q. et al, 2021; Cao Y. et al. 2021; Nan Q. et al. 2021*). Its sustainable production and field applications allow for great potential for long–term carbon storage and reducing carbon emissions, thereby mitigating climate change (*Feng et al. 2021; Yang et al. 2021; Zhang et al. 2022; Nenciu et al., 2023*).

The production of coal and biochar has a common root. Before the appearance of fossil coal, the word coal meant – the black fuel made from wood.

The basis of all coal and biochar production is pyrolysis: essentially, the decomposition of wood into its chemical constituents by heat, with or without oxygen. With the development of cylindrical metal vessels and high–temperature refractory materials, various equipment for producing biochar has emerged.

High–quality biochar has high porosity, an extended microstructure, and adsorption capacity that allow for beneficial interactions between microorganisms, nutrients, and water in the soil (*http://www.carbon–negative.us/Burners.htm, https://biocharkilns.com*).

MATERIALS AND METHODS

Biochar is an essential part of the next industrial revolution, creating a more sustainable future and leading to greater economic prosperity, increased job opportunities, and continued quality of life for humanity (Figure 1).

The use of biochar has resulted in improved soil quality and yield in agriculture and horticulture. It is also widely used as an additive for animal feed, can be used in construction materials such

as concrete or asphalt, for air and water purification, helps regulate moisture, absorbs toxins, and promotes beneficial microbial life (Figure 2).

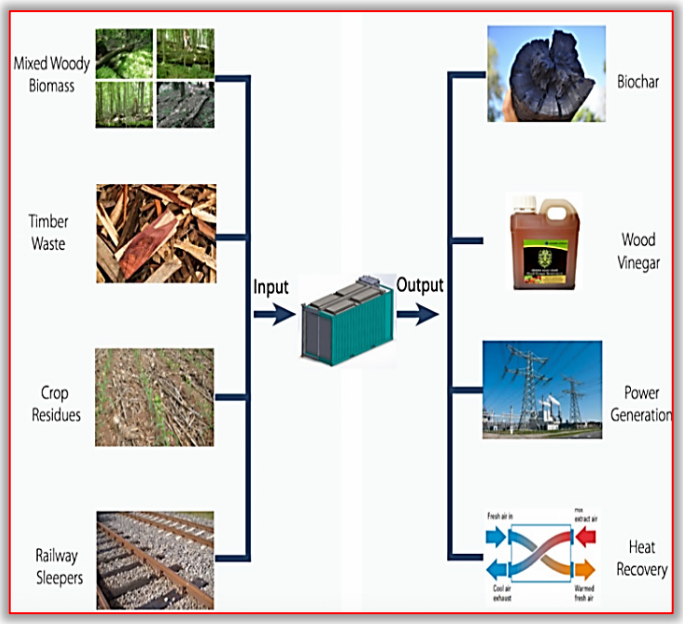

Figure 1 – Presentation of the main transformations of different raw materials (https://anzbig.org/about/about–biochar/)

It is a highly valuable resource and can be an essential part of the next industrial revolution, creating a more sustainable future and paving the way for greater economic prosperity, increased job opportunities, and continued quality of life for humanity. (*https://anzbig.org/about/about–biochar/*)

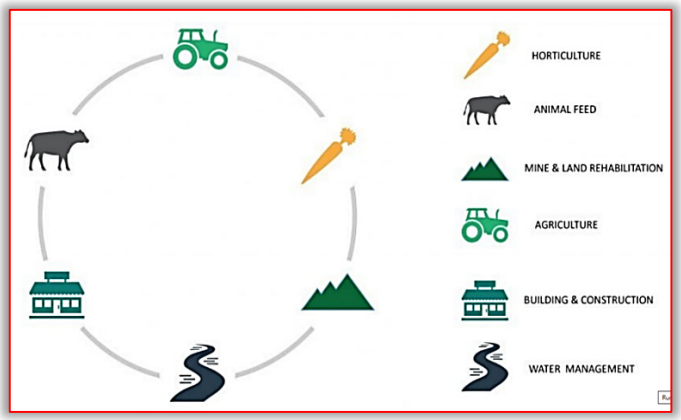

Figure 2 – The main beneficiaries of using biochar (https://anzbig.org/about/about–biochar/)

It is surprising how many people transport their yard waste (renewable biomass) to landfills or burn it in open fires until only ash remains. The technology for obtaining biochar is simple, and any farmer can produce it.

Biochar is similar to traditional charcoal, and they are identical in many respects, but the difference lies mainly in how they are used. Coal is used as fuel, and crushed coal mixed into the soil as soil amendment is biocarbon. As a soil additive, biochar offers numerous benefits. Unlike fertilizers, biochar has an extremely long life in the soil. Coal is rich in carbon and gives it the ability to persist in the soil indefinitely, being not susceptible to biological degradation.

Biochar attracts beneficial microbes and fungi, holds onto nutrients that are introduced into the soil, meaning biochar works better in the second and third year than in the first year. One of the major challenges in agriculture is to make plant nutrients available in the soil when the plant can benefit from them. Fertilizers can often only be applied at the beginning of the growing season, before the crop canopy closes and field operations are no longer feasible. Unfortunately, between the time fertilizer is applied and the crop takes it up, fertilizers can disappear from the soil or lose their characteristics through excess precipitation, consumed by weeds, or metabolized through microbial activity in the soil. Biochar helps conserve plant nutrients by storing them in its matrix and making them available when the crop needs them. This happens because of a property of biochar, certain clays, and organic matter in the soil known as cation exchange capacity.

This property, the cation exchange capacity (CEC), is a measure of the biochar's ability to retain ions, such as ammonium and potassium cations, in an exchangeable form that is available to plants. CEC not only helps conserve fertilizers added to the crop during the growing season, but also enhances the soil's capacity to capture and retain nutrients from other available sources at other times. For example, at the end of the growing season, crop residues are often left in the fields to decompose. When this organic matter decomposes, biochar captures some of the released nutrients, leaving these nutrients for the next growing season.

Biochar in the soil also has the ability to retain soil moisture, leading to significant cost savings in irrigation (*Mansoor S. et al. 2021; Zhu H. et al, 2020*). Biochar alters soil performance by retaining moisture and making it available during periods of low rainfall and warm and dry soil conditions. This is possible because biochar have very large internal surfaces. This internal surface absorbs moisture when water availability in the soil is high and releases it back into the soil when water availability is low. One might think that biochar, being black in color, heats up from the sun, but biochar helps keep the soil moist even in full sunlight.

Biochar also has a significant impact on soil drainage. Clayey soils, which are usually poorly aggregated, are too compact and do not drain efficiently. Inefficient drainage results in long periods of inadequate soil aeration. Other soils, especially sandy soils, can drain too efficiently. Excessively efficient drainage can shorten the benefits of periodic watering.

In both cases, adding biochar compensates for the deficiencies of the soil: clayey and poorly aggregated soils become less compacted and provide better aeration, and sandy soils gain additional moisture storage capacity.

Biochar also makes a significant contribution to mycorrhiza by promoting microbiota populations. Mycorrhiza is a fungus that has a symbiotic relationship with plant roots and contributes to a healthy exchange of soil–plant nutrients.

In a world dependent on fossil energy, it is easy to see the benefits of biochar carbon capture as compensation for current and future emissions from fossil fuels. Experts in the field believe that there is already an excess of carbon dioxide in the atmosphere, which requires measures to reduce it. It has been established that the main factors contributing to the increase of carbon dioxide, about 34% of emissions, have been attributed to land deforestation.

Therefore, in a way, the primary objective of biochar is to restore lost carbon to the soil due to decades of agricultural practice. After that, the exceptional durability of biochar will allow for the accumulation of more carbon in the soil, with additional fertility benefits.

Coal and biochar have the potential to sequester gigatons of atmospheric carbon per year, making it the most powerful atmospheric cleaning engine we have. If only a small portion of the carbon captured by plants can be pyrolyzed and transformed into coal (biochar), humanity's prospects will be much better, making a transition to a lower carbon emission economy. *(http://www.carbon–negative.us/Burners.htm, https://biocharkilns.com/)*

Among the main equipment used for producing biochar, we can mention:

- Ovens are commonly used for small–scale biochar production and can be constructed from a variety of materials, including brick, steel, or concrete. Ovens can be powered by a variety of heat sources, including wood, propane, or electricity.
- Slow pyrolysis reactors are used for the production of biochar on a larger scale and can be built from materials such as steel, concrete, or ceramics. Slow pyrolysis reactors are often heated using wood or other biomass as a heat source.
- Fast pyrolysis reactors are used for the production of large volumes of biochar and can be built from materials such as steel or ceramics. Fast pyrolysis reactors are fuelled by high–temperature heat sources such as gas or oil.
- Raw material preparation equipment: Biochar production requires the use of organic raw materials, which must be prepared before pyrolysis. This may include equipment for grinding, drying, or pelletizing raw materials.
- Systems used in biochar exploitation: Soil amendment systems for incorporating biochar into the soil can include equipment for mixing biochar into soil, compost, or other organic materials, as well as tools for applying the mixture to fields or gardens.

Carbon sequestration systems for burying biochar in soil or incorporating it into products may include specialized equipment for mixing and applying biochar, as well as tools for monitoring and measuring carbon sequestration over time.

Research on the thermochemical processing of vegetable waste obtained from agriculture has shown that advanced technologies can produce superior chemical compounds, biofuels and significantly reduce the negative impact on the environment (*Nenciu F. et al. 2022; Mircea, C. et al. 2020*).

Bioenergy production systems for using biochar as a fuel or feedstock can include boilers, combustion systems, or reactors for converting biochar into bio–oil or other bioenergy products (*Chi NTL. et al. 2021; ChoS–H. et al. 2021; Low YW. and Yee KF. 2021*).

RESULTS

In figures 3 a) and 3 b), a simple setup can be observed, a container in which the plant mass is burned, and biochar is obtained after the combustion.

The advantage of this biochar production system is that it can be implemented in small households by all farmers who want to use this product called biochar.

One version of an Australian company for producing biochar is presented in Figure 4, called Carboniser (Exeter Retort Kiln). The raw material used for heating the retort is biomass.

Figure 3 – a) and b) – simple small–scale production system in open field: a) Biomass burning; b) Biochar obtained after burning

Figure 4 – Fixed unit for biochar production – Carboniser

This system converts woody waste into a valuable soil amendment called BIOCHAR and can also produce cooking charcoal. These biochar production units are much more environmentally friendly than traditional kilns because they emit fewer harmful emissions (*https://www.facebook.com/*).

In figure 5a) a mobile unit for producing charcoal and biochar can be seen, which can be transported to the location where the raw material (woody waste) is located, as shown in figure 5b). The weight of such a mobile unit is 1860 kg, and it has the advantage of being easily towed. The overall dimensions of the assembly are: 3737 mm in length x 2200 mm in width x 2400 mm in height, plus 1.5 m for the furnace chimney.

The oven is completely insulated with ceramic material to operate in any type of climate. The oven has a capacity of 1.7 cubic meters. The burning time is approximately 8 hours depending on the type of wood used as raw material. The amount of material obtained after burning is about 170 kg. The raw material used for burning, also called pyrolysis (*Dutta S. et al. 2021; Lian F. et Xing B. 2017, Mircea et al., 2022; Oprescu et al., 2023*), can be made from any type of wood, from logs to twigs.

Figure 5 – a) and b) Mobile biochar production unit (https://www.biocharretort.com/): a) Mobile coal and biochar production plant; b) The finished product obtained after firing

In operation, it releases up to 75% fewer pollutants than conventional variants, and ash and waste are reduced to zero. The temperature used in the pyrolysis process is controlled with the help of an integrated digital thermometer. It has loading and unloading doors at both ends for quick access and is also easy to handle – no special skills are required (*https://www.biocharretort.com/*).

Biochar is of increasing interest due to concerns about climate change caused by carbon dioxide (CO2) and other greenhouse gas (GHG) emissions. Biochar is a way in which carbon can be extracted from the atmosphere and is a solution to reduce the global impact of agriculture (and all agricultural waste). Because biochar can capture carbon from the soil for hundreds to thousands of years, it has received considerable interest as a potential tool to slow global warming.

The burning and natural decomposition of trees and agricultural matter contribute a large amount of CO2 released into the atmosphere. Biochar can store this carbon in the soil, which can lead to a significant reduction in GHG levels in the atmosphere; at the same time, its presence in the soil can improve water quality, increase soil fertility, and increase agricultural

productivity. Biochar is biomass (wood, leaves, straw, or other biosolids) heated to high temperatures without oxygen. This process, known as pyrolysis, concentrates carbon in a form that is highly resistant to biological decomposition. When applied to soil and other products, much of its carbon content is sequestered for over 100 years (*https://biocharkilns.com/biochar/*).

The BKI ovens are now lined with refractory ceramics and equipped with an arm crane to load and unload the base material and lift the insulation cover, as shown in figure 6.

Figure 6 – BKI–type ovens, assembly view
(https://biocharkilns.com/biochar/)

In Figure 7 a) and b), a mobile biochar production plant and a biochar grinding plant can be seen, which can be manually adjusted to produce particles between 2 and 20 mm.

The combustion vessel can have a capacity of up to 3 cubic meters and is also equipped with a temperature indicator (*https://biocharkilns.com/*).

Biochar has a microporous structure and also chemically attracts organic molecules and water and tends to hold them in place. In order to make them available to plants, it must be softened or saturated with all these elements before entering the soil, otherwise it will compete with plants for water, microbes, and nutrients and may harm plants if used in its raw state. Therefore, we recommend mixing biochar with soil or a good active organic compost before it reaches the soil, so that it can absorb its full complement of water, nutrients, and microbes, so that it can make them immediately available to plants once it is added to the soil. Final concentrations after repeated application of biochar will function up to approximately 8 to 10% biochar by weight of the soil content (Peter Hirst, New England Biochar).

Figure 7 a) and b) – Bio Feeder mobile pyrolysis unit
(https://biocharkilns.com/products/):
a) Bio Feeder overview; b) Biochar crushing plant

Biochar also attracts organic molecules and water, tending to hold them in place. In order to make them available to plants, it must be soaked or saturated with all of these elements before being introduced into the soil, otherwise it will compete with plants for water, microbes, and nutrients and may harm plants if used in its raw state. Therefore, is recommended mixing biochar with soil or a good active organic compost before it reaches the soil, so that it can absorb its full complement of water, nutrients, and microbes, so that it can immediately make them available to plants as soon as it is added to the soil.

Final concentrations after repeated application of biochar will function up to about 8 to 10% biochar by weight of soil content (*Peter Hirst, New England Biochar*). The pyrolysis of wood in such a device practically takes place in 4 different stages: evaporation of the moisture present in the wood occurs as the initial phase, up to an average temperature of 170°C (338°F). At this stage, gas production is minimal. As the fire builds up inside the kiln, the temperature rises and at around 280°C (536°F) the exothermic reaction begins. Gas consisting almost entirely of

carbon monoxide and carbon dioxide is released, and a certain amount of acetic acid is formed together with small amounts of wood naphtha and tar. Then, the exothermic reaction continues during which the carbon concentration in biochar takes place. Large amounts of hydrocarbons, acetic acid, and wood naphtha and tar are produced, while temperatures rise to 380 to 400°C (716 to 752°F) (*https://biocharkilns.com/biochar/*).

(a) (b)

(c)

Figure 8 – a), b), c) – Mobile Bio Feeder pyrolysis unit with a capacity of 3 cubic meters *(https://biocharkilns.com/biochar/)*: a) wood; b) biochar; c) Overall view of the mobile unit

The weight of biomass can vary from softwood, hardwood logs to bamboo, and the moisture content also varies. Depending on the size and air gaps between the branches, it is better to speak only from a volume perspective when determining the amount of biochar, as it may weigh more on a wet day.

Often, mixing biochar with water is preferred to inoculate and protect microorganisms, so the weight will vary. Due to the presence of water and its natural evaporation, biochar should never be evaluated based on weight. In figure 8, we have a mobile pyrolysis unit with a capacity of 3 cubic meters, figure 8 c) and images of the material used to obtain biochar (figure 8 a) and the final product obtained, biochar, figure 8 b) (*https://biocharkilns.com/biochar/*).

CONCLUSIONS

The production and operation of biochar require the use of specialized equipment and systems, including ovens, pyrolysis reactors, raw material preparation equipment, soil amendment systems, carbon retention systems, and bioenergy production systems.

The choice of equipment design and systems will depend on the specific requirements of the biochar production and operation process, as well as the size and scope of the operation. The use of biochar in agriculture can be a profitable long–term investment, although the initial costs for biochar production and application in soil may be higher than those of other organic or mineral amendments, the long–term benefits of using biochar can offset these costs.

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References

[1] Cao Y, Shan Y, Wu P, Zhang P, Zhang Z, Zhao F, Zhu T (2021) Mitigating the global warming potential of rice paddy fields by straw and straw–derived biochar amendments. Geoderma 396:115081

[2] Chi NTL, Anto S, Ahamed TS, Kumar SS, Shanmugam S, Samuel MS, Mathimani T, Brindhadevi K, Pugazhendhi A (2021) A review on biochar production techniques and biochar based catalyst for biofuel production from algae. Fuel 287:119411

[3] Cho S–H, Jung S, Park Y–K, Lin K–YA, Chen W–H, Tsang YF, Kwon EE (2021) Biofuel production as an example of virtuous valorization of swine manure. ACS Sustain Chem Eng 9:13761–13772

[4] Dutta S, He M, Xiong X, Tsang DCW (2021) Sustainable management and recycling of food waste anaerobic digestate: a review. Bioresour Technol 341:125915

[5] Feng D., Guo D., Zhang Y., Sun S., Zhao Y., Chang G., Guo Q., Qin Y. (2021) Adsorption–enrichment characterization of CO2 and dynamic retention of free NH3 in functionalized biochar with H2O/NH3·H2O activation for promotion of new ammonia–based carbon capture. Chem Eng J 409:128193

[6] Lian F., Xing B. (2017) Black carbon (Biochar) in water/soil environments: molecular structure, sorption, stability, and potential risk. Environ Sci Technol 51:13517–13532

[7] Low Y.W., Yee K.F. (2021) A review on lignocellulosic biomass waste into biochar–derived catalyst: current conversion techniques, sustainable applications and challenges. Biomass Bioenerg 154:106245

[8] Ma Q., Chen W, Jin Z., Chen L., Zhou Q., Jiang X. (2021) One–step synthesis of microporous nitrogen–doped biochar for efficient removal of CO2 and H2S. Fuel 289:119932

[9] Mansoor S, Kour N, Manhas S, Zahid S, Wani OA, Sharma V, Wijaya L, Alyemeni MN, Alsahli AA, El–Serehy HA, Paray BA, Ahmad P (2021) Biochar as a tool for effective management of drought and heavy metal toxicity. Chemosphere 271:129458

[10] Mircea, C.; Nenciu, F.; Vlăduţ, V.; Voicu, G.; Cujbescu, D.; Gageanu, I.; Voicea, I. (2020). Increasing the performance of cylindrical separators for cereal cleaning, by using an inner helical coil. INMATEH Agric. Eng., 62, 249–258.

