Proceedings of

ISERD

INTERNATIONAL CONFERENCE

06th - 07th August, 2025



MELBOURNE

AUSTRALIA

In Association With:

RC Research Conferences

WRS World Research Society

PROCEEDINGS OF

ISERD

INTERNATIONAL CONFERENCE

MELBOURNE, AUSTRALIA

Organized by

Date of Event

06th – 07th August, 2025

In Association With

Corporate Address

IRAJ INTERNATIONAL
Address: IFZA Business Park, DDP Premises Number 49839 001
A1-3641379065, Dubai, UAE
Mail: info@iraj.in, www.iraj.in

Publisher: **IRAJ INTERNATIONAL**

© 2025, ISERD International Conference, Melbourne, Australia

ISBN: 978-93-90150-29-8

Edn: 549

No part of this book can be reproduced in any form or by any means without prior written permission of the publisher.

Disclaimer: Authors have ensured sincerely that all the information given in this book is accurate, true, comprehensive, and correct right from the time it has been brought in writing. However, the publishers, the editors, and the authors are not to be held responsible for any kind of omission or error that might appear later on, or for any injury, damage, loss, or financial concerns that might arise as consequences of using the book.

Type set & Printed by:

ITR Group

Khandagiri, Bhubaneswar

About IRAJ International:

IRAJ International is an advanced global organization for the Researchers & Scholars "To promote the Progress of Science, Technology and Management" by displaying their knowledge in the vicinity of Science Technology and Management for the service of mankind and the advancement of the general welfare. We have been standing tall in the field of Research & Technology since 2013, our objective is to provide a platform which will promote, encourage and support Scholars, Researchers & Professionals to carry and accomplish their research work.

IRAJ International connects Global innovators, Scientists, Engineers, Doctors, Management professionals, industry practitioners by conducting and sponsoring technical meetings, conferences, symposia, and exhibitions globally. IRAJ International Previously known as Institute of Research and Journals-IRAJ is one of the largest Professional bodies for Research Scholars worldwide, established in 2013, with headquarters at Dubai, UAE and branch office at Bhubaneswar, India. IRAJ International reach extends to every part of the globe, with more than 60000 professional members and 50000 student members.

Objective of IRAJ International:

- To provide a world class platform to researchers to share the research findings by organizing International/National Conferences.
- To use the research output of the conference in the class room for the benefits of the students.
- To encourage researchers to identify significant research issues in identified areas, in the field of Science, Engineering, Technology and Management.
- To help dissemination of their work through publications in a journal or in the form of conference proceedings or books.
- To encourage regional and international communication and collaboration; promote professional interaction and lifelong learning; recognize outstanding contributions of individuals and organizations; encourage scholar researchers to pursue studies and careers in circuit branches and its applications.
- To set up, establish, maintain and manage centers of excellence for the study of /on related subjects and discipline and also to run self-Supporting projects for the benefit of needy persons, irrespective of their caste, creed or religion.

The CPD Standards Office
CPD PROVIDER: 22862
2025-2027
www.cpdstandards.com

Accredited cpd Activity

IRAJ CPD Events: IRAJ International is a globally recognized organization dedicated to fostering innovation, research, and professional development. One of its key initiatives is organizing **continuing Professional Development (CPD) accreditation events,** which serve as a platform for professionals, academicians, and researchers to enhance their knowledge, skills, and career prospects.

Official Website: www.iraj.in

About ISERD:

International Society for Engineering Research and Development (ISERD) is a **non-profit organization** that promotes the Engineering and Technology, related latest developments and issues to be discussed and experimented through interactions amongst the researchers and academician across the globe at a common platform in association with **TheIIER**.

Official Website: www.iserd.co

Conference Committee

Program Chair:

Dr. P. Suresh
M.E, Ph.D. Professor and Controller of Examinations,
Karpagam College of Engineering.,
Coimbatore, India

Mr. Bijan Kumar Barik
Managing Director
IRAJ International, Dubai, UAE

Miss. Diptimayee Samanta Singhar
Conference Convener, ISERD
Mob: +91-8455026354

Mr. Manas Ranjan Prusty
Publication and Distribution Head

INTERNATIONAL ADVISORY MEMBERS

Prof. Goodarz Ahmadi,
Professor, Mechanical and Aeronautical Engineering, Clarkson University, USA

Dr Chi Hieu Le,
Senior Lecturer, University of Greenwich. Kent ME4 4TB. United Kingdom

PROF. (ER.) Anand Nayyar
Department of Computer Applications & I.T.KCL Institute of Management and Technology, Jalandhar
G.T. Road, Jalandhar-144001,Punjab, India.

Prof. R. M. Khaire,
Professor,Dept. Of Elex. and Telecommunication,B, V University,India

Dr.P.Suresh,
Professor,Karpagam College of Engineering,Coimbatore,Tamilnadu

Mark Leeson
Associate Professor (Reader)
Area of Expertise:nanoscale communications,
evolutionary algorithms, network coding and communication systems

Dr. P. K. Agarwal
Professor,Deptt. of Civil Engineering, MANIT Bhopal ,Ph. D: IIT Kanpur
M.E: Civil Engg.IIT Roorkee, Membership: Indian Road Congress (IRC), Institute of Urban Transport (IUT)

Shahriar Shahbazpanahi
Islamic Azad University,
Department of Civil Engineering, Sanandaj, Kurdistan, Iran, PhD (Structural Engineering),
University Putra Malaysia, Malaysia

Harun Bin Sarip
Head of Research and InnovationDept, UniKL-MICET
Doctorate: Université de La Rochelle, France
Member: International Society of Pharmaceutical Engineer, Singapore Chapter

Dr. BuchariLapau
Professor ,Pekanbaru Hang Tuah Institute of Health (STIKes HTP),
Riau, Indonesia

Dr.Bilal Ali Yaseen Al-Nassar
The World Islamic Sciences and Education University (WISE)
Faculty of Business and Finance
Department of Management
Information System (MIS), Amman- Jordan

Dr. Md. Al-Amin Bhuiyan
Associate Professor
Dept. of Computer Engineering
King Faisal University, Al Ahssa 31982, Saudi Arabia

Prof. (Er.) Anand nayyar
Department of Computer Applications & I.T.
KCL Institute of Management and Technology, Jalandhar
G.T. Road, Jalandhar-144001
Punjab, India

Prof. Aleksandr Cariow
institution or Company: West Pomeranian University of
Technology, Szczecin

Dr. P. K. Agarwal
Professor, Deptt. of Civil Engineering, MANIT Bhopal ,Ph. D: IIT Kanpur
M.E: Civil Engg.IIT Roorkee, Membership: Indian Road Congress (IRC), Institute of Urban Transport (IUT)

Dr. VPS Naidu
Principal Scientist & Assoc. Prof., MSDF Lab, FMCD
CSIR - National Aerospace Laboratories, Bangalore, India

Mr. P. Sita Rama Reddy
Chief Scientist ,Mineral Processing Department, CSIR - Institute of Minerals & Materials Technology
Bhubaneswar, India, M.Tech. (Chem. Engg., IIT, KGP)

Dr.P.C.Srikanth,
Professor & Head, E&C Dept, Malnad College of Engineering, Karnataka
Senior Member IEEE, Secretary IEEE Photonics Society,
M.Tech: IIT, Kanpur, Ph.D: In IISc Photonics lab

Prof. Lalit Kumar Awasthi,
Professor, Department of Computer Science & Engineering
National Institute of Technology(NIT-Hamirpur),
PhD, IIT, Roorkee, M. Tech, IIT, Delhi

Dr. Chandra Mohan V.P.
Assistant Professor, Dept. of Mech. Engg., NIT Warangal,
Warangal. Ph.D : Indian Institute of Technology(IIT),Delhi
M.B.A: Alagappa University

Prof. I.Suneetha,
Associate Professor, Dept. of ECE, AITS, Tirupati, India

Dr.s. Chandra Mohan Reddy,
Assistant Professor (SG) &Head,Dept. of Electronics & Communication Engineering, JNTUA College of Engineering, Pulivendula,
Ph.D,J.N.T. University Anantapur, Anantapuramu

Gurudatt Anil Kulkarni,
I/C HOD E&TC Department, MARATHWADA MITRA MANDAL'S POLYTECHNIC

Pasuluri Bindu Swetha
Dept. Of ECE, Stanley college of Engineering & Technology for Women, Hyderabad, India