[11] Nan Q., Xin L, Qin Y, Waqas M, Wu W (2021) Exploring long–term effects of biochar on mitigating methane emissions from paddy soil: a review. Biochar 3:125–134.

[12] Nenciu F., Fatu V., Arsenoaia V., Persu C., Voicea I., Vladut N–.V., Matache MG, Gageanu I, Marin E, Biris S–S, et al. (2023). Bioactive Compounds Extraction Using a Hybrid Ultrasound and High–Pressure Technology for Sustainable Farming Systems. Agriculture. 13(4):899
[13] Nenciu, F.; Paraschiv, M.; Kuncser, R.; Stan, C.; Cocarta, D.; Vladut, V.N. (2022). High–Grade Chemicals and Biofuels Produced from Marginal Lands Using an Integrated Approach of Alcoholic Fermentation and Pyrolysis of Sweet Sorghum Biomass Residues. Sustainability 14, 402
[14] Nenciu F., Voicea I., Cocarta D.M., Vladut V.N., Matache M.G., Arsenoaia V.–N. (2022). "Zero–Waste" Food Production System Supporting the Synergic Interaction between Aquaculture and Horticulture. Sustainability, 14(20):13396
[15] Nenciu F., Stanciulescu I, Vlad H, Gabur A., Turcu O.L., Apostol T., Vladut V.N., Cocarta D.M., Stan C. (2022). Decentralized Processing Performance of Fruit and Vegetable Waste Discarded from Retail, Using an Automated Thermophilic Composting Technology. Sustainability. 14(5):2835
[16] Nidheesh P.V., Gopinath A., Ranjith N., Praveen Akre A., Sreedharan V., Suresh Kumar M. (2021). Potential role of biochar in advanced oxidation processes: a sustainable approach. Chem Eng J 405:126582
[17] Oprescu M.R., Biris S–S., Nenciu F. (2023) Novel Furrow Diking Equipment–Design Aimed at Increasing Water Consumption Efficiency in Vineyards. Sustainability. 15(4):2861
[18] Shafawi A.N., Mohamed A.R., Lahijani P., Mohammadi M. (2021) Recent advances in developing engineered biochar for CO2 capture: an insight into the biochar modification approaches. J Environ Chem Eng 9:106869
[19] Woolf D., Amonette J.E., Street–Perrott F.A., Lehmann J., Joseph S. (2010) Sustainable biochar to mitigate global climate change. Nat Commun
[20] Wu P., Bhupinder Pal Singh, Hailong Wang, Zhifen Jia, Yujun Wang and Wenfu Chen (2023) Bibliometric analysis of biochar research in 2021: a critical review for development, hotspots and trend directions. Biochar 5, 6)
[21] Wu P., Wang ZY, Bolan N.S., Wang H.L., Wang Y.J., Chen W.F. (2021) Vizualizarea tendinței de dezvoltare și a frontierelor de cercetare ale biocharului în 2020: o perspectivă scientometrică. Biochar 3:419–436
[22] Xiao X., Chen B., Chen Z., Zhu L., Schnoor J.L .(2018) Insight into multiple and multilevel structures of biochars and their potential environmental applications: a critical review. Environ Sci Technol 52:5027–5047
[23] Yang Q., Zhou H., Bartocci P., Fantozzi F., Masek O., Agblevor FA, Wei Z., Yang H., Chen H., Lu X., Chen G., Zheng C., Nielsen C.P., McElroy M.B. (2021) Prospective contributions of biomass pyrolysis to China's 2050 carbon reduction and renewable energy goals. Nat Commun 12:1698
[24] Zhang X., Yang X., Yuan X., Tian S., Wang X., Zhang H., Han L. (2022) Effect of pyrolysis temperature on composition, carbon fraction and abiotic stability of straw biochars: correlation and quantitative analysis. Carbon Res 1:00017
[25] Zhu H., Yang J., Yao R., Wang X., Xie W., Zhu W., Liu X., Cao Y., Tao J. (2020) Interactive effects of soil amendments (biochar and gypsum) and salinity on ammonia volatilization in coastal saline soil. CATENA 190:104527
[26] *** (https://biocharkilns.com/products/)
[27] *** Peter Hirst, New England Biochar
[28] *** http://www.carbon–negative.us/Burners.htm
[29] *** https://biocharkilns.com/biochar/
[30] *** https://www.biocharretort.com/
[31] *** https://www.facebook.com/photo)
[32] *** https://anzbig.org/about/about–biochar/
[33] *** http://www.carbon–negative.us/Burners.htm
[34] *** https://ro.frwiki.wiki/wiki/Biochar
[35] *** https://biocharkilns.com/2011/01/09/biochar–as–a–soil–amendment–and–carbon–sequestering–tool/

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RESEARCH REGARDING THE INFLUENCE OF GENOTYPE AND EPOCH OF SOWING ON SEEDS YIELD AT CHICKPEAS (*CICER ARIETINUM* L.) IN THE PEDO–CLIMATIC CONDITIONS OF CENTRAL MOLDOVA

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Abstract: The agronomic importance of the chickpea crop is given by the improvement of soil fertility by fixing atmospheric nitrogen, the resistance to drought and high temperatures, the resistance to falling and the fact that the pods do not burst at maturity. These advantageous features reduce losses during harvesting. The present paper presents data on the influence of genotype and epoch of sowing at Cicer arietinum L. (chickpeas). The researches were organized in 2021–2022 at the Agricultural Research and Developement Station Secuieni, Neamt County. The genotypes tested in the first year of experimentation showed a high adaptability to the pedoclimatic conditions of the area, thus obtaining productions around 2100 kg/ha. Compared to the first year of experimentation, in 2022 the productions were lower, noting that the lowest production was recorded in the Kaffe variety (1796 kg/ha), and the highest in the Burnas variety (2031 kg/ha). This paper presents new data on the improvement the optimal epoch of sowing in a particular zone for optimising the seeds production obtained at chickpeas.

Keywords: chickpeas, seed, genotype, epoch of sowing, yield

INTRODUCTION

Chickpea (*Cicer arietinum* L.) ranks third among the most cultivated legumes in the world, after beans and peas (*Ohri D., 2016*). It is cultivated worldwide in about 57 countries under varying environmental conditions (*MoEF&CC 2016,*). In South and Southeast Asia chickpea production dominates with 80% of the regional contribution. Although developed countries do not contribute much to chickpea production, the yield is particularly high in some Eastern European countries.

Chickpeas is traditionally cultivated in semi–arid tropical (Asia, Australia and India) and Mediterranean regions and has recently expanded its cultivation area to higher latitudes (*Yartsev G. F. et al., 2021*). It is a microthermic plant, which grows and develops well in the conditions of a warm and semi–arid climate. In the regions of the world where chickpea grows, the average maximum temperature ranges from 21 to 29 °C during the day and from 15 to 25 °C at night (*Daba K. et al., 2016,*). In our country, this culture meets favorable conditions for growth and development and could in the future have an even greater extension, because the temperatures during the summer are high and the possibilities of irrigation of the crops are minimal.

Chickpea is a valuable crop that provides nutritious food for an expanding world population and will become increasingly important with climate change (*Muehlbauer and Sarker, 2017*). Chickpea plays a leading role in world food security, covering the protein deficiency in the daily food ration of Indian and African populations without compromising the quality of nutrition (*Malunga L.N. et al., 2014*).

The agronomic importance of the chickpea crop is given by the improvement of soil fertility by fixing atmospheric nitrogen, the resistance to drought and high temperatures, the resistance to falling and the fact that the pods do not burst at maturity. These advantageous features reduce losses during harvesting.

The optimum sowing time for chickpea depends on the interaction between the environment and the genotype used at sowing. Current chickpea genotypes have excellent frost tolerance but average daily temperature below 15 ^{0} C has been shown to cause flower abortion (*Chen Y. et al., 2017*).

In some countries the optimum sowing date results in flowering when the risk of low temperatures is high and it is particularly important to avoid frost during flowering as it can kill chickpea plants (*Kolesnikov A. A. et al., 2022*). Earlier sowing may expose the crop to more

rainfall which may increase the risk of *Ascochyta rabies* – chickpea anthracnose which has been reported to be the most destructive disease in 32 countries (*Ramirez M.L. et al. 2018, Ryley M. et al., 2015*). It will also increase crop biomass, thus increasing the risk of gray mold (*Botrytis*) and soil moisture deficit during grain filling.

Also, sowing later can result in shorter plants that will be more difficult to harvest but reduce the risk of downy mildew (*Lake L. and Sadras V.O., 2014*). The minimum germination temperature of the chickpea crop is 3–4 ^{0} C in cold areas and in the Mediterranean area the germination temperature is between 20 ° C and 30 ° C and the emergence of seedlings takes place in these conditions, from five to six days after seeding (*Nascimento W.M. et al., 2016*).

Optimal sowing time provides more time for plant growth and development, which is favorable for higher yield. Also, sowing chickpeas at the optimal time ensures a better harmony between the soil, the plant and the atmospheric system, and is also a critical factor influencing production. The highest production depends on the date of sowing (*Merga B. and Haji J., 2020, Verma M.M. et al., 2014*).The season for sowing chickpeas in the conditions of our country is early spring when the soil, at the sowing depth, reaches 3–4 ^{0} C. A delay of 10 days compared to the optimal season can reduce production by 20% *(Nascimento W.M. et al., 2016*).

This paper presents new data on the improvement the optimal epoch of sowing in a particular zone for optimising the seeds production obtained at chickpeas.

MATERIALS AND METHODS

The purpose of the research carried out at the Secuieni Agricultural Research – Development Station was to study the influence of technological factors such as: genotype and epoch of sowing. The experiments aimed to identify the genotype with the highest adaptability to climatic conditions in the area of influence and establish the optimal time to sow.

The placement was performed in the experimental field of the A.R.D.S. Secuieni, on a soil of the faeoziom (chernozem) typical cambic with medium texture, acid: pH H_2O – 5.98, characterized as: well supplied in phosphorus (77.6 ppm PAL), Ca (13.6 meq / 100 g soil Ca) and Mg (1.8 meq / 100 g soil Mg), medium supplied with active humus (1.88%) and nitrogen (16.2 ppm N–NO_3) and poorly supplied with potassium (124.6 ppm K_2O) (*Lupu Cornelia, 2017; Mîrzan Oana, 2020*).

The experiment was placed according to the method of subdivided plots, in three repetitions of type A x B, and the experimental factors studied were: A – genotype (a_1 – Kaffe, a_2 – Burnas, a_3 – Orion) and B – epoch of sowing (b_1 – sown in the second decade of March, b_2 – sown in the third decade of March, b_3 – sown in the first decade – April). The studied biological material included a Romanian chickpeas variety, Burnas and two foreign varieties, Kaffe and Orion.

The obtained results were processed and interpreted statistically according to the method of analysis of variance.

From a climatic point of view, the vegetation period, in the two year of experimentation, was characterized as hot from a thermal point of view and dry from a pluviometric point of view. The year 2021 was characterized as a warm and dry; the annual amount of rainfall that was unevenly distributed during the growing season of chickpeas. The monthly averages of temperatures recorded during the vegetation period were similar to the multiannual average, the deviations being between 0.4^0 C in June and 1.8^0 C in July. From a pluviometric point of view, the precipitations were lower than the multiannual average, registering deviations of – 23.8 mm in April and – 31.4 mm in May (*Table 1 and Table 2*).

Table 1. Temperatures recorded at A.R.D.S. Secuieni meteorological station

Average temperature °C	Months								Average vegetation period
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
2021	–0.7	–0.4	2.9	7.5	14.7	19.2	22.2	20.5	10.7
2022	–0.1	2.6	2.7	9.5	16.3	20.7	22.2	22.7	12.1
Multiannual average	–3.9	–2.2	2.8	9.5	15.4	18.8	20.4	19.5	10.03

The year 2022 was characterized by hot weather in terms of temperatures and dry in terms of rainfall. The spring was normal thermally, the monthly temperature deviations were between – 0.1℃ (March) and 0.9℃ (May) (*Table 1*).

Regarding precipitation, the amounts of water that fell were reduced in January (5.4 mm) and February (4.6 mm), these months being characterized as very dry. Rainfall in April (38.4 mm) helped the chickpea crop to sprout, and that in June (56.6 mm) to continue its development. In May, a significant rainfall deficit of – 44.9 mm was recorded (*Table 2*).

Throughout the vegetation period of chickpeas crop, the deviations from the multiannual average were different. The distribution of

precipitation was extremely uneven, on the phenophases of growth and development of the plant (*Table 2*).

Table 2. Rainfall recorded at A.R.D.S. Secuieni meteorological station

Rainfall (mm)	Months								Sum for the vegetation period
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
2021	12.2	10.8	31.8	23.8	31.4	79.4	51.6	76.8	317.8
2022	5.4	4.6	0.8	38.4	20.8	56.6	35.2	15.2	177.0
Multiannual average	20.1	19.5	26.9	46.9	65.7	85.0	82.3	60.2	406.6

RESULTS

The genotypes tested in the first year of experimentation showed a high adaptability to the pedoclimatic conditions of the area, thus obtaining productions around 2100 kg/ha. The influence of the genotype on the yield of seeds obtained from chickpeas, in 2021, materialized by obtaining fluctuating yields, between 2022 kg/ha (Kaffe) and 2249 kg/ha (Burnas) (*Table 3*). Compared the yields obtained with the average experience (control), we notice that the Burnas variety (91 kg/ha) obtained a statistically assured yield increase and interprete positive very significant and Orion variety (45 kg/ha) recorded a production statistically interpreted as distinctly significant. The Kaffe variety achieved a yield difference (–136 kg/ha) ensured statistically and interpreted as very significant negative (*Table 3*).

Table 3. The influence of genotype on seed yield at *Cicer arietinum* L., 2021

Variety	Yield (kg/ha)	% compared to control	Difference (kg/ha)	Significance
Kaffe	2022	93,69	–136	ooo
Burnas	2249	104,21	91	***
Orion	2203	102,08	45	**
Average	2158	100	Ct.	
LSD 5% =		25,24 kg/ha		
1% =		36,30 kg/ha		
0,1%=		55,72 kg/ha		

Table 4. The influence of genotype on seed yield at *Cicer arietinum* L., 2022

Variety	Yield (kg/ha)	% compared to control	Difference (kg/ha)	Significance
Kaffe	1796	93,10	–133	ooo
Burnas	2031	105,28	102	***
Orion	1961	101,65	32	*
Average	1929	100	Ct.	
LSD 5% =		26,41 kg/ha		
1% =		38,01 kg/ha		
0,1% =		59,21 kg/ha		

Compared to the first year of experimentation, in 2022 the productions were lower, noting that the lowest production was recorded in the Kaffe variety (1796 kg/ha), and the highest in the Burnas variety (2031 kg/ha). Orion and Burnas varieties stood out with yield increases of 32 kg/ha, respectively 102 kg/ha, significant and very significant compared to the average experience (control) (*Table 4*).

The average of the two years, indicates the fact that the Burnas variety has the greatest adaptability to the conditions of the area. Compared to the control variant (average experience), this variety achieved a very significant increase in yield (96 kg/ha) (*Table 5*).

Table 5. The influence of genotype on seed yield at *Cicer arietinum* L., average years

Variety	Yield (kg/ha)	% compared to control	Difference (kg/ha)	Significance
Kaffe	1909	93,39	–135	ooo
Burnas	2140	104,69	96	***
Orion	2082	101,85	38	*
Average	2044	100	Ct.	
LSD 5% =		25,82 kg/ha		
1% =		37,15 kg/ha		
0,1% =		57,46 kg/ha		

The second sowing season positively influenced the seed yield, and its level was influenced by the climatic conditions recorded in the analyzed period. In the agricultural year 2021, the yield fluctuations were quite large, the yields obtained varied from 2094 kg/ha (the third epoch of sowing) to 2202 kg/ha (the second epoch of sowing). From a statistical point of view, compared to the control (average of experience) the variant sown in the third epoch achieved a very significant negative production difference (– 64 kg/ha). However, the variants sown in the first and the second epoch obtained distinctly significant and very significant yield increases (20 – 44 kg/ha) compared to the control (*Table 6*).

Table 6. The influence of sowing epoch on seed yield at *Cicer arietinum* L. 2021

Epoch of sowing	Yield (kg/ha)	% compared to control	Difference (kg/ha)	Significance
Ist epoch	2178	100,92	20	**
IInd epoch	2202	102,03	44	***
IIIrd epoch	2094	97,03	–64	ooo
Average	2158	100	Ct.	
LSD 5% =		14,20 kg/ha		
1% =		22,38 kg/ha		
0,1% =		32,47 kg/ha		

In the second year of experimentation (2022), the yields obtained were smaller and between 1864 kg/ ha (the third epoch of sowing) and 1989 kg/ha (the second epoch of sowing). Compared to the control (average of experience) the variants sown in the third epoch achieved very significant negative production differences (–65 kg/ha), the variant sown in the second epoch achieved a very significant increase in production (60 kg/ha) (*Table 7*).

Table 7. The influence of sowing epoch on seed yield at *Cicer arietinum* L. 2022

Epoch of sowing	Yield (kg/ha)	% compared to control	Difference (kg/ha)	Significance
I[st] epoch	1934	100,25	–5	
II[nd] epoch	1989	103,11	60	***
III[rd] epoch	1864	96,63	–65	ooo
Average	1929	100	Ct.	
LSD 5% =		13,52 kg/ha		
1% =		21,98 kg/ha		
0,1% =		33,97 kg/ha		

During the experimental period (2021–2022), the highest production increases (52 kg/ha), compared to the control were obtained for the varietie sown in the second epoch, resulting in chickpea responding favorably for sowing by until until the beginning of April.

Table 8. The influence of sowing epoch on seed yield at *Cicer arietinum* L. average years

Epoch of sowing	Yield (kg/ha)	% compared to control	Difference (kg/ha)	Significance
I[st] epoch	2056	100,58	12	
II[nd] epoch	2096	102,54	52	***
III[rd] epoch	1979	96,81	–65	ooo
Average	2044	100	Ct.	
LSD 5%=		13,86 kg/ha		
1%=		22,18 kg/ha		
0,1%=		33,22 kg/ha		

In the variant sown in the third epoch, a very significant production deficit of 65 kg / ha was obtained, compared to the witness of the experience, which we deduce that it is necessary to sow the chickpea no later than the third decade of March, because the seeds do not reach maturity (*Table 8*).

CONCLUSIONS

The natural environment of the Secuieni Agricultural Research – Development Station is favorable for field crops, where in normal years as temperatures high yields are obtained for all crops established within the company, the future of which is also the chickpea crop.

The average of the two years, indicates the fact that the Burnas variety has the greatest adaptability to the conditions of the area.

During the study period (2020–2021), the highest production increases (52 kg/ha), compared to the control were obtained for the varieties sown in the second epoch, which means that chickpea is favorable for sowing until the first decade of April.

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References

[1] Chen, Y., Ghanem, M.E., and Siddique, K.H.M. (2017). Characterising root trait variability in chickpea (Cicer arietinum L.) germplasm. Journal of Experimental Botany 68, 1987–1999.
[2] Daba, K., Warkentin, T.D., Bueckert, R., Todd, C.D., and Tar'an, B. (2016). Determination of photoperiod–sensitive phase in chickpea (Cicer arietinum L.). Frontiers in Plant Science 7:478, 1–10.
[3] Kolesnikov A. A, Yartsev G., Bayikasenov R. K, Brazhnikova A. A, Kartabaeva B. B. (2022) – Crop structure and yield of chickpeas of the Krasnokutsky variety 36 depending on seeding rates and sowing methods in the conditions of the central zone of the Orenburg region Improvement of engineering and technical support of production processes and technological systems: materials of the national scientific and practical conference, with international participation (Orenburg: LLC "Printing House "Agency Press") p 31–34.
[4] Lake, L., and Sadras, V.O. (2014). The critical period for yield determination in chickpea (Cicer arietinum L.). Field Crops Research 168, 1–7.
[5] Lupu Cornelia, (2017) – Climatic characterization of the agricultural area in the sphere of influence at A.R.D.S. Secuieni – Neamț (1962–2016), Ed. Ion Ionescu de la Brad, Iași, pp. 34–35.
[6] Malunga, L.N., Bar–El, S.D., Zinal, E., Berkovich, Z., Abbo, S., Reifen, R. (2014) – The potential use of chickpeas in development of infant follow–on formula. Nutrition Journal, 13(1), 8.
[7] Mîrzan Oana, Naie, M., Leonte, A., Bostan, M., Mîrzan, B., (2020) – Researches regarding the influence of the technological factors on the biology of the species and seed yields at Carthamus tinctorius L. in A.R.D.S. Secuieni. Lucrări Științifice, seria Agronomie, 63(1): 79–82.
[8] Merga B. and Haji J., (2020) – Economic importance of chickpea: production, value, and world trade. Cogent Food Agric., 5 (1) (2020), Article.
[9] MoEF&CC (2016). Biology of Cicer arietinum (Chickpea). (New Delhi: Government of India, Ministry of Environment, Forest and Climate Change).
[10] Muehlbauer, F.J.; Sarker, A. (2016) – Economic importance of chickpea: production, value, and world trade. In:
[11] Nascimento, W.M.; Silva, P.P.; Artiaga, O.P.; Suinaga, F.A. (2016) – Grão–de–bico. In: Nascimento, W.M. Hortaliças Leguminosas. Brasília: Embrapa Hortaliças, p.89–118.
[12] Ohri, D. (2016). Genetic resources of chickpea (Cicer arietinum L.) and their utilization. In Gene Pool Diversity and Crop Improvement, V.R. Rajpal, S.R. Rao, and S.N. Raina, eds. (Springer), pp. 77–104.
[13] Ramirez, M.L., Cendoya, E., Nichea, M.J., Zachetti, V.G.L., and Chulze, S.N. (2018). Impact of toxigenic fungi and mycotoxins in chickpea: a review. Current Opinion in Food Science 23, 32–37.
[14] Ryley, M., Moore, K., Cumming, G., and Jenkins, L. (2015). Chickpea: managing Botrytis grey mould. (Pulse Australia).
[15] Verma, M.M., Ravi and Sandhu, J.S. (2014) – Characterization of the interspecific cross Cicer arietinum L. x Cicer judaicum (Boiss.). Plant Breeding 114: 549–551.
[16] Yartsev G. F, Baykasenov R. K, Pritulyak D. O., (2021) – Crop structure and yield of chickpea varieties in the conditions of the central zone of the Orenburg region From import substitution to export potential: scientific and innovative support for the production and processing of crop production: collection of materials of the international scientific and practical conference "From import substitution to expert potential: scientific and innovative support of the agro–industrial complex" (Yekaterinburg: Publishing House of the Ural State Agrarian University) pp.187–188.

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EMERGING AGRICULTURAL EQUIPMENT USING ARTIFICIAL INTELLIGENCE AND SPECTROSCOPY FOR THE AGRICULTURAL SYSTEMS OF THE FUTURE

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Abstract: Ecological agriculture advocates for sustainable, diversified, and harmonious production systems to mitigate crop and environmental contamination. Ecological plant cultivation, which abstains from the use of harmful conventional substances, has been a prominent focus in economically advanced nations for many decades. Ecological agriculture emerged as a counterbalance to intensive, conventional (industrialized) farming practices that prioritize maximizing output by employing large quantities of fertilizers and energy–intensive production enhancers, all aimed at sustaining agricultural production for a continuously expanding, mainly urban population. Agricultural robots have emerged as a response to farmers' needs for automating repetitive, time–consuming tasks, enabling them to focus on improving production quality and increasing yields. While we commonly refer to them as robots, these devices come in various forms with varying degrees of mobility. They include unmanned aerial vehicles (UAVs) or drones, milking robots, automatic harvesting systems, autonomous tractors, unmanned ground vehicles (UGVs) used in nurseries or greenhouses, sorting and packing robots, and weed control systems. The paper explores various equipment employed for mechanical weed control in ecological agriculture.
Keywords: agricultural production, emerging agricultural robots, weed control, organic farming

INTRODUCTION

Considering the rapid growth of the population, modern agriculture used excessive mechanization and chemical products, and the consequences were the degradation and pollution of the soil, as well as a low quality of food (tasteless food, health risks). In this context, it is necessary to find innovative solutions for the following needs: maintaining a high yield, creating healthier productions and environmentally friendly crops and capitalizing on local agricultural land (*Vladut et al., 2023*).

Sustainable agriculture must not only address environmental concerns but also ensure profitability for its longevity. One key approach to achieving this is cost reduction. Farmers can work towards cost reduction by enhancing the efficiency of farming techniques.

Agricultural robots have emerged as a response to farmers' needs for automating repetitive, time–consuming tasks, enabling them to focus on improving production quality and increasing yields. While we commonly refer to them as robots, these devices come in various forms with varying degrees of mobility. They include unmanned aerial vehicles (UAVs) or drones, milking robots, automatic harvesting systems, autonomous tractors, unmanned ground vehicles (UGVs) used in nurseries or greenhouses, sorting and packing robots, and weed control systems. At present, milking robots and drones dominate this market, but other intelligent systems are poised to take the lead in the near future.

Weeds are among the major causes of crop yield loss, compared to any other categories of agricultural pests (*Tillett et al. 2022*). They are also responsible for a large part of the production costs. Weed control in an environmentally safe practice, that is often considered a challenge, and can be achieved by several means, of which cultural and mechanical methods are the most common, since easily accessible to smallholder farmers. However, these methods have proven to be expensive as they are laborious and time intensive operations and are also risk exposing the soil to erosion and damaging.

In contemporary agricultural production, chemical herbicides continue to hold a significant role in weed management (*Home et al. 2022*) due to their higher effectiveness. However, their usage often raises concerns related to public health, environmental pollution, and the emergence of herbicide–resistant weed species. Future strategies for weed management should seek innovative solutions to minimize the environmental and toxicological impacts associated with these systems and address the

development of herbicide–resistant weed species (*Astrand et al. 2022*).

Mechanical weed control, one of the oldest weed management methods, involves the physical removal of weeds using mechanical equipment before or during the crop's growing season. Effective management of tillage practices plays a crucial role in mechanical weed control. The choice of various tillage systems can significantly influence the competitive dynamics between crops and weeds (*Slaughter et al. 2022; Nenciu et al. 2022; Mircea et al. 2020*).

Agriculture around the world, faces many challenges both presently and, even more significantly, in the future: limited natural resources, including non–renewable energy sources (oil, natural gas, coal) with rising prices for them· worsening economic conditions for the activities of farmers due to the unfair increase in the prices of industrial inputs and agricultural products· ensuring food security at the local, regional and global level in the conditions of a higher population density· biodiversity loss, including genetic loss both on the soil surface and, especially, in soil (*Chen et al. 2022*).

In recent years, organic agriculture has gained attention not only from researchers but also from the broader community, encompassing consumers and farmers. This interdisciplinary field, influenced by agriculture and environmental conservation, has evolved its own terminology, resulting in the development of a distinct language.

Ecological agriculture embodies a farming system dedicated to the preservation and improvement of productive ecological systems, without resorting to synthetic chemicals. This approach amalgamates traditional knowledge with scientific progress across diverse agronomic domains. A fundamental objective of ecological agriculture is the protection of the biosphere and the planet's resources.

The principles of ecological agriculture are based on the maximum utilization of local resources and the minimization of economic and ecological risks. Organic agriculture is not a "do–nothing" type of agriculture, without fertilization and without treatments. The ecological production method differs from the conventional one in that it avoids the use of chemical fertilizers and pesticides. The fundamental rule of organic farming is that natural inputs are allowed while synthetic ones are prohibited (*https://www.industrialautomationindia.in/*).

Conventional agriculture has determined the decrease in the content of organic matter in the soil and the accumulation of toxic compounds. In ecological practice, soil fertility and health are maintained by biological methods, such as: crop rotation, manual work, weeding, composting, mulching. Using organic fertilizers increases and maintains the percentage of soil organic matter (*Mariş et al. 2022*).

Starting from these realities, obtaining raw material and quality processing products, unpolluted – without the use of genetically modified organisms, the use of synthetic fertilizers and pesticides, stimulators and growth regulators, hormones, antibiotics and intensive animal breeding systems becomes current. (*Dewi et al. 2022*).

The growing population, which imposes ever–increasing demands on food production, together with the scarcity and high cost of labour in agriculture, leads to the demand for robots in agriculture (*Bakker et al. 2011; Fennimore et al. 2019*). Developed countries have long used mechanization in agriculture as the number of people involved in the sector has declined in recent decades. Experts have categorized the most common applications for robotics in agriculture based on five key activities: Crop Seeding, Fertilizing and Irrigation, Thinning and Pruning, Weeding and Spraying, and Picking and Harvesting (*Chisnicean et al. 2019; Griepentrog et al. 2010; Ghergan et al. 2019*). In addition to being labor intensive, these are time–constrained activities and need precision and accuracy to be truly effective. Another important function of agricultural robots is to collect data to monitor various parameters like soil, crop growth, infections, etc.

Modern robots are operated through a computer system equipped with the robot's operating system and essential software components required for automated task execution. Control can be done remotely or via portable control consoles, connected by cables to the robot and the control computer (*Rai et al. 2021*).

These robots feature mechanical parts, robot arms, vision cameras, sensing technology and artificial intelligence to improve crop production by minimizing the use of arable land. Several of these robots are equipped with 3D cameras that scan modules placed in front of them and collect information to perform specific operations further. These robots can be largely classified as semi–autonomous and fully

autonomous robots. Fully autonomous robots use artificial intelligence and sensors to calculate how to raise plants without disturbing nearby crops. As with other industry segments, the major factor driving the agricultural robot market is the need to increase production and reduce costs at the same time.

These robots reduce the need for human labor and are much more efficient, able to work around the clock. In addition to being effective, they are also precise and thus help avoid the harmful effects of chemicals by pinpointing the correct dose at the exact place where it is needed, eliminating wastage as well as contamination.

Just because the technology is available, it is not necessarily implementable. One of the main causes of the technology's limited use is affordability and the ever–present ROI or ROI equation. Like mechanization, robotics require huge investment, which puts them out of reach for small farmers. It is about size and scale, and the benefits only come with the ability to invest in such high technology (*https://www.futurefarming.com/*).

MATERIAL AND METHOD

Since the 1960s, several automatic plant thinning systems have been marketed. Weeds can be cut or pulled from the ground with the help of a mechanical actuator (*Bakker, 2009b. In 2002, Astrand and Baerveldt)* (*Astrand et al., 2002*) presented a rotary hoe for weed removal. The weeder was attached to a robot used to control weeds in sugar beet crops. Home et al. (2002), from Cranfield University in England, conducted a study on precision positioning of weeding tools using artificial vision (Figure1).

Figure 1 – Grain weeder, guided by artificial vision (Klose et al. 2008)

The guided weeder is fitted with hydraulic paddles designed for mechanical weed control. These paddles can be rotated around the vertical axis (see Figure 2). Each blade has a specific design that enables the tool to navigate around cultivated plants without causing harm or destruction to them (*Tillett, 2007*).

Figure 2 – Rotary disc provided with a section to protect cultivated plants *(https://optics.org/news/12/3/52)*

Cycloidal harrow for mechanical weed control inside crop rows (*Ruckelshausen, et al., 2006*). The cycloidal sweeper in Figure 3 was built at the University of Osnabrück, Germany.

Figure 3 – "Querhacke" cycloidal harrow designed at the University of Osnabrück, Germany *(Grulová et al. 2020)*

The Lukas robot (Figure4) was designed at Halmstad University in Sweden. Lukas is a mobile robot for agriculture, used for mechanical weed control on agricultural land. The robot is equipped with two visual systems. The first system works based on gray levels, and is used to recognize crop rows and guide the robot along the row. The second system, based on color vision, is able to identify crop plants among weeds. The second visual system controls a crop row weeding tool.

Figure 4 – Autonomous weed–fighting robot designed at Halmstad University

The API robot (Figure 5N) was designed at Aalborg University in Denmark. The first studies began in 2000, at the initiative of the Danish Institute for Agriculture. The API robot is used in plant mapping and selective herbicide applications.

Figure 5 – Autonomous weed control robot designed at the Danish Institute of Agricultural Sciences, Denmark *(https://optics.org/news/12/3/52)*

Another agricultural robot prototype was designed at Wageningen University in the Netherlands (Figure 6). The robot allows the investigation of a wide spectrum of research options regarding the detection of weeds and the actuation of the actuator used to remove them. The robot has implemented an autonomous navigation system based on RTK–DGPS (Real Time Kinematic Differential Global Positioning System) which, in combination with a visual system, allows the mapping of crop rows (*Bakker, 2011*).

Figure 6 – Autonomous weed–fighting robot designed at Wageningen University, Netherlands *(Boris et al. 2022)*

Figure 7 – Autonomous robot for protecting agricultural crops designed at the University of Aarhus, Denmark *(Grulová et al. 2020)*

The autonomous robot HortiBot (Figure 7) was developed at Aarhus University in Denmark for use in agricultural applications. It is equipped with a camera that allows navigation by following the rows of crops. In areas without rows, the robot is positioned by an RTK–GPS system. The herbicide spraying system is equipped with a set of video cameras that take images of the soil surface. The images are analyzed to detect weeds. When one or more weeds are detected in the image, information about their location is saved (*Griepentrog et al., 2010*).

The Weedy robot (Figure 8) was developed at Osnabrück University in Germany for use in weed control applications. The robot is a mechatronic system based on sensory fusion, for selective weed control.

Figure 8 – Autonomous weed control robot "Weedy" designed at the University of Osnabrück, Germany *(Macrii et al. 2022)*

The BoniRob robot (Figure 9) was developed at Osnabrück University in Germany, in collaboration with Amazone and Bosch. In 2009, Ruckelshausen et al. (2009) published a paper on the BoniRob autonomous robot (*Ruckelshausen, 2009*).

Figure 9 – Autonomous robot for agriculture designed at the University of Osnabrück in collaboration with Amazone and Bosch *(Tilneac et al. 2012)*

FarmWise's new weeding tool, the Vulcan, debuted at World Ag Expo 2023 and was included in the top 10 new products. Thanks to computer vision and deep learning models, Vulcan can differentiate, identify plants and remove surrounding weeds with high precision. The objective of this machine is to reduce manual weeding costs for more than 20 different vegetable crops, especially in organic farms where herbicides are prohibited.

Figure 10 – The Vulcan advanced weeding tool
https://newatlas.com/good–thinking/farmwise–vulcan–automatic–weed–pulling/

Ecorobotix is revolutionizing agriculture with its ARA ultra–high precision sprayer. ARA uses cameras and artificial intelligence to identify individual plants (both crops and weeds) in real time and provide ultra–precise crop treatment to an accuracy of 6x6cm, treating only weeds without spraying surrounding crops or soil, allowing for precise herbicide application, insecticides and fungicides plant by plant.