★★★

TABLE OF CONTENTS

Sl No	TITLES AND AUTHORS	Page No.
01.	**Strategic Aspects of Sustainable Purchasing of Sports Footwear: Consumers' Perspective** ➢ *Anja Bebic, Jaka Vadnjal, Tina Vukasovic*	**1-4**
02.	**Urban Traffic Noise Analysis and Real-Time Environmental Monitoring With IEC 61672-Compliant A-Weighted Measurements** ➢ *Nurullah Sari, Alper Kerem, Mehmet Gok*	**5-8**
03.	**Assessment of Various Grinding Aids: Efficiency and Environmental Considerations** ➢ *Yahya Kaya, Dr. Veysel Kobya, Msc. Selin Ozteber, Prof. Dr. Ali Mardani*	**9-13**
04.	**Investigation of the Water Absorption Capacity of Roller Compacted Concrete Exposed to High Temperature** ➢ *Msc. Murteda Unverdi, Msc. Selin Ozteber, Prof. Dr. Ali Mardani*	**14-19**
05.	**Carbon Emission Assessment of 3D Printing Concrete Mixtures** ➢ *Hatice Gizem Sahin, Ali Mardani*	**20-23**
06.	**Effect of Using UV-Modified Waste Hemp Fiber on Certain Fresh and Hardened Properties of Cementitious Systems** ➢ *Yagmur Basar, Aliye Akarsu Ozenc, Ali Mardani, Semiha Eren*	**24-28**
07.	**Effect of Waste Steel Fiber Length and Utilization Rate on the Flow Performance of Blast Furnace Slag 3D Printable Concrete Mixtures** ➢ *Fatih Eren Akgumus, Hatice Gizem Sahin, Ali Mardani*	**29-34**
08.	**Pregnancy Health Education in Oman: the Necessity for Enhanced Initiatives Focused on women's Health.** ➢ *Asma Saif Yahya Al-Hadabi, Dr Sharifah Shafinaz Binti Sh Abdullah*	**35-39**
09.	**The Impact of the Social Context on Student Attitudes and Performance: A Case Study in a South African University** ➢ *Cindy Ramhurry*	**40-46**
10.	**Artificial Intelligence-Assisted Semantics in Biomimetic Design Education: Enhancing Generative Design Capabilities** ➢ *Wei-Chen, Chang, Chin-Horng Chan*	**47-51**

★★★

EDITORIAL

It is my proud privilege to welcome you all to the ISERD International Conference at Melbourne, Australia in association with TheIRES. I am happy to see the papers from all part of the world and some of the best paper published in this proceedings. This proceeding brings out the various Research papers from diverse areas of Science, Engineering, Technology and Management. This platform is intended to provide a platform for researchers, educators and professionals to present their discoveries and innovative practice and to explore future trends and applications in the field Science and Engineering. However, this conference will also provide a forum for dissemination of knowledge on both theoretical and applied research on the above said area with an ultimate aim to bridge the gap between these coherent disciplines of knowledge. Thus the forum accelerates the trend of development of technology for next generation. Our goal is to make the Conference proceedings useful and interesting to audiences involved in research in these areas, as well as to those involved in design, implementation and operation, to achieve the goal.

I once again give thanks to the IRAJ International, WRS & Research Conferences for organizing this event in Melbourne, Australia. I am sure the contributions by the authors shall add value to the research community. I also thank all the International Advisory members and Reviewers for making this event a Successful one.

Editor-In-Chief

Dr. P. Suresh
M.E, Ph.D. Professor and Controller of Examinations,
Karpagam College of Engineering.,
Coimbatore, India.

★★★

STRATEGIC ASPECTS OF SUSTAINABLE PURCHASING OF SPORTS FOOTWEAR: CONSUMERS' PERSPECTIVE

[1]ANJA BEBIC, [2]JAKA VADNJAL, [3]TINA VUKASOVIC

[1,2,3] Doba Business School, Maribor, Slovenia
E-mail: [1]anja.bebic1@net.doba.si, [2]jaka.vadnjal@gmail.com, [3]tina.vukasovic@net.doba.si

Abstract - As sustainability becomes a central pillar of modern business strategy, understanding the consumer's role in driving sustainable innovation is increasingly important. This paper explores how consumer preferences and behavior influence the development and positioning of sustainable sport footwear products. Drawing on consumer behavior theory and strategic management literature, this paper analyzes how environmental awareness, value-based decision-making, and lifestyle alignment influence market trends and brand strategies in the sports industry. By examining sustainability initiatives from both multinational corporations and emerging sports brands, the paper highlights strategic approaches to embedding eco-consciousness into product design and branding. The aim is to offer a theoretical foundation and practical insights into how businesses can align sustainability with competitive advantage, contributing to a more responsible and adaptive global market.

Keywords - Consumer Behavior, Sports Footwear Industry, Strategic Marketing, Sustainability.

I. INTRODUCTION

Environmental concerns regarding industries' impact on nature and natural resources have become today's most pressing issues. Sustainability has evolved over the last few decades from a specialized concept to a widely used one in international discourse. Despite generating wealth and prosperity, the rapid pace of industrialization and globalization has created urgent challenges [1]. Consumer choices and preferences have a significant impact on markets, society, and the environment [2].

It is crucial to emphasize the magnitude of the sports apparel and clothing industry's detrimental environmental effects because it is a subset of the larger fashion sector. It emphasizes the significance of the subject and the necessity of investigating new environmentally friendly options and motivators in this field. According to Spindler et al. (2023), the production and distribution of fashion emits more greenhouse gases than both international travel and shipping combined [2]. The impact of the footwear industry on the environment is also recognized in other sources [3], which further emphasizes the importance of the topic to be further analyzed and discussed.

The environmental concerns influence consumers' preferences toward more environmentally friendly options [4]. With growing consumer awareness and corporate pledges to eco-friendly solutions, sustainability in the sportswear and footwear sector is changing. However, there remains a lack of knowledge regarding how strategic management impacts marketing success and influences consumer perceptions. This paper examines how the strategic tools are used and expands on preexisting customer viewpoints.

The aim is to offer a theoretical foundation and practical insights into how businesses can align sustainability with competitive advantage, contributing to a more responsible and adaptive global market. The primary objective of this paper is to examine how consumers view eco-friendly sportswear and footwear, and to apply strategic marketing tools for analyzing the sustainable sports footwear market.

II. CONSUMERS' PERSPECTIVE

a) Environmental awareness

Green purchasing behavior is positively correlated with environmental attitudes, worries, perceived environmental responsibility, and peer influence. Sustainable purchases are more likely to be made by clients who place a high value on social and environmental responsibility [4]. Similarly, perceived consumer effectiveness the belief that one's activities may make a difference and sustainable purchasing behavior are positively correlated [5].

Recycled materials, including rubber, polyester, and ocean garbage, are being used by manufacturers in response to customer expectations for sustainability. The sports apparel and footwear industry faces several major challenges, including sourcing sustainable materials, guaranteeing supply chain transparency and traceability, managing cost implications, and balancing sustainability goals with popular fashion trends and design paradigms [6]. It highlights the significance of customer awareness at the level of their requirements and needs, which in turn influences their expectations of brands.

Still, the challenges in incorporating consumers' strategies that increase consumer awareness and encourage sustainable purchases are extremely hard

to create [7]. It can be concluded that consumer awareness has to be perceived as an external factor that can be used in creating sustainable strategies, but environmental awareness can hardly be pushed or imposed.

b) Value-based decision making

The association between sustainability features and willingness to pay a premium was somewhat mediated by perceived sustainability [8]. Additionally, premium pricing illustrates the psychological process by which customers evaluate a business based on their attitudes, attributions, and thought processes regarding its social responsibility initiatives [9]. Customers who purchase eco-friendly products receive psychological benefits since they make it clear that they care about the environment and are willing to pay more for it, and society [9].

Since over 90% of consumers report that they are already feeling the disruptive effects of climate change in their lives, they are placing a greater emphasis on sustainability in their consumption habits. To reduce their environmental impact, 46% of people claim they are purchasing more environmentally friendly products [10]. Research [11] emphasizes that Generation Z customers have a positive experience with eco-friendly products and are likely to be prepared to pay more for them in the future.

It can be concluded that when consumers perceive a higher value in a product because it is sustainable, they are willing to pay a higher price in most cases. It is important as one of the ways to analyze the influence of consumers' perspectives.

C) Lifestyle alignment

Lifestyle changes imply not only the adoption of deliberate pro-environmental behavior but also adjustments to behaviors that individuals do not always associate with environmental concerns [12]. Family, friends, and larger social groups may influence sports enthusiasts' intentions to purchase sustainable sports goods. Sports fans are encouraged to view purchasing sustainable sports products as a tangible way to demonstrate their social responsibility through positive social assessments of green consumption practices and support for environmental initiatives.

The favorable influence of subjective standards on purchase intentions is greatly increased by this quest for social acceptance [13]. By using eco-friendly materials and sustainable production methods, sustainable sports products satisfy the functional needs of sports lovers while lowering potential health concerns in comparison to traditional sports items that may pose health dangers [13]. Sports fans who care about their health are more likely to see buying sustainable sports goods as a way to support social health advocacy, meeting both their health objectives and the demands of society for healthy living and environmentally friendly consumption [13].

Minimalism is also explored as a lifestyle associated with purchasing sustainable products [14]. It is a great example of how lifestyle influences the decision to purchase sustainable products. Research [15] shows that the pandemic changed the lifestyle of consumers and made a shift to more sustainable product selection.

III. STRATEGIC TOOLS APPLICATION

As brands around the world strive for financial success, sustainable management practices, which depart from traditional techniques by focusing on social responsibility and maximizing brand profit, have become crucial.

The global footwear sector made significant strides in sustainability in 2021. To reduce waste and carbon emissions, Nike launched its "*Move to Zero*" campaign that year. Adidas introduced the "Future craft. Footprint" running shoe, Under Armour the "*Flow Velociti Wind*" running shoe with responsive cushioning, New Balance the "*Fresh Foam More Trail v1*," which highlights the use of more recycled materials, and Puma teamed up with Nintendo to launch a new line of athletic footwear in an attempt to reduce its carbon footprint [16].

IV. COMPANY ANALYSIS – ALLBIRDS

Allbirds was chosen as an example of a business founded as a sustainable alternative to athletic footwear in response to shifting consumer attitudes and climate conditions. The company encourages comfort and simplicity. However, the company's unique selling point is that it provides premium, entirely sustainable goods. The company's goal is to minimize the adverse effects that production has on the finite natural resources, from packaging to the actual product. Additionally, the business offers the opportunity to purchase shoes designed to extend their lifespan.