Ecorobotix was founded to radically change agriculture for the better, respecting the environment and reducing the use of chemicals, the impact on the soil, the use of water and energy. Ecorobotix offers a revolutionary plant–by–plant data solution and ultra–high precision crop treatment that reduces the use of chemicals (herbicides, pesticides, liquid fertilizers) by 70–95%, while increasing crop yields by ~5% and massively reducing the CO2 footprint.

Figure 11 – ARA – EcoRobotix's plant sprayer that uses artificial intelligence, computer vision and computer systems to detect and selectively spray weeds with a micro–dose of herbicide | © Ecorobotix *(https://optics.org/news/12/3/52)*

Weeding tools are upgraded to self–thinking smart tools with cameras and AI. Especially for arable crops, gardening and vegetables, but not only. Pasture weeds such as dandelions, docks and thistles are also targeted with algorithms. – Photo: René Koerhuis

For several years now, there has been a clear trend when it comes to weeding tools. These are upgraded with cameras and AI to smart tools that think for themselves, with parts, teeth, spray nozzles and even lasers. The availability of sophisticated cameras at affordable prices has led to an enormous uptake of AI–powered desert tools. Especially in relation to autonomous rovers and field robots.

The Dutch company Andela Techniek & Innovation is developing a machine for robotic weed removal, and the One prototype – the 12–row ARW–912 – is running on an organic carrot and onion farm in the Netherlands. The weeding robot was specially developed for removing weeds from the row. The Andela Robot Weeder (ARW–912) has 12 weeding units for rows at a maximum distance of 75 centimeters.

The width of the all–aluminium vehicle is 9 meters long with a caterpillar undercarriage on a 3–meter track width and a single wheel at the front. RTK GPS ensures that the weeding robot stays on course.

The electric power for the propulsion of the machine, for the computing unit and for the control and weeding system comes entirely from solar panels mounted on the roof. There are a total of 43 electric motors on the ARW–912.

Figure 12 – The autonomous weeding robot is 9 meters wide and has 12 weeding units. On the roof are solar panels for electric motors.

The CEOL field robot is an inter–row crawler developed in Toulouse by the company Agreenculture. It can work several hectares per day completely autonomously thanks to its GPS RTK and the rear tool holder allows it to tow different implements.

Figure 13 – The CEOL field robot

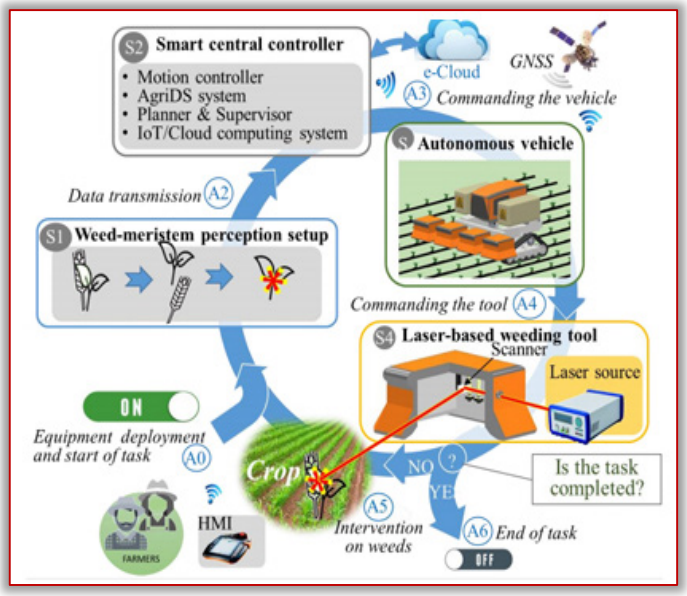

Figure 14 – WeLASER autonomous weed controlling system with lasers

The WeLASER solution is focused on non–chemical weed control. The idea behind it is to damage the growth center of the weed with high energy blasts from a high–powered laser beam source.

Scientists from Laser Zentrum Hannover (LZH) are developing an image processing system that uses artificial intelligence to distinguish crops from weeds. They also teach the system to recognize the position of the weed meristem (plant growth center). Target coordinates are used at LZH to control a robust multi–row scanning system so that the laser beam is directed to destroy the weed.

For field use, the systems will be installed on an autonomous vehicle. These will then be coordinated through an intelligent controller that uses the Internet of Things (IOT) and cloud computing techniques to manage and implement agricultural data.

LZH also develops concepts for ensuring laser safety for all involved, such as farmers and machine operators. The partners want to test the prototype on sugar beet, corn and winter grain crops. The prototype should be available by 2023 and then further developed for commercialization.

Dahlia Robotics' vision is to eliminate the need for herbicides in agriculture and make organic food production the standard.

A robot that drives autonomously in the field, recognizes weeds in crops and mechanically removes weeds. Guided by artificial intelligence, the robot controls an internal weeding system while avoiding accidental damage to crop plants. A mechanical end effector removes the weed plants.

Figure 15 – Dahlia Robotics weeding system

The robots named Tom, Dick and Harry, were developed by the Small Robot Company to rid the field of ingrown weeds with minimal use of chemicals and heavy machinery.

Figure 16 – Modern agricultural systems named Tom, Dick and Harry, developed by the Small Robot Company

The technology can scan 20 hectares a day, collecting data that is then used by Dick, a "crop care" robot, to destroy weeds. Then it's Harry robot turn to plant seeds in the weed–free soil.

The company has been working on its autonomous weed killers since 2017, and in April this year launched Tom, its first commercial robot, which is now operational on three UK farms. The other robots are still in the prototype stage, being tested.

Scott–Robinson says the company hopes to launch its full robot system by 2023, which will be offered as a service at a rate of around £400 per hectare. The monitoring robot is first placed on a farm, and the weeding and seeding robots are only delivered when the data shows they are needed. To develop the zapping technology, Small Robot Company has partnered with another UK start–up, RootWave (*Bakker et al. 2011*).

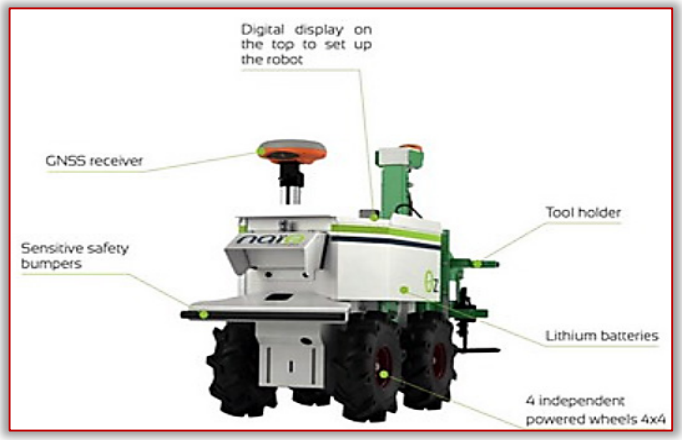

Figure 17 – Naio OZ robot design

The Naio OZ robot can perform a wide variety of operations by itself, such as weeding, or seeding. Additional advantages of the OZ robot include its constant availability and lack of fatigue, its ability to work for 8 hours on a single charge (covering 1 hectare), its precision through the use of RTK GPS, its capability to tow loads of up to 150 kilograms, its soil–friendly design with a weight of only 180 kilograms when equipped with all tools, its agility thanks to 4–wheel drive, its versatility with a wide range of compatible tools, and its eco–friendliness achieved by using an electric motor and batteries.

Advanced agricultural management equipment is not limited to conventional agricultural applications; it can also encompass decentralized systems. One example is an automated composting system proposed in recent research (*Nenciu et al., 2022*). Decentralized thermophilic composting has demonstrated its effectiveness in managing organic waste, especially fruits and vegetables.

This approach reduces processing time, decreases the waste's mass, volume, and moisture content, all while providing superior control over the composting process. This innovative composting technology using emerging tools ensures efficient management of critical processing parameters, including temperature, material moisture content, mixing intensity, and airflow rate. As a result, it leads to better waste treatment, eliminates unpleasant odors, and minimizes the presence of pathogenic agents.

CONCLUSIONS

Robotization encompasses a range of equipment and processes designed to enhance the efficiency of all production lines. In essence, tasks once performed by humans in the past can now be executed by robots with an extremely low error rate. Elements such as artificial intelligence, software, sensors, and electric motors contribute to the extensive field of robotics. Some of the key advantages of robotization include increased production throughput, guaranteed quality, the ability to sustain operations without interruptions, independence from weather conditions, quick decision–making in response to encountering specific obstacles, and the potential for utilizing renewable energy sources.

Among the drawbacks of robotization, we can mention high development costs associated with altering work processes or technologies, the necessity for human intervention in the case of system errors or updates, and the potential for malfunctions in terms of the proper functioning of the programs governing robot operations.

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References

[1] Astrand B., Baerveldt A. J., (2005) A visionbased row–following system for agricultural field machinery, Mechatronics, Volume 15, Issue 2, Pag. 251–269.

[2] Babanatsas T. (2019). Integrarea elementelor de robotică în realizarea unui sistem pentru recoltarea măslinelor, Teză doctorat, Timișoara,

[3] Bakker T., van Asselt K., Bontsema J., Müller J., van Straten G., (2011). Autonomous navigation using a robot platform in a sugar beet field, Biosystems Engineering.

[4] Boris B., Cebanu, D. (2022). Sănătatea solului ca bază pentru tranziția către o agricultură mai durabilă,

[5] Chen, J., Wu, J., Wang, Z., Qiang, H., Cai, G., Tan, C., & Zhao, C. (2021). Detecting ripe fruits under natural occlusion and illumination conditions. Computers and Electronics in Agriculture, 190, 106450.

[6] Chisnicean L., Bobicev T., Chisnicean V., (2019). Aplicarea unor elemente organice la cultivarea speciilor aromatice și condimentare, Conferința Știința în Nordul Republicii Moldova:realizări,probleme,perspective, Bălți, Moldova, 26–27 iunie 39–42

[7] Dewi, T., Risma, P., & Oktarina, Y. (2020). Fruit sorting robot based on color and size for an agricultural product packaging system. Bulletin of Electrical Engineering and Informatics, 9(4), 1438–1445

[8] Fennimore, S. A., & Cutulle, M. (2019). Robotic weeders can improve weed control options for specialty crops. Pest management science, 75(7), 1767–1774.

[9] Gan, H., Lee, W. S., Alchanatis, V., Ehsani, R., & Schueller, J. K. (2018). Immature green citrus fruit detection using color and thermal images. Computers and Electronics in Agriculture, 152, 117–125.
[10] Ghergan, O., Țucu, D., Iusco, A., Drăghicescu, D., & Merce, R. (2019). Small greenhouse robotized solutions: state of the art and future perspectives. În F. o. University of Zagreb (Ed.) Proceedings of the 47th International Symposium, Actual Tasks on Agricultural Engineering, Opatija, Croatia
[11] Griepentrog H.W., Ruckelshausen A., Jørgensen R.N., Lund I., (2010) Autonomous systems for plant protection, Precision Crop Protection, The Challenge and Use of Heterogeneity, Springer, pp. 323–334.
[12] Gruľová, D., Caputo, L., Elshafie, HS, Baranová, B., De Martino, L., Sedlák, V., De Feo, V. (2020). Chemotipul de timol Origanum vulgare L. ulei esențial ca potențial erbicid selectiv pe bază de bio pe specii de plante monocotiledone. Molecule, 25 (3) 595.
[13] Home M. C. W., Tillett N. D., Hague T., Godwin R. J., (2002) An experimental study of lateral positional accuracy achieved during inter–row cultivation, 5th EWRS Workshop on Physical and Cultural Weed Control, pp. 101– 110. http://www.ewrs.org/pwc/doc/2002_Pisa.pdf
[14] Klose R., Ruckelshausen A., Thiel M., Marquering J., (2008). Weedy – a Sensor Fusion Based Autonomous Field Robot for Selective Weed Control, International Conference Agricultural Engineering/AgEng, Pag. 167–172.
[15] Macrii, L., Cebanu, D., Zaharco, D., & Avram, A. (2022). Alcătuirea structurală a cernoziomului tipic sub diverse practici agricole de lungă durată , Conferința Știința în Nordul Republicii Moldova: realizări, probleme,perspective 6, Bălți, Moldova, 20–21 mai , pag.165–170
[16] Mariș, Ș. A. (2022). Optimizarea echipamentului tehnologic robotizat destinat lucrărilor în sere și solarii (Doctoral dissertation, Timişoara: Editura Politehnica).
[17] Mircea, C.; Nenciu, F.; Vlăduț, V.; Voicu, G.; Cujbescu, D.; Gageanu, I.; Voicea, I. (2020). Increasing the performance of cylindrical separators for cereal cleaning, by using an inner helical coil. INMATEH Agric. Eng., 62, 249–258.
[18] Nenciu F, Fatu V, Arsenoaia V, Persu C, Voicea I, Vladut N–V, Matache MG, Gageanu I, Marin E, Biris S–S, et al. (2023). Bioactive Compounds Extraction Using a Hybrid Ultrasound and High–Pressure Technology for Sustainable Farming Systems. Agriculture. 13(4):899.
[19] Nenciu F., Stanciulescu I., Vlad H., Gabur A., Turcu O.L., Apostol T., Vladut V.N., Cocarta D.M., Stan C. (2022). Decentralized Processing Performance of Fruit and Vegetable Waste Discarded from Retail, Using an Automated Thermophilic Composting Technology. Sustainability. 14(5):2835. https://doi.org/10.3390/su14052835
[20] Nenciu F., Voicea I., Cocarta D.M., Vladut V.N., Matache M.G., Arsenoaia V–N. (2022). "Zero–Waste" Food Production System Supporting the Synergic Interaction between Aquaculture and Horticulture. Sustainability., 14(20):13396
[21] Rai, M., Zimowska, B., Shinde, S. (2021) Potențialul bioerbicid al diferitelor specii de Phoma: oportunități și provocări. Appl Microbiol Biotechnol 105, 3009–3018
[22] Ruckelshausen A., Biber P., Dorna M., Gremmes H., Klose R., Linz A., Rahe R., Resch R., Thiel M., Trautz D. and Weiss U., (2009). BoniRob: an autonomous field robot platform for individual plant phenotyping, European Conference Precision Agriculture (ECPA) pp. 841–847.
[23] Slaughter D.C., Giles D.K., Downey D., (2008) Autonomous robotic weed control systems: A review, Computers and Electronics in Agriculture, Volume 61, Issue 1, April 2008, Pag. 63–78, www.sciencedirect.com.
[24] Tillett N.D., Hague T., Grundy A.C., Dedousis A.P., (2007). Mechanical within–row weed control for transplanted crops using computer vision, Biosystems Engineering, Volume 99, Issue 2, February 2008, pp. 171–178,
[25] Tilneac, M. (2012) Contribuții la Utilizarea Roboților in Agricultură Pentru Aplicații de Combatere a Buruienilor, Teză de doctorat, Timişoara–2012
[26] Vlăduț, N.–V.; Ungureanu, N.; Biriș, S.–Ș.; Voicea, I.; Nenciu, F.; Găgeanu, I.; Cujbescu, D.; Popa, L.–D.; Boruz, S.; Matei, G.; et al. (2023). Research on the Identification of Some Optimal Threshing and Separation Regimes in the Axial Flow Apparatus. Agriculture 13, 838
[27] https://optics.org/news/12/3/52
[28] https://www.futurefarming.com/tech–in–focus/field–robots/dahlia–robotics–develops–rob
[29] https://www.futurefarming.com/tech–in–focus/field–robots/12–row–weeding–robot–clears–weeds–autonomously/
[30] https://www.industrialautomationindia.in/articleitm/11821/Robots–in–Agriculture/articles
[31] http://madr.ro/docs/dezvoltare–rurala/rndr/buletine–tematice/PT4.pdf
[32] https://newatlas.com/good–thinking/farmwise–vulcan–automatic–weed–pulling/
[33] https://optics.org/news/12/3/52
[34] https://www.ggba–switzerland.ch/10–foodtech–and–agritech–companies–that–are–revolutionizing–the–food–industry–in–western–switzerland/
[35] https://www.vmdtv.eu/trei–roboti–ajuta–fermierii–sa–curete–solul–de–buruieni–si–sa–planteze/

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RESEARCH AND DEVELOPMENT OF A LOW–COST PROTOTYPE MEDICAL DELIVERY DEVICE: A CASE STUDY ON THE INSULIN PEN

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Abstract: This study explores the evolution, design considerations, and challenges associated with insulin delivery devices, with a particular focus on the development of a prototype insulin pen to address existing limitations. Material selection, including considerations such as durability, friction properties, and compatibility with insulin formulations, is crucial in insulin pen design. Common materials such as medical–grade plastics, metals, and glass are discussed, along with design considerations aimed at enhancing user–friendliness and safety. Key components of insulin pens, including the button, plunger, needle, and cap, are examined in detail, highlighting their roles in accurate insulin dosage and patient safety. Despite technological advancements, challenges such as user interface complexity, needle–related injuries, and cost constraints persist. Future directions in insulin delivery device development, including the integration of emerging technologies and innovations, are also discussed. By addressing these challenges and leveraging advancements in material science and design optimization, we can further enhance the efficiency and usability of insulin delivery devices, ultimately improving diabetes management outcomes and patient quality of life.

Keywords: insulin delivery, prototype, medical device, ergonomics, dose accuracy, usability testing

INTRODUCTION

In the realm of medical devices, the evolution of insulin delivery systems stands as a testament to relentless innovation in addressing the complex needs of individuals managing diabetes (Gillian and McCarthy, 2017; Garg and McVean, 2024). Since the groundbreaking discovery of insulin in 1920, the landscape of insulin administration has undergone remarkable advancements, aiming to optimize blood sugar regulation and mitigate the risk of associated health complications (Kesavadev et al., 2020). From humble beginnings marked by basic vial and syringe setups to the contemporary era characterized by disposable pens and sophisticated closed–loop systems, the trajectory of insulin delivery devices reflects a convergence of patient–centric design, technological prowess, and safety imperatives (Rima and Shah, 2016; Krishna, 2020; Harper et al., 2021). Notably, the integration of ergonomic principles has played a pivotal role in refining these devices, fostering user–friendliness and accessibility, particularly for individuals with impairments (Gillian and McCarthy, 2017; Kar et al., 2022).