SWOT

SWOT analysis is used to demonstrate how strategic tools can be useful in developing a plan that suits the preferences of the target audience.

Strengths	Opportunities
Strong brand identity as an ethical company - Usage of high-quality materials - Carbon footprint labeling - Good design solutions	- Higher price compared to fast fashion brands - Limited offer - Niche market
Weaknesses	**Threats**
- Expanding the offer - Collaborations Growing demand for sustainable fashion	- Competition from bigger brands launching their sustainable alternatives - Increased green washing skepticism - Economic changes

Table 1

The Allbirds' selection of materials expresses dedication to sustainability, which is one of their fundamental competencies. An excellent narrative that is tailored to the demands of clients gives the organization market leverage, according to a review of its publications and online presentation. It is evident that a very open approach fosters consumer trust in the brand, which is one of the key factors motivating people to purchase eco-friendly clothing and shoes. The fact that narrative sets the business apart from competing products is another advantage of using it. Personalized content and building a direct contact with the customer are the main goals. Analyzing the company's shortcomings reveals that many green products are more expensive than fast fashion alternatives.

Since Allbirds primarily sells shoes, there is a chance that it will eventually broaden its product line to include other closely related and comparable items that are also environmentally friendly, providing customers with a sustainable experience. Allbirds is a prime example of a business that successfully leveraged its strengths despite challenges like high pricing. It demonstrates the effectiveness of a sound strategic approach and the long-term success that comes from using a comprehensive approach. Using an analytical approach could help the business remain relevant in the future.

Porter's Five Model

Porter's Five Forces Model is another helpful tool that can help businesses better understand the evolving nature of market demands and better meet the needs of their customers.

Threat of New Entrants	MODERATE	The materials used by Allbirds are hard to replicate. Additionally, entering the market requires high expenses. Still, it can happen. As a result, this threat is moderate.
Bargaining power of suppliers	MODERATE	There are limited sources of sustainable materials. The company Allbirds' commitment to sustainability provides the possibility for long-term relationships with suppliers.
Bargaining power of buyers	HIGH	First of all, price comparison can be one of the reasons Gen Z and Millennial consumers opt for another company. Although loyalty exists, other sustainable options that can occur in the market can have a significant impact.
Threat of Substitutes	HIGH	Consumers have many sustainable alternatives (not only other companies but also second-hand markets), and another aspect is that other aspects, such as performance, aesthetics, or popularity, are more important than sustainability.
Industry Rivalry	HIGH	Nike's sustainable collections, ACBC, Adidas, etc.

Table 2

The idea is to focus on specialized material solutions, which helps Allbirds stand out from other companies that begin offering similar or identical products. The following methods can be taken to improve performance in sportswear and decrease substitution threats. Constantly improve consumer involvement to ensure their loyalty and trust.

STP model

Based on market analysis, Allbirds separates the following segments. In terms of demographics, Allbirds should target Generation Z and Millennials, who are more environmentally conscious and tend to earn higher incomes than the average individual. Allbirds targets individuals who want to establish a long-term relationship with the brand.

One of Allbirds' primary goals is to appeal to environmentally conscious consumers who value the environmental impact of their purchases. Additionally, this category can be narrowed down to active and casual lifestyle customers who desire to build a relationship with a brand.

Allbird bills itself as "The World's Most Comfortable and Sustainable Shoes and Apparel," emphasizing eco-friendliness, innovation, and comfort. It is footwear for everyday use. The brand is transparent about its carbon footprint and is committed to achieving a net-zero future.

According to the company's analysis, it has measures in place to respond to identified threats. For example, by offering a more affordable but more sustainable option of purchasing pre-owned footwear, Allbirds addresses prospective alternatives to their products (the second-hand market). It also offers a wide selection of items to meet the diverse needs of its customers.

V. CONCLUSION

When it comes to sustainable footwear and apparel, lifestyle changes and the growing relevance of sports make it increasingly important to choose environmentally friendly options. Younger generations have a significant impact as future purchasers, and their desire to live in a more sustainable society is a demand that companies must meet. This topic requires further research to uncover the details that explain the motivators and barriers consumers face when making sustainable decisions. There is agreement on Generation Z's power to reshape markets, the relevance of sustainability, its impact on businesses, the barriers associated with products, and the urgency of making a change. Future research could include other variables to investigate how different factors influence customer behavior and how these variables interact.

REFERENCES

[1] M. Mathew, M. and R. Spinelli, "Decoding sustainable drivers: A systematic literature review on sustainability-induced consumer behaviour in the fast fashion industry," Sustainable Production and Consumption, vol.55. pp. 132-145, May 2025.

[2] V. Spindler, V., H. Schunk and T. Könecke, "Sustainable consumption in sports fashion – German runners' preference and willingness to pay for more sustainable sports apparel," Sustainable Production and Consumption, vol. 42, pp. 411-422, Nov 2023.

[3] A. Bodoga, A. Nistorac, M.C. Loghin and D. N. Isopescu, "Environmental Impact of Footwear Using Life Cycle Assessment—Case Study of Professional Footwear," Sustainability, vol.16(14), p. 6094, Apr 2023.

[4] J. M. Lopes, S. Gomes, N. Suchek and S. Nogueira, "The hidden reasons behind generation Z's green choices," Discover Sustainability, 5(520), Dec 2024.

[5] I. Elgammal, M. Ghanem and O. Al-Modaf, "Sustainable Purchasing Behaviors in Generation Z: The Role of Social Identity and Behavioral Intentions in the Saudi Context," Sustainability, vol.16(11), p.4478, Feb 2024.

[6] A. Mukherjee and L. Bharti "Present Challenges and Future Opportunities of Sustainable Retailing in the Apparel Industry," In Sustainable Textiles: Production, Processing, Manufacturing & Chemistry ((STPPMC)) (pp. 59–95), Mar 2025.

[7] A., Manley, Y. Seock and J. Shin, "Exploring the Perceptions and Motivations of Gen Z and Millennials Toward Sustainable Clothing," Exploring the Perceptions and Motivations of Gen Z and Millennials Toward Sustainable Clothing, vol. 51(4), pp. 313–327, Mar 2023.

[8] S. Yadav, Y. Xu, and H. Hergeth, "Walking the Talk: Unraveling the Influence of the Sustainability Features of Leather Alternatives on Consumer Behavior Toward Running Shoes," Sustainability, vol. 16(2), p.830, Jan 2024.

[9] Z.Q. Sun and S.J. Yoon, "What Makes People Pay Premium Price for Eco-Friendly Products? The Effects of Ethical Consumption Consciousness, CSR, and Product Quality," Sustainability, vol.14(23), p. 15513, Nov 2022.

[10] PWC. "Consumers willing to pay 9.7% sustainability premium, even as cost-of-living and inflationary concerns weigh: PwC 2024 Voice of the Consumer Survey". May 2024. Available at: https://www.pwc.com/gx/en/news-room/press-releases/2024/pwc-2024-voice-of-consumer-survey.html (access May 23, 2025).

[11] S. Gomes, J. M. Lopes, and S. Nogueira, "Willingness to Pay More for Green products: A Critical Challenge for Gen Z," Journal of Cleaner Production, vol. 390(1), p. 136092, Mar 2023.

[12] B. Gatersleben, E. White, W. Abrahamse W, T. Jackson, D. Uzzell, "Values and sustainable lifestyles," Architectural Science Review, vol. 53(1), pp.37-5, Feb 2010.

[13] Y. Li and N. An, "The Impact of Health Consciousness and Environmental Awareness on Sports Enthusiasts' Purchase Intentions for Sustainable Sports Products," World, vol. 6(1), p. 20, Jan 2020.

[14] J. Kang, C.M.J. Martinez and C. Johnson, "Minimalism as a sustainable lifestyle: Its behavioral representations and contributions to emotional well-being," Sustainable Production and Consumption, vol.27, pp.802-813, July 2021.

[15] R.M. Dangelico, V. Schiaroli and L Fraccascia, "Is Covid-19 changing sustainable consumer behavior? A survey of Italian consumers," Sustainable Development, vol.30 (6), pp. 1477-1496, Dec 2022.

[16] P.S. Borah, S. Kofi and N. Marwa, "Generation Z's green purchase behavior: Do green consumer knowledge, consumer social responsibility, green advertising, and green consumer trust matter for sustainable development?" Business Strategy and the Environment, vol. 33(5), pp. 4530-4546, Feb 2024.

[17] Allbirds, "The World's Most Comfortable Shoes. Allbirds". Available at:https://www.allbirds.com/?srsltid=AfmBOopONLt5Mm3qGhiaT3ThUyCeSVUTZ6FcSpfUV6yHgKJz9JN-KtOd (accessed on: May 23, 2025).

★★★

URBAN TRAFFIC NOISE ANALYSIS AND REAL-TIME ENVIRONMENTAL MONITORING WITH IEC 61672-COMPLIANT A-WEIGHTED MEASUREMENTS

[1]NURULLAH SARI, [1]ALPER KEREM, [2]MEHMET GOK

[1,2]Department of Electrical and Electronics Engineering, Kahramanmaraş Sütçü İmam University, Turkey
[3]Department of Computer Engineering, Kahramanmaraş İstiklal University, Turkey
Email: [1]nurullah.sri@gmail.com, [2]alper.kerem@ksu.edu.tr, [3]mehmet.gok@istklal.edu.tr

Abstract - With increasing traffic density and human activities in urban areas, environmental noise levels have risen significantly. According to the World Health Organization, prolonged exposure to high levels of noise can lead to permanent adverse effects on both physical and psychological health. In this study, a system based on A-weighted sound measurements compliant with the IEC 61672 standard was developed to enable real-time monitoring and analysis of noise pollution originating from urban traffic. The developed system can accurately detect environmental noise levels and automatically record instances where the noise threshold is exceeded. The collected data provide detailed analysis and reporting capabilities for local authorities to support decision-making processes related to environmental noise. Furthermore, this study introduces a novel approach that goes beyond existing noise monitoring methods in the literature, enabling effective identification of noise pollution in urban environments.