Among these innovations, insulin pens have emerged as a cornerstone in the management of both type 1 and type 2 diabetes mellitus (T1DM and T2DM), revolutionizing insulin therapy with their simplicity and convenience (Hyllested–Winge, 2016; Lilly et al., 2019; Masierek et al., 2022). Yet, amidst the remarkable progress, persistent challenges loom, spanning from user interface complexities to needle–related injuries, portability constraints, and cost considerations (Rini et al., 2019; Krishna, 2020). It is within this context that this study embarks on the design journey of a prototype insulin pen, with a focused mission to confront these challenges head–on and elevate device efficiency to new heights. Through a comprehensive examination of user needs, technological capabilities, and safety imperatives, this case study endeavors to contribute to the ongoing evolution of medical delivery devices, with insulin pens serving as a compelling focal point for innovation and advancement

MATERIALS AND METHODS

Material selection for insulin pen design is critical, with considerations such as durability, friction properties, and compatibility with insulin. Common materials include plastics like Delrin and Zytel nylon resin, known for their strength and low friction, as well as metals like stainless steel for components requiring durability and corrosion resistance (Schneider and Lange, 2018; Watterson et al., 2022). Glass is often used for insulin cartridges due to its inert properties, ensuring compatibility with insulin formulations (Economidou et al., 2021). Bio–compatible coatings may be applied to ensure safety during contact with insulin and the patient's skin. Various components, such as the button, ratchet rotor, and plunger, play crucial roles in insulin pen functionality and are designed with user–friendliness and durability in mind.

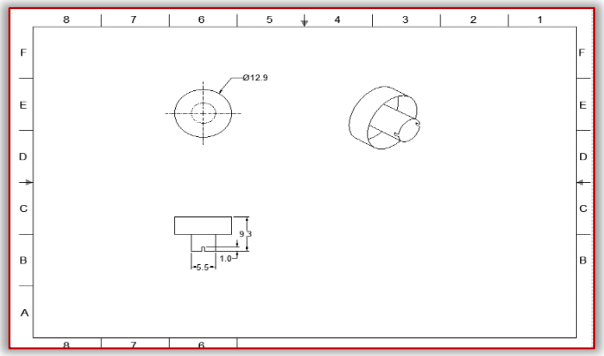

Figure 1: Insulin pen button

The specific material used for the button on an insulin pen can vary depending on the design (Harper et al., 2021). Commonly, the pen button (figure 1), are constructed from medical–grade plastics that are safe for use in healthcare settings. These materials combination is chosen for their ability to withstand the mechanical requirements of the device, resist wear and tear, and maintain the sterility required for medical devices

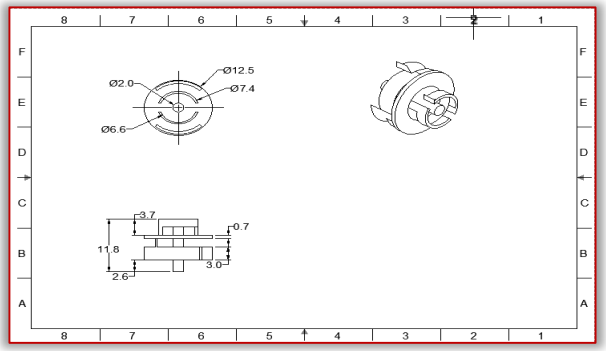

Figure 2: Ratchet Rotor

Hence, ratchet rotor (figure 2) is an important component of the insulin pen. The function of the ratchet rotor is that it serves as the control for the dose of the insulin. It may also serve has the lock for the button, the lock prevents accidentally dosing.

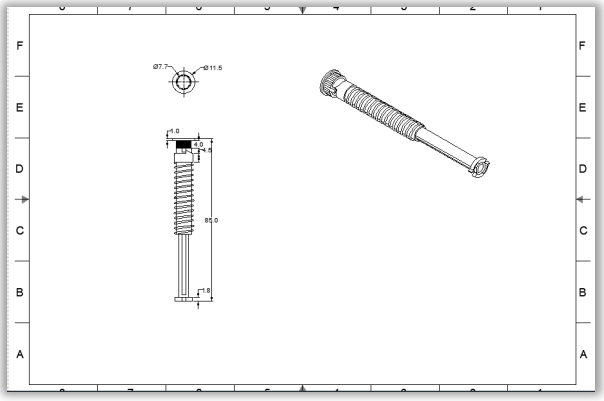

Figure 3: Control cylinder of an insulin pen

However, control cylinder (figure 3) of an insulin pen functions as the dose control mechanism. The dosing mechanism is a critical part responsible for accurately setting and delivering the prescribed dose of insulin. Control cylinder is part of this mechanism, the role of the control cylinder is regulating and controlling the movement of internal components to ensure precise insulin dosage.

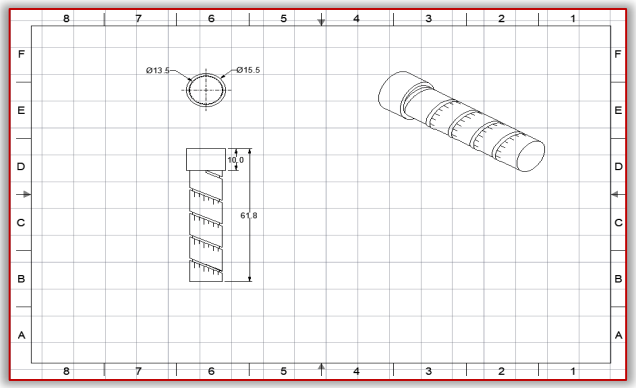

Figure 4: Plunger of the insulin pen.

Furthermore, insulin pen's plunger (Figure 4) is also an important component for precise insulin delivery. The plunger is within the pen barrel or cartridge. The plunger functions as a piston. During the injection process, the desired insulin dose is set and the injection button is pressed, the plunger moves within the cartridge, displacing insulin to ensure accurate administration. The plunger is designed to maintain the insulin pen's integrity, preventing leaks, and ensuring a smooth injection experience. The insulin pen's plunger works with the dosing mechanism. The reliable performance of the plunger is essential for individuals with diabetes in achieving accurate and effective self–administration of insulin (Paun et al., 2019)

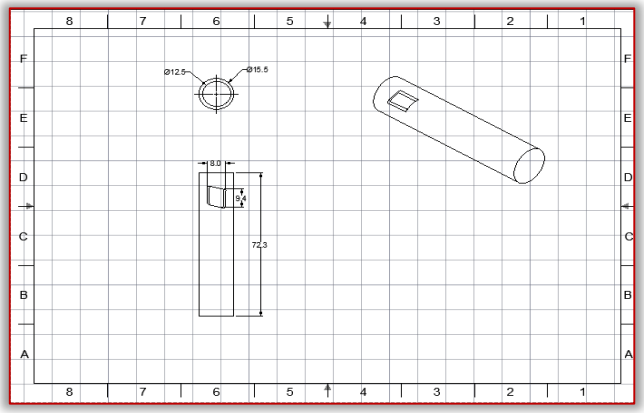

Figure 5: Cover of the insulin pen

Similarly, the covering of an insulin pen (figure 5) refers to the external casing or housing that encases the internal components of the pen. This covering is a crucial aspect of the pen's design, providing protection, durability, and often ergonomic features for ease of use. The covering is typically made from medical–grade plastics or other materials that meet safety and hygiene standards. These materials ensure the pen's

integrity, durability, and compatibility with medical use. The covering serves as a protective layer, safeguarding the insulin cartridge, dosing mechanism, and other internal components from external elements, contamination, and damage. It helps maintain the sterility of the insulin delivery system. The shape, size, and texture are often optimized for easy handling, allowing individuals with diabetes to comfortably grip and manipulate the pen during dose selection and administration. The covering of an insulin pen plays a crucial role in ensuring the functionality, safety, and user–friendliness of the device. It reflects the careful consideration given to both the practical and aesthetic aspects of insulin pen design to meet the needs of individuals managing diabetes.

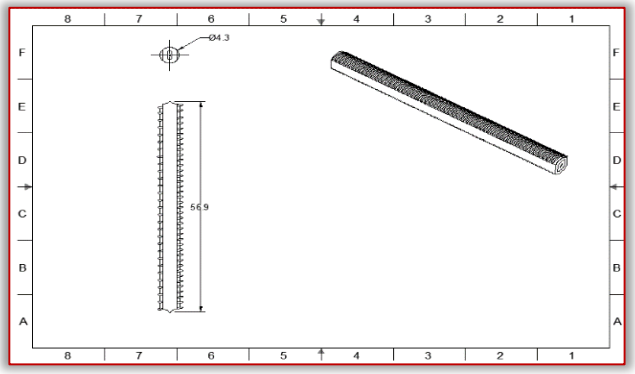

Figure 6: Jack screw of the insulin pen

In insulin pens, the dosing mechanism is crucial for accurately selecting and delivering the prescribed dose of insulin. It often involves components such as a dose dial, gears, and possibly a ratchet system. The jack screw (figure 6) is part of this mechanism, and it plays an important role in facilitating the controlled movement of internal components to ensure precision in setting and administering insulin doses. The major function of the pawl in an insulin (figure 7) is to lock and hold the container and the cartridge of the insulin pen for smooth delivery of the insulin into the body.

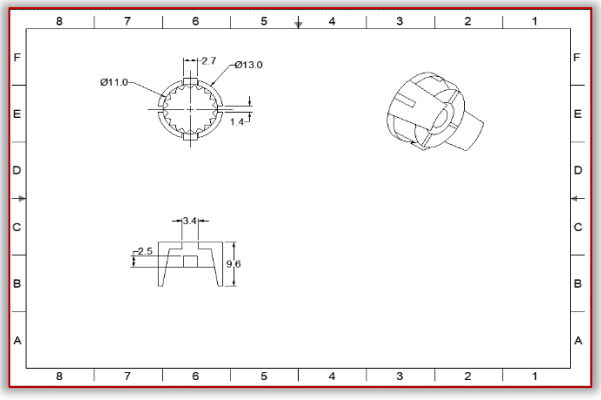

Figure 7: Pawl of the insulin pen.

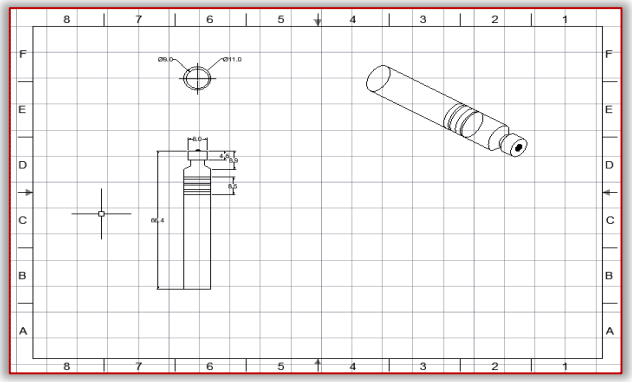

Figure 8: Container of the insulin pen

The container and the cartridge of an insulin pen (figure 8) refers to the external casing or housing that encases the internal components of the pen. This cartridge is a crucial aspect of the pen's design, providing protection, durability, and often ergonomic features for ease of use. The container is typically made from medical–grade plastics or other materials that meet safety and hygiene standards. These materials ensure the pen's integrity, durability, and compatibility with medical use. The container serves as a protective layer, safeguarding the insulin cartridge, dosing mechanism, and other internal components from external elements, contamination, and damage. It helps maintain the sterility of the insulin delivery system. The shape, size, and texture are often optimized for easy handling, allowing individuals with diabetes to comfortably grip and manipulate the pen during dose selection and administration.

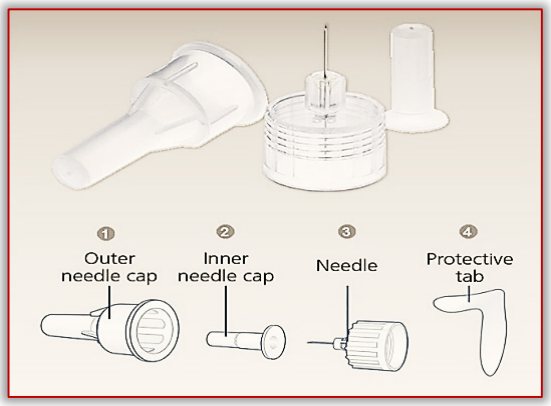

Figure 9: Needle of the insulin pen.

Moreso, the needle of an insulin pen (figure 9) is also a crucial component responsible for delivering insulin subcutaneously. Insulin pen needles are typically made of high–quality, medical–grade stainless steel. This material ensures strength, sharpness, and bio–compatibility, meeting the necessary safety standards for medical devices. Insulin pen needles come in various sizes, including different lengths and gauges (thickness). The choice of

needle size depends on factors such as individual patient needs, insulin type, and injection technique (Rini et al., 2019; Economidou et al., 2021). The tip of the needle can have different designs, such as beveled or straight. Beveled tips are common and allow for a smoother entry into the skin, reducing discomfort during injections. While many insulin pen needles are designed to be universally compatible with various insulin pens, users should verify compatibility with their specific pen model to ensure proper functioning. Some insulin pen needles incorporate technologies aimed at reducing pain during injections, such as ultra–thin needles or features to minimize skin trauma. Proper needle selection and technique are essential for successful and comfortable insulin administration. Users should follow the guidance provided by healthcare professionals and the manufacturer's instructions for their specific insulin pen and needle (Sparre et al., 2022).

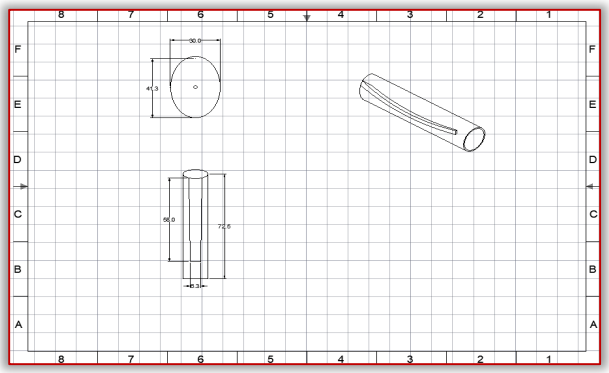

Figure 10: Cap of the insulin pen

The cap of an insulin pen (figure 10) is a protective covering for the needle, ensuring its sterility and preventing accidental needle pricks before use. The primary function of the cap is to safeguard the needle from contamination and maintain its sterility (Pillalamarri et al., 2018). It serves as a barrier that shields the needle from external elements, ensuring a clean and safe injection. Insulin pen needle caps are typically made of medical–grade plastic. This material is selected for its durability, lightweight nature, and compatibility with healthcare standards. Like the needle, the cap is designed for single–use only. After the cap is removed for an injection, it should not be reapplied, and it is discarded along with the used needle in an appropriate container. In addition to protecting the needle, some insulin pen needle caps may have additional safety features, such as tamper–evident seals or locking mechanisms, to enhance user safety. The cap of the insulin pen plays a crucial role in maintaining the integrity of the needle and ensuring a hygienic injection process. Users should always follow proper procedures for removing and disposing of the cap as part of their insulin administration routine (Pillalamarri et al., 2018; Sparre et al., 2022).

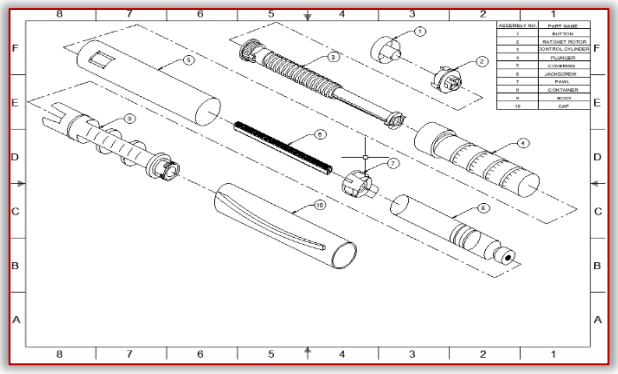

Figure 11: Components diagram of insulin pen

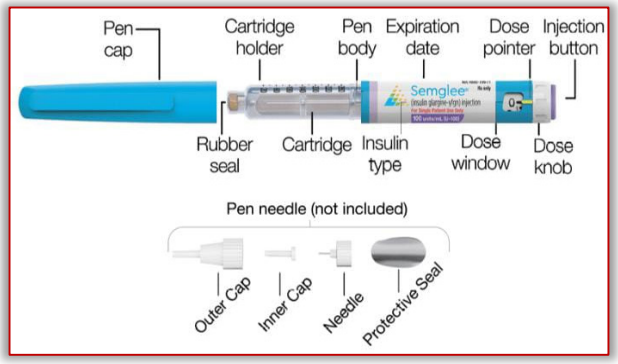

Figure 12: Coupled diagram of insulin pen

RESULT AND DISCUSSION

Figure 12 shows clearly delineates each component of the insulin pen, including the pen body, cartridge, needle, needle cap, dose dial, and dose display window. This clarity ensures that users can easily identify and understand the function of each part of the device. The diagram (figure 12) illustrates the sequential process of assembling the insulin pen, starting with the insertion of the cartridge into the pen body, followed by the attachment of the needle. The dose dial is then used to set the desired insulin dose, and the dose button is pressed to release the insulin. This step–by–step depiction helps users understand the proper assembly procedure and ensures accurate dosing.

Figure 12 further illustrates the mechanical interactions between the components of the insulin pen, such as how turning the dose dial adjusts the insulin dose and how pressing the dose button releases the insulin. These mechanical features are essential for facilitating the precise delivery of insulin and ensuring user confidence in the device's functionality. Safety features, such as the needle cap, are clearly depicted in the assembly diagram. The needle

cap serves to protect the needle when not in use, reducing the risk of accidental needlesticks and enhancing user safety. Additionally, the diagram may include features for preventing the reuse of needles, further reducing the risk of contamination.

The design of the insulin pen components reflects high–quality materials and construction, ensuring durability and reliability (figure 11). Components such as the pen body and cartridge are constructed from sturdy materials that can withstand repeated use, while the needle is designed for smooth insertion and minimal discomfort. These quality considerations contribute to the overall reliability and longevity of the insulin pen. Similarly, the ergonomic design of the insulin pen is evident in the assembly diagram, with features such as a comfortable grip and intuitive controls. The pen body is designed to fit comfortably in the user's hand, facilitating easy manipulation of the dose dial and dose button. These ergonomic considerations enhance the overall user experience, making the insulin pen accessible and user–friendly for individuals managing diabetes.

Testing insulin pen effectiveness involves assessing dose accuracy, usability, safety features, durability, and regulatory compliance (Sharp and Ives, 2021). Tests include laboratory studies, clinical trials, human factors testing, and post–market surveillance to ensure safe and accurate insulin delivery (Krishna, 2020; Payne et al., 2021). Dose accuracy testing involves evaluating the pen's ability to deliver precise doses across different volumes, considering factors like temperature variations and injection speed.

The equation for dose accuracy is often expressed as a percentage of the intended dose.

$$\text{Dose Accuracy} = \frac{\text{DELIVERED DOSE}}{\text{INTENDED DOSE}} \times 100 \quad (1)$$

In the above equation the following value to calculate dose accuracy. Dose Accuracy (%): The percentage of the intended dose that is actually delivered. Delivered Dose: The actual amount of insulin delivered by the pen, measured in units or another appropriate unit of measurement. The prescribed or set dose that the user intended to administer, also measured in units or the relevant unit of measurement. This equation gives a percentage that represents how close the delivered dose is to the intended dose. Ideally, the dose accuracy should be as close to 100% as possible, indicating that the delivered dose matches the intended dose precisely. Statistical analyses help interpret results and ensure compliance with regulatory standards. Incorporating healthcare professionals and end–users in the testing process is essential for gathering comprehensive feedback and addressing real–world challenges (Rima and Shah, 2016; Kesavadev et al., 2020).

Despite technological progress, challenges persist in insulin delivery devices. These include issues such as user interface complexity, needle–related injuries, portability concerns, and cost constraints. Addressing these challenges is crucial to further enhance the efficiency and usability of insulin delivery devices, ultimately improving diabetes management outcomes (Watterson et al., 2022).

Material selection is a critical aspect of insulin pen design, with considerations such as durability, friction properties, and compatibility with insulin formulations. Common materials used include medical–grade plastics, metals like stainless steel, and glass for insulin cartridges (Gillian and McCarthy, 2017.; Watterson et al., 2022). Bio–compatible coatings are applied to ensure safety during contact with insulin and the patient's skin. Design considerations focus on user–friendliness, durability, and compatibility with medical standards (Kyfonidis and Lennon, 2019). Insulin pens consist of various components, each playing a crucial role in insulin administration. These include the button, ratchet rotor, control cylinder, plunger, covering, jack screw, pawl, cartridge, needle, and cap. Each component is designed with precision and safety in mind, ensuring accurate insulin dosage, sterility, and protection against contamination and needle–related injuries.

Looking ahead, future directions in insulin delivery device development may involve the integration of emerging technologies and innovations. This could include advancements in smart insulin pens with digital connectivity for enhanced monitoring and dosage tracking. Additionally, further research into materials and design optimization could lead to even more user–friendly and efficient insulin delivery devices, ultimately improving diabetes management outcomes and patient quality of life.

CONCLUSIONS

The study highlights the continuous evolution and design considerations of insulin delivery devices, with a focus on developing a prototype insulin pen to address existing challenges. By

understanding the historical progression, current challenges, and future directions in insulin delivery device development, we can work towards improving diabetes management outcomes and enhancing the quality of life for individuals with diabetes.

The assembly diagram of the insulin pen reflects a well–engineered design that prioritizes user safety, ease of use, and manufacture–ability. By integrating ergonomic principles, mechanical precision, and clear user instructions, the insulin pen offers a reliable and user–friendly solution for individuals managing diabetes, contributing to improved health outcomes and quality of life. The designing and prototyping insulin delivery devices are crucial for improving healthcare efficiency and patient outcomes. Interdisciplinary collaboration, incorporating feedback loops, and leveraging emerging technologies are recommended for optimizing device design and functionality. Regular usability testing and validation with healthcare practitioners ensure that devices meet user needs and integrate seamlessly into healthcare workflows. By prioritizing these strategies, we can continue advancing medical device innovation and enhancing the quality of diabetes care.

References

[1] Economidou S.N, Uddin M.J, Marques MJ, Douroumis D, Sow WT, Li H, Reid A, Windmill JF, Podoleanu A. (2021). A novel 3D printed hollow micro needle micro electromechanical system for controlled, personalized transdermal drug delivery. Additive Manufacturing. 1;38:101815.

[2] Garg S.K, and McVean J.J. (2024). Development and Future of Automated Insulin Delivery (AID) Systems. Diabetes Technology & Therapeutics. 1;26(S3):1–6.

[3] Gillian M. and McCarthy, E. R. (2017). Design Experiments. Identifying areas for adolescents and young adults with type 1 diabetes. Design Experiments. Identifying areas for adolescents and young adults with type 1 diabetes, 14.

[4] Harper A, Wilson W, Choi Y.M. (2021).Development of a Simplified Insulin Pump Interface for Improved User Interaction. In Advances in Industrial Design: Proceedings of the AHFE 2021 Virtual Conferences on Design for Inclusion, Affective and Pleasurable Design, Interdisciplinary Practice in Industrial Design, Kansei Engineering, and Human Factors for Apparel and Textile Engineering, July 25–29, 2021, pp.184–191, Springer International Publishing.

[5] Hyllested–Winge, T.S. (2016). Medical Devices: Evidence and Research. NovoPen Echo®insulin delivery device, 1–9.

[6] Kar A, Ahamad N, Dewani M, Awasthi L, Patil R, Banerjee R. (2022). Wearable and implantable devices for drug delivery: Applications and challenges. Biomaterials. 283:121435.

[7] Kesavadev J, Saboo B, Krishna M.B, Krishnan G. (2020). Evolution of insulin delivery devices: from syringes, pens, and pumps to DIY artificial pancreas. Diabetes Therapy.11 (6):1251–69.

[8] Krishna, J.K. (2020). Evolution of Insulin Delivery Devices: From Syringes, Pens, and Pumps to DIY Artificial Pancreas. Evolution of Insulin Delivery Devices: From Syringes, Pens, and Pumps to DIY Artificial Pancreas, 19.

[9] Kyfonidis C, Lennon M. (2019). Making diabetes education interactive: tangible educational toys for children with type–1 diabetes. In proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1–12.

[10] Lilly L.C, Mader J.K, Warner J. (2019). Developing a simple 3–day insulin delivery device to meet the needs of people with type 2 diabetes. Journal of Diabetes Science and Technology. 13(1):11–9.

[11] Masierek M, Nabrdalik K, Janota O, Kwiendacz H, Macherski M, Gumprecht J. (2022). The review of insulin pens—past, present, and look to the future. Frontiers in endocrinology. 8;13:827484.

[12] Paun M.A, Schnegg A, Joly S, Orhan J.B, Lepple–Wienhues A, Dehollain C. (2019). Three–Dimensional Model and Evaluation of an Insulin Injection Pen for Precise Dose Capacitive Measurement. IEEE Access. 7:117426–35.

[13] Payne M, Pooke F, Chase J.G, Campbell J, Holder–Pearson L, Knopp J. (2021).The separation of insulin pump hardware and software–a novel and low–cost approach to insulin pump design. IFAC–Papers Online. 54(15):502–7.

[14] Pillalamarri S.S, Huyett L.M, Abdel–Malek A. (2018). Novel bluetooth–enabled tubeless insulin pump: a user experience design approach for a connected digital diabetes management platform. Journal of diabetes science and technology. 12(6):1132–42.

[15] Rima B. and Shah, M. P. (2016). Insulin delivery methods: Past, present and future. Insulin delivery methods: Past, present and future, 1–9.

[16] Rini C, Roberts B. C, Morel D, Klug R, (2019). Selvage B, Pettis RJ. Evaluating the impact of human factors and pen needle design on insulin pen injection. Journal of diabetes science and technology. 13(3):533–45.

[17] Schneider A.E, and Lange J. (2018). Pen devices for self–injection: contrasting measured injection force with users' perceived ease of injection. Expert Opinion on Drug Delivery. 1;15(2):115–25.

[18] Sharp P, and Ives E. (2021). Insulin delivery devices 100 years on. Practical Diabetes. 38(4):21–6.

[19] Sparre T, Hansen N.A, Wernersson A.S, Guarraia M. (2022). Development of an insulin pen is a patient–centric multidisciplinary undertaking: a commentary. Journal of Diabetes Science and Technology. 16(3):617–22.

[20] Watterson J.L, August A, Fourt J, Brettler T. (2022). The role of human–centered design in insulin pen innovation and the future of insulin delivery. Journal of diabetes science and technology. 6(3):623–7.

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USING STREAMLIT AND BASIC4ANDROID (B4A) TO CREATE THE SAME APPLICATION – B4A VERSION

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Abstract: The paper describes "Unfold Sheets Parts" application designed to unfold the sheet metal parts (the unfolding of the following types of surfaces: cylinder intersected by two planes – 2 variants, intersection of two/ three cylinders of equal diameter and cylindrical elbow) designed with two programming languages: Streamlit and B4A. The Streamlit version of application use Python & Matplotlib to generate the unfolded geometry and to plot the numerical & graphical results; the application is publicly available on the Internet, does not contain any viruses and not store data to any external server. The B4A version of application is available to download for smartphones as "UnfoldSheetsParts.apk" in the "Programming" section of reference; this application does not share data over the internet, the code runs entirely on the user's smartphone, does not contain any viruses and not store data to any external server. Specific elements of the two languages are presented in comparison, as well as the conceptual differences resulting from their use in the creation of the application.
Keywords: sheet metal parts, B4A version of application, Streamlit version

INTRODUCTION

B4A includes all the features needed to develop an Android app and is 100% free. The app code is written in the Integrated Development Environment (IDE) self–editor and can be tested on PC using an emulator or directly on smartphone using B4A–Bridge software or USB connection. B4A–Bridge is a free software which run on mobile device (smartphone or tablet) and was created using B4A. B4A–Bridge includes an internal FTP server, and the connection is made over the local network. Running the app using B4A–Bridge or USB will activate a dialog on the device to confirm the app's installation on the device, because Android doesn't allow the installation from unknown sources. The B4A–Bridge installation and connection process are detailed in reference [5].

THE REQUIRED SOFTWARE PACKAGES

To develop a B4A app the following software packages are required to install on PC following steps specified in reference [6]:

- Oracle Java 8;
- Android SDK Command line tools + Required Resources;
- B4A;
- B4A–Bridge – allows the IDE to connect to the device over the wireless network as an alternative to USB debug mode, which is also supported.

B4A is a tool development for Android applications developed by Anywhere Software and the language is similar to Visual Basic with additional support for objects and driven by events. In B4A, a page displayed to a user is named Activity and a control placed on Activity is named View. The details of Views are saved in a file named Layout with the "bal" extension. The code which controls the Layout is called an Activity Module. After installation the following tools are available in the B4A environment:

- an Integrated Development Environment (IDE) – it is a code editor provided with menus and toolbars, module tabs, code area, windows area, logs and windows tabs;
- Visual Designer – organize Views into Layout and see how they look on either an emulator or a real device; the following type of controls can be placed on Activity: Button, Check Box, Edit Text, Horizontal Scroll View, Image View, Label, List View, Panel, Progress Bar, Radio Button, Scroll View, Seek Bar, Spinner, Tab Host, Toggle Button, WebView, Custom View (Animated Counter, Another Progress Bar, B4X Bread Crumb, B4X ComboBox, B4X Float Text Field, B4XImageView, B4XSeekBar, B4X Switch, B4XPlusMinus, Round Slider, B4X Loading Indicator, Swift Button, B4X Radio Button, Custom List View, Made With Love, Scrooling Label); the Layout created in Visual Designer

can be saved by typing Ctrl+S and is recommended to save with the same name like the Activity module; the Visual Designer environment is detailed in reference [7];

- Libraries Manager – contain SQL databases, GPS, serial ports, camera, Web services, JSON, animations, network, Text to Speech, Voice Recognition, WebView, Charts, Graphics and others;
- B4X suite – a library for B4A (Android), B4i (IOS), B4R (Arduino) and B4J (desktop, server and Raspberry Pi) allowing to develop cross–platform applications; using cross–platform libraries, B4A, B4J and B4i projects can share 90% of the code;
- the Android Virtual Device Manager (AVD) is a utility provided by Google as part of the Android SDK which allows to create emulated Android devices; through this tool many devices can be created, with different hardware specifications and different screen resolutions;
- Debugger – debugging is the process of removing errors in the code using breakpoints and logging events, which produces messages in the Logs tab placed at the right of the IDE;
- Compiling – to test and distribute the app, the B4A code must be compiled by converting into Java files and create a Manifest file and an APK file which are stored in the Objects folder of the project.

To develop a B4A project a folder in which will be saved the B4A code and other files must be created. Every project consists of one or more files with code called modules. Every project has an Activity Module called "Main" which is stored within a file with the extension "b4a" and cannot be changed. It may also contain other modules which are stored in folder:

- Activity modules – an app need several different screens; each one of these will require its own activity module; Activity modules are paused when they are not visible; if only Activity are used in the project is not possible to run any code while the application is not visible;
- Class modules – a class represents an object and encapsulates the data and functionality of that object; a class contains properties, which gives the state of a particular instance, and methods, which allow the properties of an instance to be manipulated or queried;
- Code modules – code modules contain only code; no Activity is allowed in Code modules; the purpose and advantage of code modules is that they allow the same code to be shared in different programs;
- Service modules – used to run the app when this is not visible; a service is unaffected by the currently visible activity; this allows to run tasks in the background; services usually use status bar notifications to interact with the user and do not have any other visible elements.

A complete documentation about Basic4Android is specified in reference [8]. Also, the B4A full documentation can be found at reference [9], where can be downloaded all booklets and tutorials source code.

THE APPLICATION STRUCTURE

A general view of the B4A Integrated Development Environment, Library Manager and Compiling window are presented in Figure 1. Figure 2 shows a general view of Visual Designer.

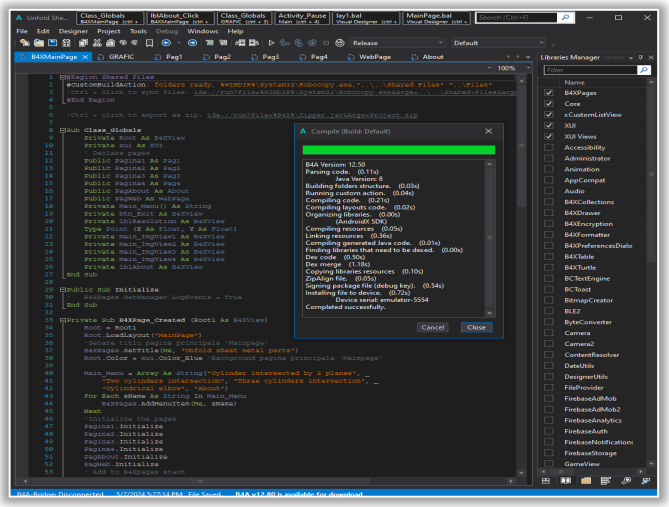


Figure 1. The B4A IDE & Library Manager

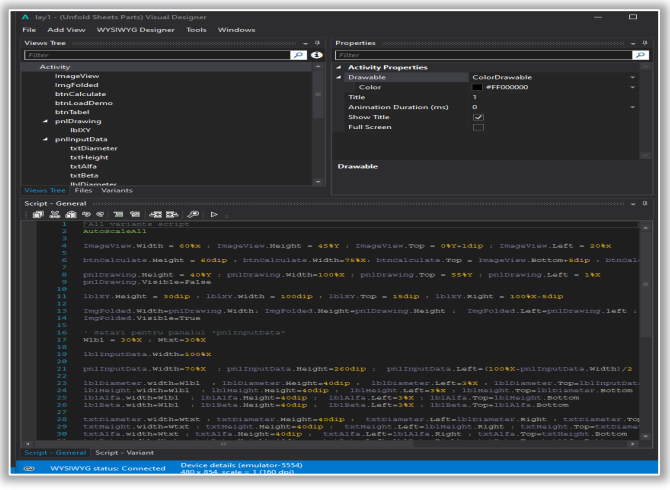


Figure 2. The Visual Designer

The folder content of the "Unfold Sheets Parts" application is presented in Figure 3, where:

- B4A – is the folder of Android app, which is described in the present paper; the content of B4A folder is shown in Figure 4; the folder Files

contain the 18 images and also the Layout (about.bal, lay1.bal, lay2.bal, lay3.bal, lay4.bal, layweb.bal, mainpage.bal) used by the application; the content of B4A app Objects folder is shown in Figure 5;

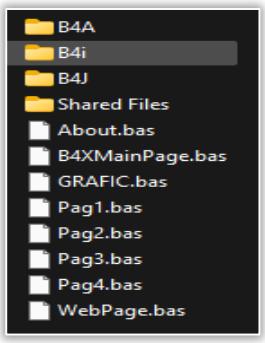


Figure 3. The structure of the "Unfold Sheets Parts" application

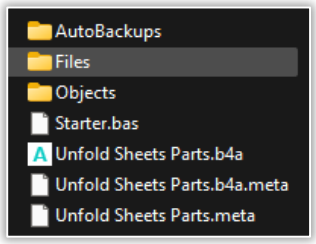


Figure 4. The content folder of B4A app

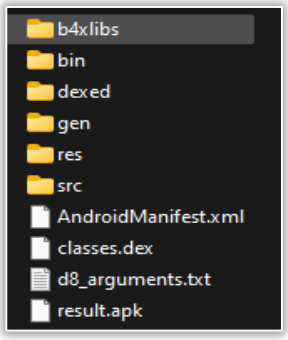


Figure 5. The content of B4A app Objects folder

- B4i – is the folder of IOS app, which is not covered in this paper.
- B4j – is the folder of desktop, server and Raspberry Pi app, which is not covered in this paper.
- Shared files – is the folder where are placed common files between B4A, B4i and B4j.
- B4XMainPage.bas – is the main module which create the interface presented in Figure 6; the vertical three dots placed at top–right open a menu used to launch modules Pag1.bas ÷ Pag4.bas or About.bas; the icon is used to exit the application; at right side of this icon the smartphone resolution is displayed; the icon launch the About.bas module; also, by left mouse click on any image, one of the modules Pag1.bas ÷ Pag4.bas can be launched;
- Grafic.bas – is the proprietary module responsible for plotting the geometry or an unfolded drawing;
- Pag1.bas – is the module 1 responsible for calculation and plotting the result for the "*One cylinder intersected with 2 planes*" option with the interface presented in Figure 7.
- Pag2.bas – is the module 2 responsible for calculation and plotting the result for the "*Two cylinders intersection*" option with the interface presented in Figure 8.
- Pag3.bas – is the module 3 responsible for calculation and plotting the result for the "*Three cylinder intersection*" option with the interface presented in Figure 9.
- Pag4.bas – is the module 4 responsible for calculation and plotting the result for the "*Cylindrical elbow*" option with the interface presented in Figure 10.
- About.bas – is the module responsible for general information about the app.
- WebPage.bas – is the module responsible for author info.