Keywords - Noise Analysis, Real-Time Noise Monitoring, A-Weighted Measurement, Urban Environment, IEC 61672.

I. INTRODUCTION

Environmental noise, particularly from urban traffic, is a major contributor to public health problems such as sleep disturbance, cardiovascular diseases, and psychological stress [1]. Traditional noise monitoring systems typically use static sensors and periodic measurements, which are insufficient for real-time source identification and event-based analysis [2,3]. This study proposes a system that allows continuous, real-time, and high-resolution monitoring and analysis of urban noise using IEC 61672-compliant A-weighted measurements.

II. RELATED WORK

Several recent studies have addressed urban noise monitoring using machine learning and IoT-based systems. Himabindu et al. [4] proposed an ANFIS-based real-time noise reduction framework. Lan et al. [5] generated dynamic traffic noise maps by integrating traffic speed and noise data. Zhang et al. [6] used random forest and k-nearest neighbors (KNN) to predict highly dynamic traffic noise. Liu et al. [7] analyzed technical challenges in IoT-based smart noise mapping. Marques et al. [8] developed a real-time IoT-based noise monitoring system. However, most of these approaches fail to fully integrate high-fidelity acoustic measurement with automated event detection and logging, especially for real-time urban traffic noise analysis. There remains a need for systems that both comply with IEC 61672 and offer event-triggered data logging.

III. METHODOLOGY

This study focuses on detection of the cars exceeding a noise level in urban traffic. To accomplish this task, we employ a USB connected microphone with adequate specifications. A Python program running on PC acquires sound data using this microphone and detects noise level by using IEC 61672 standart.
Then the proposed system takes the photograph of the loudy vehicle to further assess the recognition tasks.

3.1 Acoustic Sensor Selection

A Behringer BU200 USB microphone was used due to its supercardioid pattern, 132 dB maximum SPL, and 50 Hz–17 kHz frequency response [9]. The integrated ADC (24-bit, 48 kHz) ensures a wide dynamic range for environmental noise analysis. Its USB-C interface enables mobile and field applications.
Figure 1 shows the super cardioid polar pattern of the BU200 microphone, which ensures high directionality and effective rejection of off-axis noise for environmental sound measurements.

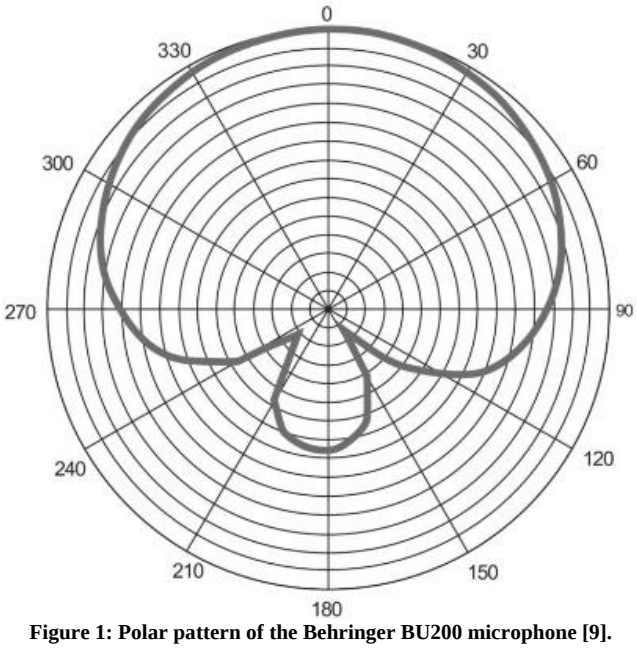


Figure 1: Polar pattern of the Behringer BU200 microphone [9].

3.2 A-Weighted Filtering and Standard Compliance

The A-weighted filter was designed in accordance with IEC 61672-1:2013 [2]. The analog transfer function is given by:

$$H_A(s) = G_A \frac{(\omega_4)^2 . s^4}{(s+\omega_1)^2 . (s+\omega_2)(s+\omega_3)(s+\omega_4)^2} \quad (1)$$

where $\omega = 2\pi f_k$, with pole frequencies: $f_1 = 20{,}60$ *Hz*, $f_2 = 107{,}7$ *Hz*, $f_3 = 737{,}9$ *Hz*. *ve* $f_4 = 12.194{,}0$ *Hz*, and normalization at 1 kHz($G_A = -2.0\ dB$). The transfer function is digitized using bilinear transformation with frequency pre-warping for accurate digital implementation [10].

Frequency Band	Frequency (Hz)
f1	20.6
f2	107.7
f3	737.9
f4	12194.0

Table 1: A-weighting filter pole frequencies according to IEC 61672-1:2013 [2].

Table 1 summarizes the reference pole frequencies for the A-weighting filter as specified in IEC 61672-1:2013.

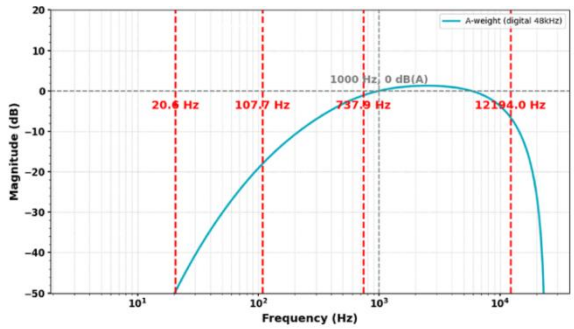


Figure 2: A-weighted filter frequency response (48 kHz digital application) [2].

Figure 2 demonstrates the frequency response of the designed digital A-weighted filter, confirming its compliance with the IEC 61672 standard for precise acoustic measurement.

Figure 3 presents the Python implementation of the IEC 61672-compliant digital A-weighted filter used in the signal processing workflow.

```
def digital_a_weighting(fs):
    f1, f2, f3, f4 = 20.6, 107.7, 737.9, 12194.0
    w1, w2, w3, w4 = 2 * np.pi * f1, 2 * np.pi * f2, 2 * np.pi * f3, 2 * np.pi * f4
    GA = 10 ** (-2.0 / 20)  # -2.0 dB gain normalization at 1 kHz
    b = [GA * w4 ** 2, 0, 0, 0, 0]
    a = np.polymul( a1: [1, 4 * w4, 6 * w4 ** 2, 4 * w4 ** 3, w4 ** 4], a2: [1, 2 * w1, w1 ** 2])
    a = np.polymul(a,  a2: [1, w2])
    a = np.polymul(a,  a2: [1, w3])
    bz, az = signal.bilinear(b, a, fs)
    return bz, az
```

Figure 3: Python code for digital A-weighted filter implementation

3.3 Real-Time Monitoring and Data Logging

Instantaneous noise levels ($L_{dB(A)}$), were computed every 100 ms. When the measured value exceeded a user-defined threshold ($L_{threshold}$), timestamp, lane ID, and noise value were logged to a CSV file, as shown in Equation (2):

$$L_{dB(A)} > L_{threshold} \quad (2)$$

Where, $L_{threshold}$ denotes the user-configurable noise level limit.

Figure 4 illustrates the system architecture, including the signal acquisition, digital filtering, threshold detection, and event logging components.

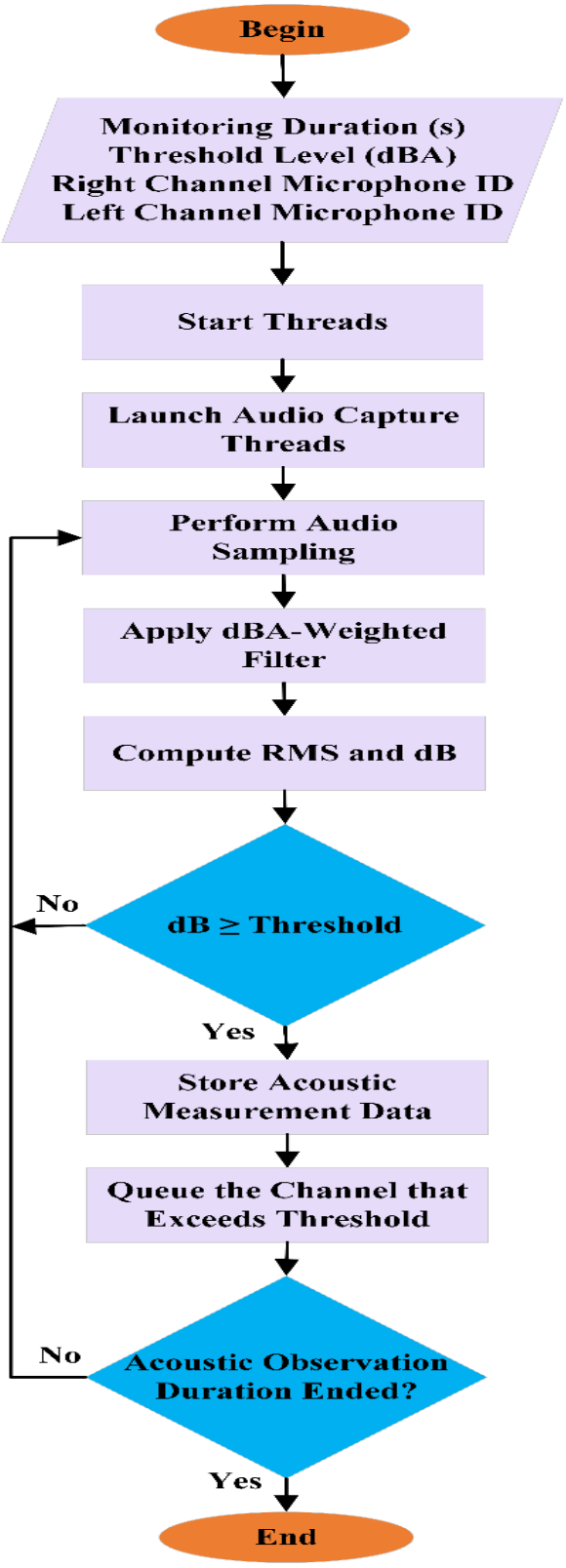


Figure 4: Block diagram of the proposed system.

Figure 5 displays the Python code used for real-time acquisition and threshold-based logging of A-weighted sound pressure levels.

```python
def audio_callback(indata, frames, time, status):
    rms = np.sqrt(np.mean(indata ** 2))
    spl_dbA = 20 * np.log10(rms) + 34
    if spl_dbA > threshold:
        timestamp = datetime.now().isoformat()
        with open('noise_log.csv', 'a', newline='') as f:
            writer = csv.writer(f)
            writer.writerow([timestamp, spl_dbA])

fs = 48000
threshold = 80  # dB(A)
with sd.InputStream(callback=audio_callback, channels=1, samplerate=fs):
    sd.sleep(10000)  # 10 seconds as example
```

Figure 5: Python code for digital A-weighted filter implementation

4. EXPERIMENTAL SETUP

The measurement system was installed at a two-lane urban road. Microphones were placed 3 meters from the road edge at a height of 1.2 meters, according to ISO 362-1/2:2022 [11]. Data collection covered peak and off-peak periods for a representative noise profile.

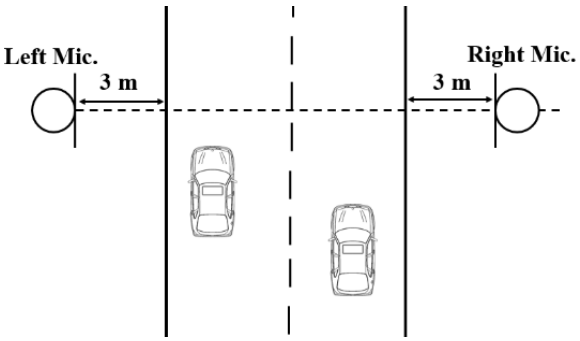


Figure 6: Field installation diagram of the measurement setup.

V. RESULTS AND DISCUSSION

5.1 System Performance

The system's deviation from a reference sound level meter was within ±1 dB(A), confirming compliance and suitability for field measurements [2].

5.2 Event-Based Noise Analysis

Figure 7 shows noise levels for both left and right lanes, with threshold exceedance events clearly visible. Sudden peaks correspond to high-noise events such as heavy vehicle passage or horn use. The right lane, with denser traffic, exhibited more frequent and higher-magnitude exceedances.

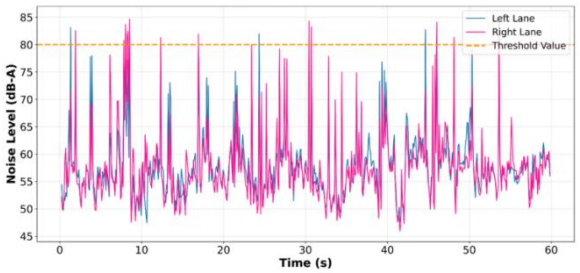


Figure 7: Time series of noise levels for each lane with threshold indication.

5.3 Data Visualization

CSV-based data was visualized with Python's Matplotlib, providing clear temporal and lane-based insights for stakeholders.

VI. CONCLUSION

This study presents a robust and scalable system for real-time urban noise analysis using IEC 61672-compliant A-weighted measurements. The system enables event-based monitoring, supports authorities with actionable data, and provides a platform for smart city integration. Future research will focus on multi-sensor arrays, advanced event classification, and integration with GIS for comprehensive urban noise management.

FUNDING

This work was supported by the Scientific Research Projects Coordination Unit of Kahramanmaraş Sütçü İmam University under Grant No: 2024/418 YLS. The funder had no role in study design, data collection, analysis, interpretation, or publication.

REFERENCES

[1] World Health Organization, Environmental Noise Guidelines for the European Region. WHO Regional Office for Europe, 2018.

[2] IEC 61672-1:2013, Electroacoustics - Sound level meters – Part 1: Specifications. International Electrotechnical Commission, Geneva, 2013.

[3] A. N. Rimell, S. H. Barr, and R. S. Langley, "Design of digital filters for frequency weightings (A and C) required for risk assessments of workers exposed to noise," Industrial Health, vol. 53, no. 1, pp. 21–27, 2015.

[4] M. Himabindu et al., "Adaptive Neuro-Fuzzy Systems for Real-Time Noise Reduction in Urban Soundscapes," Proc. 2024 Int. Conf. Trends Quantum Comput. Emerg. Bus. Technol. (TQCEBT), 2024, pp. 1-6, doi: 10.1109/TQCEBT59414.2024.10545290.

[5] Z. Lan et al., "Dynamic Traffic Noise Maps Based on Noise Monitoring and Traffic Speed Data," Transp. Res. Part D: Transp. Environ., vol. 94, p. 102796, 2021.

[6] Y. Zhang et al., "Predicting Highly Dynamic Traffic Noise Using Rotating Mobile Monitoring and Machine Learning Method," Environ. Res., vol. 229, p. 115896, 2023, doi: 10.1016/j.envres.2023.115896.

[7] Y. Liu et al., "Internet of Things (IoT) for Noise Mapping in Smart Cities: State of the Art and Future Directions," IEEE Netw., vol. 34, no. 4, pp. 112-119, Jul./Aug. 2020, doi: 10.1109/MNET.011.1900634.

[8] G. Marques et al., "A Real-Time Noise Monitoring System Based on Internet of Things for Enhanced Acoustic Comfort and Occupational Health," IEEE Access, vol. 8, pp. 139741-139755, 2020, doi: 10.1109/ACCESS.2020.3012919.

[9] Behringer, "BU200," [Online]. Available: https://www.behringer.com/behringer/product?modelCode=0507-AAX. Accessed: Jan. 1, 2025.

[10] A. N. Rimell et al., "Design of digital filters for frequency weightings (A and C) required for risk assessments of workers exposed to noise," Industrial Health, vol. 53, no. 1, pp. 21-27, 2015.

[11] X. Wang, "Pass-by Noise: Regulation and Measurement," in Automotive Tire Noise and Vibrations, 1st ed., Elsevier, 2020, pp. 297-304, doi: 10.1016/B978-0-12-818409-7.00013-1.

★ ★ ★

ASSESSMENT OF VARIOUS GRINDING AIDS: EFFICIENCY AND ENVIRONMENTAL CONSIDERATIONS

[1]YAHYA KAYA, [2]DR. VEYSEL KOBYA, [3]MSC. SELIN OZTEBER, [4]PROF. DR. ALI MARDANI

[1,2,3,4] Bursa Uludag University, Faculty of Engineering, Civil Engineering Department, Bursa, Turkey
E-mail: yahyakaya00@gmail.com, v.kobya@gmail.com, ozteberselin@uludag.edu.tr, alimardani@uludag.edu.tr

Abstract - Cement manufacturing has been a central focus in energy efficiency research due to its intensive energy requirements and substantial contributions to greenhouse gas emissions. Notably, nearly two-thirds of the total energy demand in cement production arises from the grinding stage. Grinding aids (GAs) are commonly employed during clinker grinding to enhance energy efficiency and mitigate environmental impacts. Although their fundamental action mechanisms are relatively well understood, the practical effects of GAs in cement systems remain primarily theoretical, with limited experimental validation. The identification of highly effective GAs remains a complex task, owing to the multifaceted criteria involved in their evaluation. In industry, amine- and glycol-based GAs are most commonly applied. This study focuses on comparing these two classes of GAs—amines and glycols—regarding both grinding efficiency and environmental footprint. The comparison is grounded in measurements of electrical energy consumption and associated CO_2 emissions during grinding operations. Triethanolamine (TEA), diethylene is opropanolamine (DEIPA), and diethylene glycol (DEG) were each incorporated at a dosage of 0.075% by weight, relative to the total mass of clinker and gypsum, to attain a target Blaine fineness of 3900 ± 100 cm²/g. Four CEM I 42.5R cement types were prepared, including a control sample without GA. The evaluation criteria included the grinding duration and number of cycles required to reach the target fineness. The use of GAs led to improved grinding efficiency ranging from 11% to 14%, independent of their chemical class. Among the tested additives, DEG exhibited the highest performance, whereas DEIPA yielded the least favorable results in terms of both grinding efficiency and environmental impact.

Keywords - About Four Key Words or Phrases in Alphabetical order, Separated by Commas.