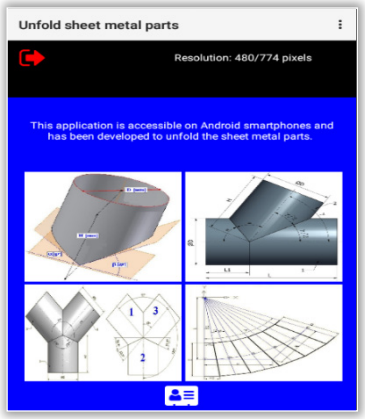


Figure 6. The main window of the B4A app

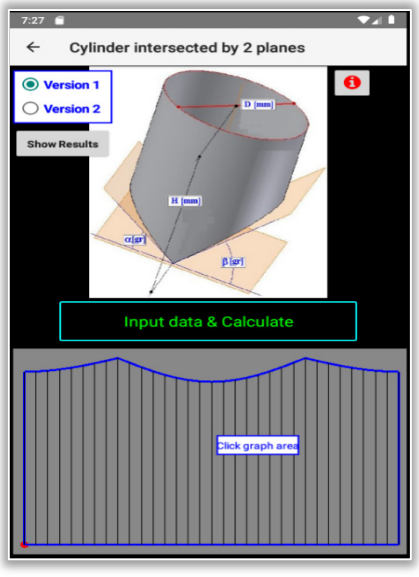


Figure 7. The main window of the module 1

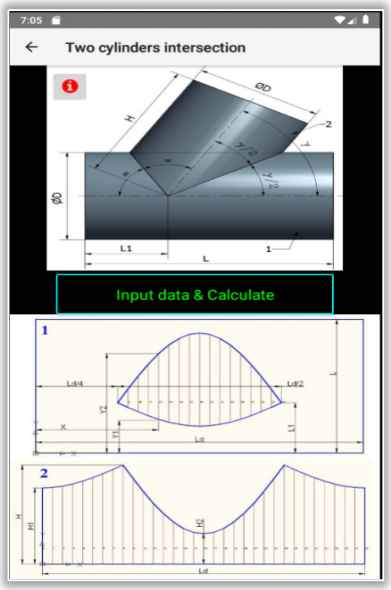


Figure 8. The main window of the module 2

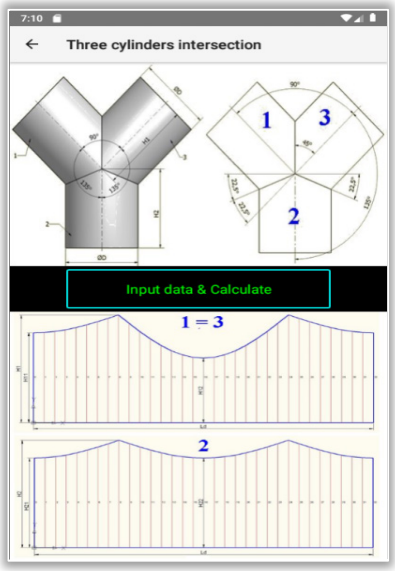


Figure 9. The main window of the module 3

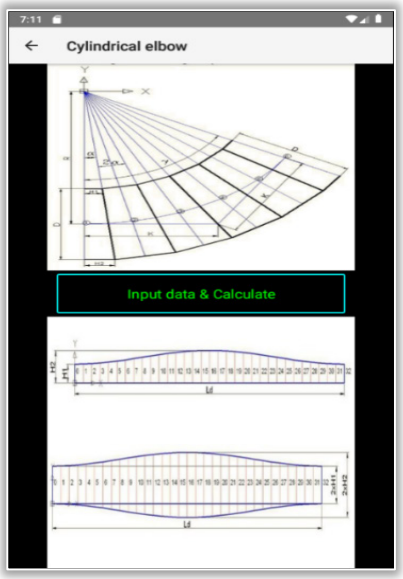


Figure 10. The main window of the module 4

Figure 11 show the fields required for module 1 "One cylinder intersected with 2 planes" while Figure 12 show the message with numerical results generated after click on Calculate button. Figure 13 show the fields required for module 2 "Two cylinders intersection" while Figure 14 show the message with numerical results generated after click on Calculate button.

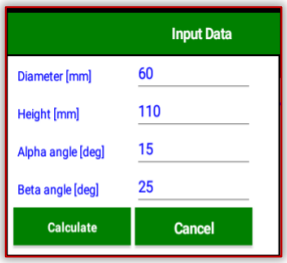


Figure 11. The fields required for module 1

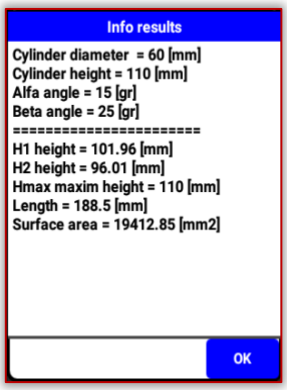


Figure 12. The Info results message for module 1

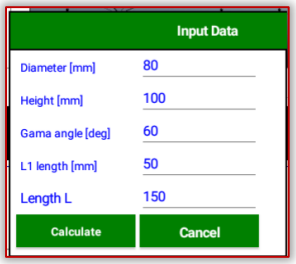


Figure 13. The fields required for module 2

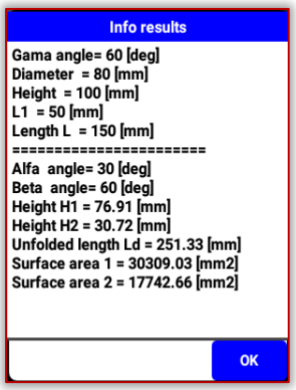


Figure 14. The Info results message for module 2

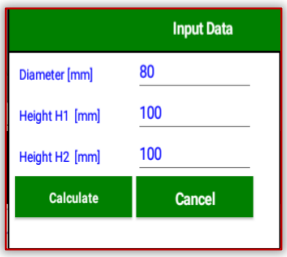


Figure 15. The fields required for module 3

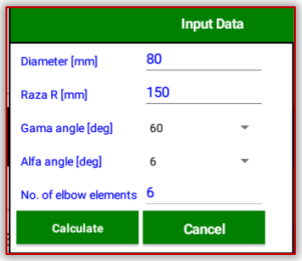


Figure 17. The fields required for module 4

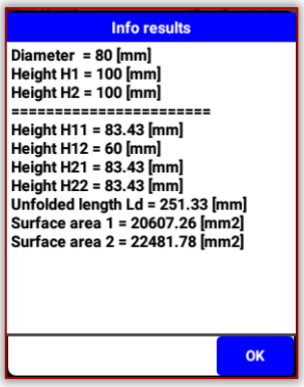


Figure 16. The Info results message for module 3

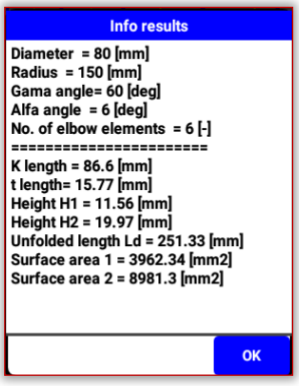


Figure 18. The Info results message for module 4

ID/Angle	X [mm]	Y [mm]
1 / 0	0.0	101.96
2 / 11.25	5.89	102.12
3 / 22.5	11.78	102.57
4 / 33.75	17.67	103.32
5 / 45	23.56	104.32
6 / 56.25	29.45	105.53
7 / 67.5	35.34	106.92
8 / 78.75	41.23	108.43

Figure 19. The Results table for module 1

Figure 15 show the fields required for module 3 "Three cylinders intersection" while Figure 16 show the message with numerical results generated after click on Calculate button. Figure 17 shows the fields required for module 4 "Cylindrical elbow" while Figure 18 show the message with numerical results generated after click on Calculate button. For module 1 the unfolded drawing is presented in Figure 7 and the numerical results are presented in tabular format in Figure 19, generated after click on Show Results button from the same Figure 7.

THE GRAFIC MODULE

The proprietary module Grafic.bas was used in all cases when must be drawn the geometry or an unfolded drawing and contain the following routines:

- Public Sub Initialize (iTarget As Panel, iCanvas As Canvas, iXGmin As Float, iYGmin As Float,iXGmax As Float, iYGmax As Float) – with the following parameters: Panel, Canvas, drawing limits which must be call before any drawing process;
- Sub RealToPix (Xreal As Float, Yreal As Float) As Point – to convert real coordinates into drawing coordinate;
- Sub PixToReal (Xpix As Float, Ypix As Float) As Point – to convert drawing coordinates into real coordinate;
- Public Sub DrawCurve (iListXY As List, iCuloare As Long, iGrosime As Int, iMarcare As Boolean, iEraseScreen As Boolean, iNX As Int, iNY As Int) – with the following parameters: coordinates array, the curve color and width, option to mark the curve or erase the drawing area and number of horizontal & vertical lines of rectangular grid.
- Public Sub DrawGrila () – to draw the horizontal & vertical rectangular grid.

The next line will initialize the chart:

chrt.Initialize (pnlDrawing, cvsDrawing, XGmin, YGmin, XGmax, YGmax)

where chrt must initially be declared in Sub Class_Globals with the following declaration:

Public chrt As GRAFIC

Then, a curve can be drawn on canvas with the following call:

chrt.DrawCurve (ListXY, Colors.Blue, 3dip, False, True,0, 0)

where the ListXY array must be converted into pixel coordinates by calling RealToPix routine.

For module 1 an example of unfolded drawing is presented in Figure 7. For module 4, Figure 20, 21, 22 shows example of elbow geometry drawn with Grafic module.

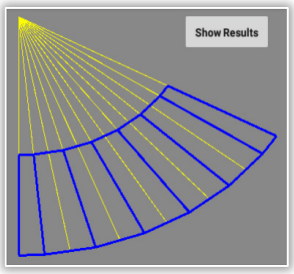


Figure 20. The elbow geometry for γ=60 α=5 no.=7

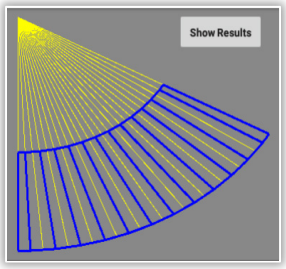


Figure 21. The elbow geometry for γ=60 α=2.5 no.=13

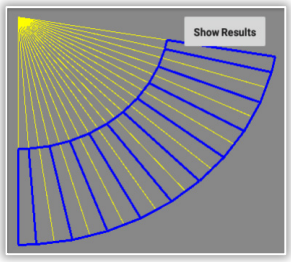


Figure 22. The elbow geometry for γ=80 α=4 no.=11

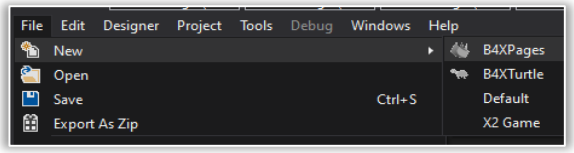
STEPS TO CREATE A B4A APPLICATION

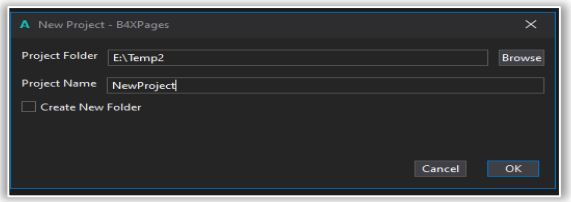
The process of creating a new B4A application must follow the next steps:

- load the B4A IDE environment with click on B4A icon;
- from B4A main menu select File → New → BXPages; in the New Project window specify the Project Folder and Project Name, Figure 23;
- the structure folder from Figure 23 is created; the three folders B4A, B4i and B4J include the codes required to create applications for Android, IOS, computers (Windows, Linux platforms) respectively; in the B4A folder there is the "Files" folder containing the files created with the Visual Designer and files used during the execution of the code, like images or videos; also the mainpage.bal file was created automatically, while the Shared Files

folder includes files that the three different type applications can share;

- also, the B4XMainPage is created with minimal code included, Figure 24, saved in B4XMainPage.bas file; the B4XMainPage is always the user's first contact form with the application;
- to insert new pages select from the menu Project → Add New Module → Class Module → B4XPage and give it the desired name; a number of pages can be created function the application requirements;
- from B4A main menu select Tools → Run AVD Manager; in this environment it is possible to create many emulated devices configuration with different hardware specifications and screen resolutions [10]; to connect to a emulated device select WYSIWYG → Connect option menu from Visual Designer;
- to open the Visual Designer select from the menu Designer – Open Designer; the mainpage.bal file is open with a minimal interface containing only Button1 control placed in the Activity, Figure 25; other controls can be placed on this view or others views used Add View option menu from Visual Designer interface;
- click on  icon from B4A main menu or press F5 keyboard taste to start the compiling process;
- after a successful code compilation, B4A will look for any selected emulated device or a real devices which have been connected to the computer and will provide a list of those devices; the real or emulated device can be selected from that list to run the compiled code.





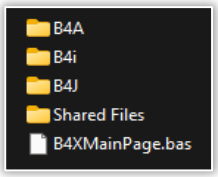


Figure 23. Create a new project

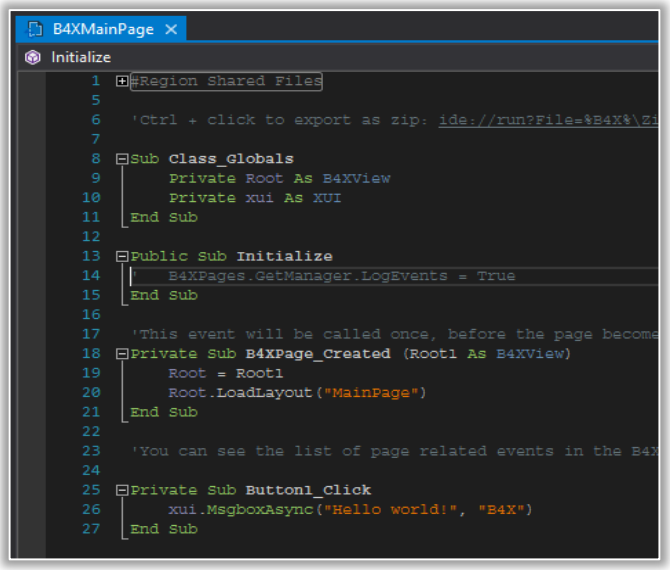


Figure 24. The B4XMainPage

The left side of Visual Designer from Figure 25 show a preview of the controls placed in the Activity window, while the right side contain the list of control placed in the view; click on any control will activate the properties of the selected control like: Name, Type, Event Name, Parent and others; these properties depend of the selected type control and can be modified by the programmer; also, the Script – General window can be used to define the controls position with code lines. The "Files" folder can be used to add images or icons used in the view. The "Variants" folder can be used to define different screen sizes and orientations of the emulator; so it is possible to create multiple layout variants, one to match every different device, and to adapt to changes in device orientation.[11]

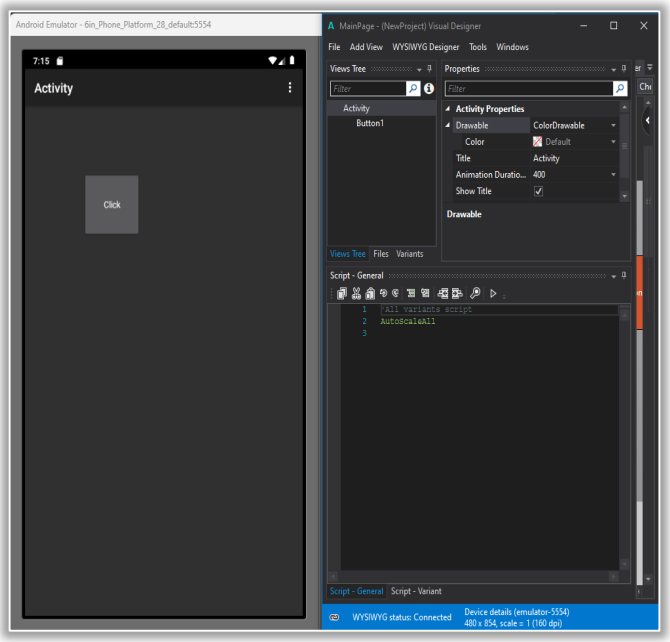


Figure 25. The mainpage interface in Visual Designer

CONCLUSIONS

The application was created in Basic4Android software and can be run on smartphones type only.

The limits of this paper length do not allow detailing all modules, but the application's complete code is available for download as zip file "'"UnfoldSheetsParts–Project.zip" from reference [4] at "Programming" section.