I. INTRODUCTION

Global environmental challenges such as greenhouse gas emissions, air pollution, and climate change have prompted the urgent need for sustainable solutions. Among these, reducing CO_2 emissions in industrial processes, increasing the use of renewable energy, and improving energy efficiency have become essential strategies [1], [2]. In this context, the Paris Climate Agreement, adopted in 2015, set the objective of limiting global temperature rise to 1.5°C annually, primarily to protect sensitive ecosystems like coral reefs from extinction by the end of the century [3]. In line with this commitment, Turkey has pledged a 21% reduction in greenhouse gas emissions by 2030. National emission data show that the energy sector contributes 86.1% of total emissions, while industrial activities and final consumption account for 13.6% [4]

Among energy-intensive industries, cement production stands out due to its substantial raw material usage and high levels of energy consumption and carbon emissions. The sector is responsible for roughly 2% of global electricity consumption and 5% of industrial electricity use, contributing 5–7% of total global CO_2 emissions [5]. Producing one ton of cement typically requires about 1.2 tons of raw materials and 130 kWh of energy, resulting in nearly one ton of CO_2 emissions [6], [7].

A significant portion—approximately one-third—of the total energy consumed in cement production is used during the clinker grinding stage. However, much of this energy is lost through heat, vibration, and noise. To address these inefficiencies, the application of grinding aids (GAs) has gained increasing attention for their ability to reduce energy consumption and environmental impact [2], [8]-[10] Commonly used GAs include ethanolamines (such as TEA, DEA, MEA, and TIPA) and glycols (EG and PG) [2], [11]-[14].

Although the fundamental working mechanisms of GAs have been widely studied, the detailed chemical and physical interactions between these additives and cement components remain insufficiently understood [13], [15], [16] Generally, surface chemical compounds are believed to enhance grinding efficiency by reducing particle surface energy and improving particle size distribution [17]-[19]. This improvement is attributed to the adsorption of polar functional groups (e.g., –OH, $–NH_2$, –COOR, $–SO_3$) onto particle surfaces, which modifies surface charge, inhibits crack closure and agglomeration, and prevents material build-up inside the mill [20], [21] These interactions promote better particle dispersion and optimize the grinding process.

Remarkably, surface energy differences can exist between cements with and without GAs, even at identical Blaine fineness values, which can influence hydration behavior and compatibility with other chemical additives [22]. In addition, the presence of GAs alters particle morphology, promoting the formation of rounder and less angular grains [23].

Experimental results support the performance enhancing effects of GAs. For example, reference [22] observed that TEA and TIPA-based formulations led to 14–26% improvements in grinding efficiency at dosages of 0.015%, with higher TIPA ratios yielding better outcomes. Reference [12] found that DEG and PG additives provided efficiency gains of 10% and 18% at 0.028% and 0.053% dosages, respectively. Moreover, the residue on a 90 µm sieve decreased from 2.76% in the control sample to 1.27% and 0.9% in the additive-containing mixtures. Similarly, reference [13] reported that glycerin dosages ranging from 0.01% to 0.04% produced 16% to 33% increases in grinding efficiency. In that study, the surface energy of the cement was also reduced, from 65–130 mJ/mm² in the control sample to 59–98 mJ/mm² with the addition of 0.04% glycerin.

Despite the extensive research demonstrating the effectiveness of GAs in improving grinding performance, there is still a lack of detailed data quantifying their environmental benefits, particularly in terms of CO_2 reduction and energy savings. To address this gap, the current study evaluates both the grinding efficiency and environmental impact of amine- and glycol-based additives. Four different CEM I 42.5R cement types were produced using 0.075% of TEA, DEIPA, and DEG, along with a control mix containing no additive. Grinding efficiency was assessed by measuring the time and number of cycles required to reach a target Blaine fineness, while environmental performance was evaluated based on calculated energy savings and corresponding reductions in CO_2 emissions.

II. MATERIALS AND METHODS

A. Materials

In this study, CEM I 42.5R-type cements were produced by grinding a mixture containing 96% clinker and 4% gypsum in a laboratory-scale ball mill to a target Blaine fineness of 3700 ± 100 cm²/g, per the TS EN 197-1 standard. The cement produced without the addition of a GA was designated as the reference sample ("C"), while the cements containing GAs were labeled based on the specific admixture used. The main physical and chemical properties of the clinker and gypsum employed in the experiments are presented in Table 1. Similarly, the key physical and chemical characteristics of the GAs are summarized in Table 2.

Component	Chemical Content (%)	
	Clinker	Gypsum
SiO_2	21.52	4.98
Al_2O_3	5.43	1.21
Fe_2O_3	3.31	0.83
CaO	65.38	28.94
MgO	1.04	0.83
SO_3	0.38	39.67
Na_2O+0.658 K_2O	0.83	0.37
Cl	0.01	-
Combined Water (T<230° °)	-	18.93
Other, %	1.58	4.24
Loss of ignition	0.52	

Table 1. Some properties of clinker and gypsum

GA type	Alkaline content (%) (Na_2O)	Density (g/cm^3)	Solid content (%)	Chloride content (%)	pH. 25 ° C	Number of Functional Groups
TEA	<10	1.100	50.0	<0.1	10.0	3
DEIPA	<10	1.079	50.0	<0.1	9.7	3
DEG	<10	1.118	50.0	<0.1	7.2	2

Table 2. Some physical and chemical properties of the GAs used

B. Methods

As part of the experimental procedure, clinker and gypsum were initially subjected to size reduction using a jaw crusher. The crushed clinker was subsequently sieved to a particle size of 3.35 mm, per the Bond Standard, to prepare it for grinding.

The grinding process was performed using a Bond-type laboratory ball mill with a 5 kg capacity and a 1.5 kW motor, as illustrated in Figure 1.

The Blaine fineness of the ground cements was measured using an automatic Blaine apparatus, depicted in Figure 2.

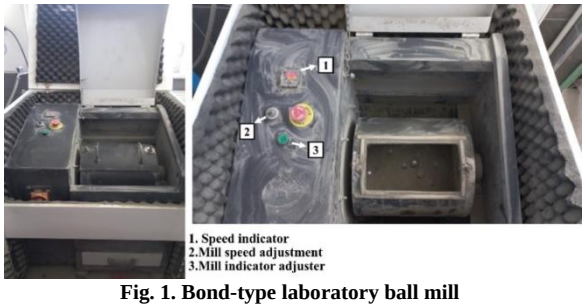


Fig. 1. Bond-type laboratory ball mill



Figure 2. Automatic Blaine device

The energy consumption of the mill during the grinding process was calculated using Equation 1.

$$Eg = (220 \times Tg \times A \times 1000) / (m \times Tg) \quad (1)$$

Here, Eg represents the grinding energy (kWh/ton), Tg is the grinding time (hours), A denotes the amperage, m refers to the feed amount (kg), and Tg refers to the mill factor, a constant value of 4 provided by the manufacturer.

Based on data from the Turkish Cement Manufacturers Association, Turkey's cement production in 2023 reached approximately 65 million tons (Turkish Cement Manufacturers Association, 2023). According to the 2021 national electricity grid emission factor report published by the Ministry of Energy and Natural Resources of the Republic of Turkey, the emission factor for electricity consumption was reported as 0.7258 tCO_2/MWh (Turkish National Grid Emission Factor Data, 2021[24]). Using this information, the potential reduction in annual energy consumption and associated CO_2 emissions from the use of GAs in cement grinding processes was estimated for the Turkish cement industry**.**

III. RESULTS AND DISCUSSION

A. Grinding Efficiency

Table 3 presents the grinding energies (kWh), calculated using Equation 1, along with the corresponding relative grinding efficiencies for cements produced without additives (control) and with different GAs to achieve the target Blaine fineness of 3900 ± 100 cm²/g. The relative grinding efficiencies are expressed in comparison to the reference cement.

	Blaine Fineness (cm²/g)	Required Number of Revolutions for Target Fineness	Grinding Time for Target Fineness (min)	Energy Consumed (kWh)	Relative Energy Efficiency (%)
Control	3860	7600	89,41	37,54	-
TEA	3820	6690	78,71	33,04	11,97
DEIPA	3880	6720	79,06	33,19	11,58
DEG	3900	6550	77,06	32,35	13,82

Table 3. Grinding efficiency results

As presented in Table 3, the use of TEA, DEIPA, and DEG as GAs resulted in energy savings of 11.97%, 11.58%, and 13.82%, respectively, compared to the reference cement. The amine-based admixtures TEA and DEIPA exhibited lower grinding efficiencies than the glycol-based DEG, indicating that the efficiency of glycol-based admixtures may improve at higher dosages, contrary to earlier findings [14], [25], [26].

B. Environmental Impact

Based on the obtained data, the impact of GA implementation on the annual electrical energy consumption and CO_2 emissions associated with the cement grinding process in Turkey was evaluated. A summary of the estimated results is provided in Table 4.

Energy efficiency and CO_2 emissions	Control	TEA	DEIPA	DEG
Amount of cement produced annually in Turkey, kiloton	64854			
Energy consumed in the grinding phase in the production of 1 ton of cement, kWh	37,54	33,04	33,19	32,35
Total energy consumed in clinker grinding in Turkey, GWh	2434	2142	2152	2098
Provided energy savings, GWh	-	292	282	336
The amount of CO_2 released from the electricity consumed during grinding, in kiloton	1776	1563	1570	1531
Amount of avoided CO_2 emissions, kiloton	-	213	206	245

Table 4. A summary of the estimated outcomes

As presented in Table 4, the implementation of GAs in Turkey's annual cement production could result in energy savings ranging from 282 to 336 GWh. Based on data reported by [27], the annual electricity consumption of a typical four-member household in Turkey is approximately 2600 kWh. Accordingly, the use of TEA, DEIPA, and DEG could meet the annual electricity needs of approximately 112,000, 108,000, and 129,000 households, respectively. Furthermore, the corresponding reductions in CO_2 emissions are

estimated at 213, 206, and 245 kilotons, respectively.

Assuming that a mature tree can sequester approximately 12 kg (0.012 tons) of CO_2 annually through photosynthesis [28], the environmental benefits of GA usage can be further contextualized. In the absence of GA usage, the annual CO_2 emissions from clinker grinding are estimated at approximately 1,637 kilotons, equivalent to the sequestration capacity of nearly 165.5 million trees. This figure is reduced to approximately 133 million trees with TEA, 128 million with DEIPA, and 153 million with DEG.

IV. CONCLUSION

This study examines the grinding efficiency and environmental impacts of commonly used GAs—DEIPA, TEA, and DEG. The key findings from the experiments are summarized below.

1) Regardless of the GA type, the use of grinding aids has been found to enhance grinding efficiency, reduce CO_2 emissions, and support more environmentally sustainable cement production.
2) In terms of grinding efficiency, amine-based additives demonstrated lower performance compared to the glycol-based DEG, with DEG yielding the highest efficiency and DEIPA the lowest.
3) Similarly, in terms of environmental impact, DEG exhibited the most favorable outcome, while DEIPA showed the least. Nevertheless, despite its relatively lower grinding efficiency, DEIPA still provided notable energy savings and environmental advantages over the reference cement.

REFERENCES

[1] Boesch, M. E., & Hellweg, S. (2010). Identifying improvement potentials in cement production with life cycle assessment. Environmental science & technology, 44(23), 9143-9149.

[2] Zhang, T., Gao, J., & Hu, J. (2015). Preparation of polymer-based cement grinding aid and their performance on grindability. Construction and Building Materials, 75, 163-168, https://doi.org/10.1016/j.conbuildmat.2014.10.046.

[3] Darby, M. (2018). Five Ways 20C Global Warming is Worse Than 1,5 0C, http://www.climatechangenews.com/2016/04/21/five-ways-2c-global-warming-isworse-than-1-5c/.

[4] Dulkadiroğlu, H. (2018). Türkiye'de elektrik üretiminin sera gazi emisyonlari açisindan incelenmesi. Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 7(1), 67-74.

[5] Madlool, N. A., Saidur, R., Hossain, M. S., & Rahim, N. A. (2011). A critical review on energy use and savings in the cement industries. Renewable and sustainable energy reviews, 15(4), 2042-2060.

[6] ICS, (2009). Cement Technology Roadmap 2009 Carbon emission reduction up to 2050, Conches-Geneva, Switzerland: World Business Council for Sustainable Development.

[7] Mardani-Aghabaglou, A. (2016). Investigation of cement-superplasticizer admixture compatibility, PhD Thesis. Turkey, Izmir, Ege University, Engineering Faculty, Civil Engineering Department, NO. 10103689, 290 pp. https://tez.yok.gov.tr/UlusalTezMerkezi/

[8] Jankovic, A., Valery, W., & Davis, E. (2004). Cement grinding optimisation. Minerals Engineering, 17(11-12), 1075-1081. https://doi.org/10.1016/j.mineng.2004.06.031

[9] Kaya, Y., Kobya, V., & Mardani, A. (2024.a). Evaluation of fresh state, rheological properties, and compressive strength performance of cementitious system with grinding aids. Journal of Applied Polymer Science, 141(15), e55212.

[10] Kaya, Y., Kobya, V., Mardani, A., & Assaad, J. J. (2024 b). Effect of modified Triethanolamine on grinding efficiency and performance of cementitious materials. Talanta Open, 9, 100293.

[11] Jolicoeur, J., Morasse, S., Sharman, J., Tagnit-Hamou, A., Slim, F., & Page, M. (2007). Polyol-type compounds as clinker grinding aids: Influence of powder fluidity and on cement hydration. In 12th International Congress on the Chemistry of Cement (pp. 1-6).

[12] Assaad, J. J. (2015). Assessment of rheology variations of cement pastes containing clinker grinding aids compliant with ASTM C465. Advances in Civil Engineering Materials, 4(1), 94-114. https://doi.org/10.1520/ACEM20140038

[13] Sun, Z., Liu, H., Ji, Y., & Pang, M. (2020). Influence of glycerin grinding aid on the compatibility between cement and polycarboxylate superplasticizer and its mechanism. Construction and Building Materials, 233, 117104.https://doi.org/10.1016/j.conbuildmat.2019.117104

[14] Kobya, V., Kaya, Y., & Mardani-Aghabaglou, A. (2022). Effect of amine and glycol-based grinding aids utilization rate on grinding efficiency and rheological properties of cementitious systems. Journal of Building Engineering, 47, 103917.

[15] Mishra, R. K., Weibel, M., Müller, T., Heinz, H., & Flatt, R. J. (2017). Energy-effective grinding of inorganic solids using organic additives. CHIMIA International Journal for Chemistry, 71(7-8), 451-460.

[16] Sun, Z., Yang, H., Shui, L., Liu, Y., Yang, X., Ji, Y., ... & Luo, Q. (2016). Preparation of polycarboxy late-based grinding aid and its influence on cement properties under laboratory condition. Construction and Building Materials, 127, 363-368. https://doi.org/10.1016/j.conbuildmat.2016.10.007

[17] Choi, H., Lee, W., Kim, D. U., Kumar, S., Kim, S. S., Chung, H. S., & Ahn, Y. C. (2010). Effect of grinding aids on the grinding energy consumed during grinding of calcite in a stirred ball mill. Minerals Engineering, 23(1), 54-57.

[18] Przwara, P., Breitung-Faes, S., & Kwade, A. (2018.a). Impact of the powder flow behavior on continuous fine grinding in dry operated stirred media mills. Minerals Engineering, 128, 215-223.

[19] Chipakwe, V., Semsari, P., Karlkvist, T., Rosenkranz, J., & Chelgani, S. C. (2020). A critical review on the mechanisms of chemical additives used in grinding and their effects on the downstream processes. Journal of Materials Research and Technology, 9(4), 8148-8162.

[20] Jeknavorian, A. A., Barry, E. F., & Serafin, F. (1998). Determination of grinding aids in Portland cement by pyrolysis gas chromatography-mass spectrometry. Cement and concrete research, 28(9), 1335-1345. https://doi.org/10.1016/S0008-8846(98)00109-4

[21] Assaad, J. J., & Issa, C. A. (2014). Effect of clinker grinding aids on flow of cement-based materials. Cement and Concrete Research, 63, 1-11. https://doi.org/10.1016/j.cemconres.2014.04.006

[22] Katsioti, M., Tsakiridis, P. E., Giannatos, P., Tsibouki, Z., & Marinos, J. (2009). Characterization of various cement grinding aids and their impact on grindability and cement performance. Construction and Building Materials, 23(5), 1954-1959.https://doi.org/10.1016/j.conbuildmat.2008.09.003

[23] Ma, S., Li, W., Zhang, S., Hu, Y., & Shen, X. (2015). Study on the hydration and microstructure of Portland cement containing diethanol-isopropanolamine. Cement and Concrete Research, 67, 122-130.

[24] Savaş, D. Ö. (2021). Bursa İnegöl ilçesi sera gazı envanterinin çıkarılması ve iklim değişikliği eylem planı kapsamında sera

gazı azaltım planı (Master's thesis, Bursa Uludağ Üniversitesi).

[25] Assaad, J. J., Asseily, S. E., & Harb, J. (2009). Effect of specific energy consumption on fineness of Portland cement incorporating amine or glycol-based grinding aids. Materials and structures, 42, 1077-1087.

[26] Przwara, P., Breitung-Faes, S., & Kwade, A. (2018.b). Impact of grinding aids on dry grinding performance, bulk properties and surface energy. Advanced Powder Technology, 29(2), 416-425.

[27] Karaca, C. (2012). "Güneş Ve Rüzgar Enerjisinden Elektrik Enerjisi Üretimi Sistemi Tasarımı, Yüksek Lisans Tezi," T.C. Selçuk Üniversitesi Fen Bilimleri Enstitüsü.

[28] Argun, M. E., Ergüç, R., & Yunus, S. A. R. I. (2019). Konya/Selçuklu ilçesi karbon ayak izinin belirlenmesi. Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi, 7(2), 287-297.

[29] Chen, J., Jia, J., & Zhu, M. (2024). Understanding the effect of alkali content on hydration, hardening, and performance of Portland cement comprehensive review. Materials Today Communications, 109728.

★★★

INVESTIGATION OF THE WATER ABSORPTION CAPACITY OF ROLLER COMPACTED CONCRETE EXPOSED TO HIGH TEMPERATURE

[1]MSC. MURTEDA UNVERDI, [2]MSC. SELIN OZTEBER, [3]PROF. DR. ALI MARDANI

[1,2,3] Bursa Uludag University, Faculty of Engineering, Civil Engineering Department, Bursa, Turkey
E-mail: [1]murtedaunverdi@uludag.edu.tr, [2]ozteberselin@uludag.edu.tr, [3]alimardani@uludag.edu.tr

Abstract - This study explores the influence of high-temperature exposure on the water absorption capacity of Roller Compacted Concrete (RCC), a material commonly used in durable and cost-effective infrastructure. To determine the optimal mixture, five RCC mixes with varying water-to-cement (w/c) ratios from 0.35 to 0.47 were prepared, with 0.41 identified as optimal. Specimens produced with this ratio were exposed to 300°C, 600°C, and 900°C, while control samples were maintained at 25°C. Water absorption was measured according to ASTM C642. Results revealed a notable increase in absorption with temperature: 42% at 300°C, 183% at 600°C, and 298% at 900°C. These increases are attributed to thermal damage, including the decomposition of calcium hydroxide, micro structural deterioration, and aggregate disintegration. The findings demonstrate that high temperatures significantly reduce RCC's resistance to moisture ingress, posing a threat to long-term durability. This research enhances the understanding of RCC's thermal performance and provides valuable guidance for designing concrete mixtures better suited to environments with extreme heat exposure.