References

[1] *** Streamlit How is Streamlit works? https://streamlit.io/
[2] *** Guides for B4A, How to work with B4XVisualDesigner? https://www.b4x.com/guides/B4XVisualDesigner.html
[3] *** Autors application built by Basic4Andorid https://unfoldsheetsparts.streamlit.app/
[4] *** Autors application built by Streamlit https://dorian–nedelcu.streamlit.app/
[5] *** TinyURL, How TinyURL shortening web service, which provides short aliases for redirection of long URLs? https://tinyurl.com/224zmad3
[6] *** Basic4Android How is Basic4Android works? https://www.b4x.com/b4a.html
[7] *** Basic4Android, How to Install link for B4A software? https://www.b4x.com/b4a.html
[8] Wyken Seagrav 2015 Rapid Android App Development using BASIC, Penny Press Ltd.
[9] *** Basic4Android, Full documentation for B4A, https://www.b4x.com/android/documentation.html
[10] *** Android forum for B4A Where to find information for Basic4Andorid software? https://www.b4x.com/android/forum/threads/gui–avd–manager–emulator.80348/

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OVERVIEW OF THE USE OF BINAURAL MEASUREMENTS TO EVALUATE SOUND QUALITY

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Abstract: This paper provides an overview of the use of binaural measurements and psychoacoustic evaluation of sound quality in various industries. Currently, product manufacturers focus on reducing the noise emitted by their products. Some product groups must comply with specified standards regarding sound power levels. However, not always the amount of sound produced is the only criterion that is taken into account. Sound quality and how customers perceive it is also important. Therefore, they focus on improving it. Psychoacoustics as a scientific discipline offers new perspectives and methods of optimizing the acoustic performance of products focused on sound quality.
Keywords: sound quality, psychoacoustics, binaural measurements, sound quality

INTRODUCTION

The basic concept of sound quality is to determine how people perceive it, which was proposed by Blauert in 1994 [1]. Sound quality, a characteristic of sound that influences listeners' perception, plays an important role in determining listener and customer satisfaction. With advances in noise control technologies, sound quality research, which examines how people recognize, evaluate and perceive sound, has become an important subject of interest, especially in the automotive, transportation, and electrical appliance industries around the world. [2][3]

The concept of sound quality, which can be applied to describe both positive (music, speech) and negative effects (noise), finds a generalization in the concept of sound quality of the product [4]. In its most general sense, the term also covers traditional aspects of sound quality, since concert halls, musical instruments, musical performances, sound equipment, noisy production machinery, equipment or automobile which are the cause of noise are also 'products' in the broad sense of the word.

Blauert and Jekosh [5] define product sound quality as "the adequacy of sound in the context of a specific technical objective and/or task". For all products that produce perceptible sound, the sound quality of the product is assessed with each use.

The goal of product sound quality is not only to make the sound pleasant, just as with noise control, the only goal is not to minimize the sound level. A more important factor than the pleasantness of sound is often the informational value of the sound. Passing on information about the state of operation of a product is often a factor that determines why sound perception is desirable. In particular, if the subject has been exposed to the sound of the product many times, the sound system serves as a very sensitive indicator of the functional state of the device that emits the sound. [6][7][8]

The artificial psychoacoustic head (Figure 1) is a self–contained measurement device that allows accurate binaural recordings to be performed immediately after switching on. Recordings can be stored directly on the memory card, which allows independent operation without the need for a computer. Thanks to the authentic recording and playback of any sound events and their digital archiving, the system enables a comparative and accurate assessment of various possible sound events. Because psychoacoustic head technology is compatible with traditional measurement technology, subjective and objective sound field analyzes can be combined in one survey. Thanks to the patented head geometry, it is possible to mathematically describe the reproduction of the geometry of the human head and shoulders, as well as the exact reproduction of all acoustically relevant parts of the human outer ear.[9][10]

Figure 1. Artificial Head Measurement System

The application possibilities of the artificial psychoacoustic head include:

- optimization of sound design of products,
- analysis and optimization of sound quality of technical products (cars, household appliances, power tools and others),
- product development and quality control through binaural measurements.

The field of environmental acoustics has undergone significant changes in the last two decades. The broad multidisciplinary discussions undertaken in the scientific community to better understand the large variations in noise annoyance responses fostered the development of a new, participatory, and positive-oriented approach known as the soundscape approach.

In contrast with the traditional approach, which aims at protecting and mitigating noise pollution based on outdoor noise simulation models and limit values derived from noise annoyance dose–response curves at a large territorial scale, the soundscape approach focuses on describing or designing the quality of acoustic environments, mainly at a local scale and through the involvement of individuals.

AUTOMOBILE INDUSTRY

Psychoacoustic investigation of sound quality in the automotive industry refers to virtually all sounds present in the acoustic environment of a vehicle, such as the sound of doors closing, starter sound, engine noise, tire noise, wind noise, electric window opening sound, air conditioning system noise and car radio sound. [11]

In Kousuke Noumura and Junji Yoshida [12] they talk about sound quality as an important factor that influences sales and customer interest. In the article Modeling perception and quantifying sound quality in the cabin, they write that in order to increase the overall marketability of a car, it is necessary to improve sound quality. In this article, they talk about sensory evaluation tests that are carried out on locals in the USA, Germany and Japan, and the perception of car interior sounds is analyzed.

The results of the statistical analysis indicate that perception is divided into two main categories: luxury and sports, and that even people with different preferences perceive luxury and sports equally.

The Japanese with the highest percentage preferring sound for sports acceleration, followed by Americans and Germans. In this research, an algorithm is proposed to calculate psychoacoustic metrics such as volume and force of fluctuation, which they say are basic metrics for evaluating sound quality.

The results of various studies have shown that both interaction effects, vibrations have both positive and negative effects on the perception of sound. It has been partially observed that vibration can reduce noise interference. [13]This effect is very interesting for sound and vibration design in the automotive industry. [14][15]

However, some studies have confirmed that there is no evidence of an interaction between sound and vibration. For example, Amman [16], assumes that there is no significant interaction between sound and vibration and states that "setting sound and vibration targets for automotive programmes that are independent of each other seems to be a justified approach.

Sound quality studies in the automotive industry also focus on sounds such as the sound of car doors closing. The sound from closing the vehicle doors has two main functions. First of all, it signals that the door has been closed correctly, which means that it must be loud enough for passengers to hear.

In addition, it can contribute to the overall impression of the car which is very important, since closing the door is one of the operations that the customer can perform when viewing the car in the dealer's lobby. It was the sound of doors closing that Etienne Parizet, Erald Guyader and Valery Nosulenko focused on in the article Analysis of the sound quality of closing car doors. They analyzed the perception of the sound from closing the car door, emphasizing the image of the quality of the car that the listener can have in mind with this sound. They carried out different experiments such as classification experiment, pair comparisons with the evaluation of similarity and preferences and, finally, the analysis of free verbalization.

The results showed that although volume appeared to be the most important sound parameter in previously published studies, this one did not. The reason, according to the authors, was likely that previous studies had only focused on nuisance caused by sounds. [17]

Studies of car sound quality also look at other parts of the vehicle, such as horn sound. Guillaume Lemaître et al. [18]In their research, Horn Sound Quality: A Psychoacoustic Study of Timbre, they focused on the sound of horns. The aim of their article was to study the perceived quality of horn sounds in order to help design new sounds in a psychoacoustic frame.

Figure 2. Measurement of the sound of closing car doors

Car horns are used for their main and legal function, which is to warn road users of potential danger. The sound of the horn must be clearly interpretable as a warning. But at the same time, horn manufacturers want to tune their sounds to match car categories and brand identities. Thus, horn sound design involves a trade–off between the need to customize the sound and the need to provide effective warning signals.

To meet these limitations, horn manufacturers want to create new sounds using a new device, made from an electronic synthesizer and speaker. In this context, the aim of this study was to identify the characteristics of horn sounds that convey information about danger to the listener. This will allow horn manufacturers to design new sounds that are still perceived as warning signs for cars. The aim was to provide horn manufacturers with acoustic specifications.

PUBLIC TRANSPORT

The automotive industry is not the only one in which psychoacoustic measurements are applied. The psychoacoustic assessment of sound quality, for example in the interior of trains, was devoted to Guillaume Lemaitre et al. [19] The research focused on the effect of background noise on a train on passenger activities. Their article "How does train background noise affect passengers' actions? – The establishment of noise thresholds" providing comfort to passengers refers to a study of passengers' perception of interior train noise in order to determine acoustic thresholds for different passenger activities. One of the main advantages of rail transport is that it allows passengers to engage in various activities while driving, such as reading, working, watching movies, etc. Therefore, in this research, they decided to determine the acoustic thresholds by conducting an experiment in which participants sat in a mockup of a high–speed train and performed tasks common to first and second class passengers (watching a TV series and reading text).

During the execution of the tasks, participants in the experiment were played different background sounds and evaluated to what extent these sounds affected their activities (acceptability rating). The results showed that, overall, reading text requires a quieter environment than watching a movie. Interestingly, the results also showed that only the volume of sounds affected participants' judgment when their attention was distracted from assigned tasks by sounds.

Our previous work with similar sounds showed that perception was also influenced by other, different sound characteristics when their attention was focused on sounds. Therefore, using a greener setup than in this experiment seems more appropriate for determining which aspects of train noise are important to consider.

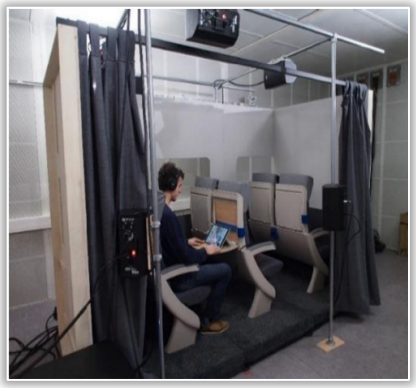

Figure 3. Person performing assigned tasks in a train block

Enlai Zhang et al. [20] also devoted themselves to acoustic comfort in public transport. Specifically, in their article Comprehensive evaluation model of acoustic comfort of the interior of an electric bus and its application, they dealt with acoustic comfort in a sample of eight electric buses. In this paper, 64 noise samples were obtained from eight electric buses, and their corresponding degrees of acoustic comfort are obtained by subjective evaluation tests using a score comparison method.

Measurements were taken with the air conditioning on and off as two working conditions. They also ran in two places in the bus, in the driver's seat and in the rear seat (Figure 3) and at speeds of 30 km/h and 50 km/h. During the test, the vehicles drove separately on a professional track, and with stable operation of the vehicle, a handheld–mounted handheld binaural acquisition system Squadriga II and BHS II was used to collect internal noise signals.

A jury of engineers, drivers and acoustics experts with extensive experience in bus noise was

organised for the subjective evaluation tests. Acoustic comfort was identified as a subjective evaluation index, a method of evaluating scores, and acoustic comfort was divided into ten standard levels from 1 to 10.

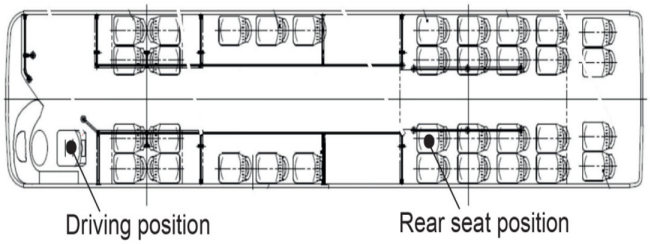

Figure 4. Measuring points on the bus

AIR CONDITIONERS

The rating of sound quality and acoustic comfort of users applies not only to the automotive industry, but also to various types of electrical appliances. For example, air conditioners are considered the main source of noise in the built environment. Both the sound level and sound quality of the air conditioner can really affect the acoustic comfort of the user.

The aim of the study, titled Multidimensional psychological assessment of air conditioning sounds and prediction using correlation parameters, authored by Yoshiharu Soeta and Ei Onogawa [21] was to find out factors that significantly influence the subjective response to the sound of air conditioners. Subjective loudness, sharpness, and harassment were evaluated using the pair comparison method.

A binaural microphone (BHS I, HEAD Acoustics) was used for measurement. The sounds were generated by three output units and one air conditioning input unit in a reflection–free room. The stimuli were presented to the participants binaurally using headphones (HD800, Sennheiser). Subjective volume, sharpness and annoyance caused by air conditioning sounds were evaluated.

Multiple linear regression analysis showed that the LAeq energy index was a significant factor influencing the perception of volume, sharpness and annoyance of air conditioning sounds.

Jin Yong Jeon [22] in the article Subjective and objective evaluation of air conditioning noise, it is devoted to the evaluation of sound comfort of air conditioning units.

The noise from the air conditioning system installed in the ceiling of the classrooms was evaluated by examining the subjective responses to air conditioning noise.

The results of multiple regression analysis of psychoacoustic parameters and subjective preferences showed sharpness as a major factor in describing the sound quality of air conditioning noise. A semantic differential test was also conducted to evaluate the sound quality characteristics of the air conditioner.

CONCLUSIONS

The authors of this article describe the possibilities and areas of use of binaural measurements in psychoacoustic evaluation of sound quality. Whereas the use of binaural recording and psychoacoustic analysis is well known in the field of product sound quality especially with respect to the automotive field, the application of these tools within the soundscape analysis is new. The article describes the use of these ratings in the automotive, public transport and other industries. The binaural recording using an artificial head is the only and simply method to capture sound events comparable to the human ears. Using calibrated equalized headphones it is possible to reproduce earsignals at the listener ear to create the same hearing event like in the original sound situation.

For more than 40 years applications of binaural recordings are being intensively used in the automotive industry to optimize vehicle interior sound. That means the advantage of this technology for the analysis of complex sound situations in combination with assessment and evaluation is proven since a long time.

Binaural perception has been acknowledged as a crucial aspect in evaluating acoustic environments as humans perceive acoustic environments through binaural hearing, which allows the perception of spatial characteristics in addition to spectral and temporal characteristics.

Acknowledgement

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References

[1] Blauert J. Product–sound assessments: An enigmatic issue from the point of view of engineering. Proc internoise94, Yokohama, Japan, vol. 2; 1994. p. 857–62

[2] JEKOSCH U. Meaning in the context of sound quality assessment. Acta Acustica 1999; 85(5):681–4.

[3] JIAO FL, LIU K. Sound quality in noise control: II. Subjective assessment. Proceedings of 2003 national conference environmental acoustics; 2003

[4] BLAUERT, J.; JEKOSCH, V.: Sound – quality evaluation: A multi – layered problem. Acta Acustica United with Acustica, 83 (5), 1997, 743–753 p.

[5] BLAUERT, J.; JEKOSCH, U.: A layer model of sound quality. J. Audio Eng. Soc., 2012, 60(1/2), 4–12 p.

[6] FUCHS, A.; NIJMAN, E.; PRIEBSCH, H., H.: Automative NVH Technology. Springer, 2016, 117 p

[7] IVANOV, B.; ONG, T., H.: Influence of individual trim items on the acoustic behavior of the car interior. Chalmers University of Technology, Sweden, 2007, 124 p
[8] SWART, D., J.: The psychoacoustics of electric vehicle signature sound. Stellenbosch University, 2018, 173 p.
[9] HOWARD, D., M.; ANGUS, J.: Acoustics and psychoacoustics. Elsevier, 2006, 405 p.
[10] HOWARD, D., & ANGUS, J. (2009). Acoustics and psychoacoustics. Fourth edition. Focal Press, Oxford, UK. 496 strán.
[11] A. MISKIEWICZ AND T. LETOWSKI, "Psychoacoustics in the Automotive Industry", Acta Acustica United with Acustica, vol. 85, pp. 646–649, Sept 1999.
[12] NOUMURA KOUSUKE, JUNJI YOSHIDA. Perception modeling and quantification of sound quality in cabin. UAE paper 2003; 01:1514.
[13] GENELL, A.; VÄSTFJÄLL, D.: Vibrations can have both negative and positive effects on the perception of sound, Int. J. Vehicle Noise and Vibration, Vol. 3, No. 2, 2007
[14] BELLMANN, M.: Perception of whole–body vibrations: from basic experiments to effects of seat and steering wheel vibrations on the passenger's comfort inside vehicles, dissertation, University of Oldenburg, Germany, 2005
[15] DARE, T., P.; BERNHARD, R. J., Accelerometer Measurements of Tire Tread Vibrations and Implications to Wheel–Slap Noise, Tire Science and Technology, Vol. 41, 2013, 109–126 p.
[16] AMMAN, S.; MOUCH, T.; MEIER, R.: Sound and vibration perceptual contributions during vehicle transient and steady–state road inputs, Int. J. Vehicle Noise and Vibration, Vol. 3, No. 2, 2007
[17] ETIENNE PARIZET, ERALD GUYADER, VALERY NOSULENKO. Analysis of car door closing sound quality. Applied Acoustics, Elsevier, 2008, 69, pp.12–22.
[18] LEMAÎTRE, GUILLAUME & SUSINI, P. & WINSBERG, SUZANNE & MCADAMS, STEPHEN & LETINTURIER, BORIS. (2007). The sound quality of car horns: A psychoacoustical study of timbre. Acta Acustica united with Acustica. 93. 457–468.
[19] LEMAÎTRE, GUILLAUME & AUBIN, FABRICE & LAMBOURG, CHRISTOPHE & LAVANDIER, CATHERINE. (2022). How does the train background noise affect passengers' activities? Determining thresholds of noise levels ensuring a good comfort for passengers.
[20] E. ZHANG, et al.: A COMPREHENSIVE EVALUATION MODEL OF ELECTRIC BUS INTERIOR ACOUSTIC COMFORT AND ITS APPLICATION, International Journal of Acoustics and Vibration, Vol. 27, No. 4, 2022 (pp. 361–366)
[21] SOETA YOSHIHARU, ONOGAWA EI, Multidimensional Psychological Evaluation of Air Conditioner Sounds and Prediction via Correlation Parameters, Frontiers in Built Environment, VOLUME 7, 2021
[22] JEON, JIN YONG & YOU, JIN & KIM, SU. (2006). Subjective and objective evaluation of air–conditioning noise. The Journal of the Acoustical Society of America. 119. 3412

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We are extremely grateful and heartily acknowledge the kind of support and encouragement from all contributors and all collaborators!

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