Keywords - Durability of Concrete, High Temperature Exposure, Water Absorption Capacity, Roller Compacted Concrete (RCC), Thermal Degradation

I. INTRODUCTION

The escalating intensity of adverse climatic conditions and the ongoing increase in global temperatures necessitate a comprehensive understanding of the impacts of elevated thermal exposure on construction materials, particularly concrete [1], [2]. Roller Compacted Concrete (RCC), recognized for its robust mechanical properties and enhanced durability, is extensively utilized in applications such as pavements, dams, and industrial infrastructures (Fig. 1) [3]-[5]. In contrast to conventional concrete, RCC is distinguished by its low water-to-cement (w/c) ratio and high density, attributes that confer superior performance across a variety of environmental conditions [6]-[8].

Owing to benefits such as reduced production expenses, enhanced durability, and expedited application processes, RCC has emerged as a preferred material in contemporary construction practices [9]-[14]. Empirical studies indicate that the implementation of RCC can achieve cost reductions ranging between 15% and 30% relative to traditional concrete alternatives [3], [15]-[18]. The material's rapid production capability, economic efficiency, and superior performance have positioned RCC as a widely adopted infrastructure component within the construction sector, particularly for projects necessitating resilient and durable surface solutions [19]-[22].

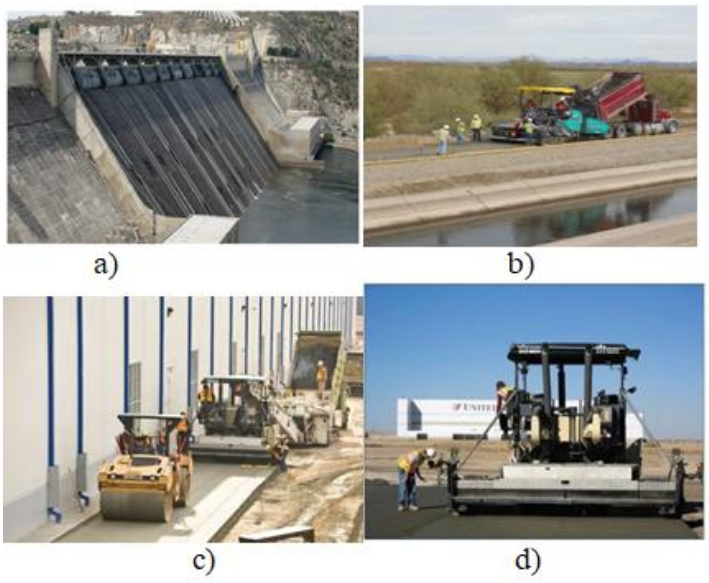


Fig. 1. RCC applications: a) Grand Coulee dam[23] b) RCC road [24] c) Industrial facility [25] d) Airport [25]

Water absorption capacity is recognized as a pivotal parameter influencing the durability, freeze-thaw resilience, and structural integrity of concrete materials. Furthermore, elevated thermal exposures induce alterations in the microstructural attributes of concrete. As a result, increased temperatures may elevate porosity and permeability within the concrete matrix, thereby augmenting its water absorption potential. Empirical evidence suggests that rising temperatures correlate with enhanced porosity, which subsequently elevates water absorption rates and potentially compromises the structural soundness of concrete over prolonged periods[2], [26]-[29].

In addition, the escalation in water absorption capacity within RCC may not solely induce short-term material degradation but could also adversely affect its long-term durability under diverse environmental stressors. Specifically, augmented porosity facilitates deeper penetration of deleterious ions and moisture ingress. These phenomena tend to exacerbate under high-temperature conditions [30]-[33]. Moreover, the synergistic interaction between thermal exposure and moisture dynamics can substantially modify the capillary absorption process, thereby complicating the evaluation of RCC's performance under thermal loading scenarios [2], [34], [35],[39], [40].

Prior investigations have demonstrated that high-temperature exposure significantly impacts the water absorption capacity of concrete, driving increases in porosity and permeability [38]-[40]. This augmentation in porosity not only detrimentally affects the mechanical properties of RCC but also introduces heightened vulnerability to durability degradation and service life reduction under aggressive environmental exposures [30], [37], [41], [44]. Consequently, elucidating these complex interactions is imperative for the formulation of robust strategies aimed at bolstering RCC's thermal resistance. Considering the profound implications on performance and longevity, the thermal stability of RCC under elevated temperatures remains an essential area of scientific inquiry.

The present study endeavors to elucidate the influence of high-temperature exposure on the water absorption characteristics of RCC. By advancing the understanding of RCC behavior under thermal stress, this research aspires to inform the development of enhanced, more durable concrete formulations. Accordingly, mixtures with w/c ratios ranging from 0.35 to 0.47 were prepared to identify the optimum water content. Subsequently, new mixtures corresponding to this optimal w/c ratio were developed and subjected to thermal exposures between 300°C and 900°C. Their water absorption properties were systematically assessed in comparison to control specimens maintained at ambient conditions (25°C). The findings are anticipated to yield critical insights into the water absorption dynamics of RCC under elevated temperature regimes.

II. MATERIALS AND METHODS

A. Materials

In this investigation, CEM I 42.5 R cement, produced in strict compliance with the TS EN 197-1 standard, was employed. The detailed chemical composition alongside the physical and mechanical characteristics of the cement are delineated in Table 1.

This research utilized crushed limestone aggregates classified into gradations of 5 mm, 5–12 mm, and 12–22 mm. Aggregate gradation was established following the EN 933-1 standard. To achieve an optimal particle distribution, the gradation limits specified in TS 802 were referenced, with the particle size distributions incorporated into the mixtures illustrated in Fig. 2. The saturated surface dry (SSD) bulk densities, water absorption values, and assigned proportions of the aggregates are detailed in Table 2.

Oxide		**Amount (%)**
SiO_2		18.86
Al_2O_3		5.71
Fe_2O_3		3.09
CaO		62.70
MgO		1.16
SO_3		2.39
$Na_2O+0.658\ K_2O$		0.92
Cl^-		0.01
Loss on ignition		3.20
Free CaO		1.26
Physical properties		
Specific gravity		3.15
Blaine specific surface (cm^2 / g)		3530
0.045 mm sieve passing (%)		7.6
Mechanical properties		
Compressive strength (MPa)	1-day	14.7
	2-day	26.80
	7-day	49.80
	28-day	58.5

Table 1. The chemical composition, physical, and mechanical properties of the cement

Type	**Crushed limestone**		
Size (mm)	0-5	5-12	12-22
SSD specific gravity	2.68	2.68	2.69
Water absorption capacity (%)	1.64	0.51	0.40
Ratio (%)	60	20	20

Table 2. Physical properties of aggregates and using ratios

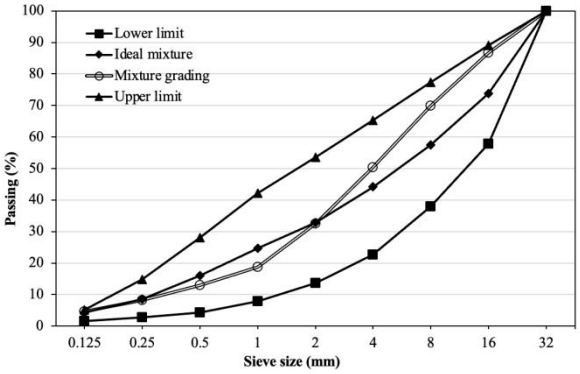


Fig. 2. Gradation curve of aggregates used in the mixtures and comparison with the TS 802 standard

B. Mixture Proportions

The mix design of the RCC was conducted following the guidelines of the ACI 207.5R-99 standard, based on a unit volume of 1 m3. Five distinct mixtures were formulated with w/c ratios of 0.35, 0.38, 0.41, 0.44, and 0.47, each incorporating 300 kg/m3 of cement. The specific quantities of water, cement, and aggregates employed in these mix designs are summarized in Table 3.

Mixture	Cement	Water	Aggregate (mm)			w/c ratio
			0-5	5-12	12-22	
C-0.35	300	105	1270	423	425	0.35
C-0.38	300	114	1255	418	420	0.38
C-0.41	300	123	1240	413	415	0.41
C-0.44	300	132	1226	408	410	0.44
C-0.47	300	141	1212	404	406	0.47

Table 3. Mix proportions for 1 m^3 RCC design (kg/m^3)

Determination of optimum water content and w/c ratio

To establish the optimum water content, mixtures were prepared using five distinct w/c ratios. The specimens were cast in three successive layers within 150 × 300 mm cylindrical molds. Compaction was conducted for each layer by applying a 5 kg steel plate load for 20 seconds, in compliance with ASTM C1435 (2020) standards. Subsequently, samples extracted from the compacted specimens were oven-dried at 105°C to accurately determine the water content of the RCC mixtures.

The water content was calculated using the following formula:

$$w = \frac{m_{wet} - m_{dry}}{m_{dry}} \; x\; 100 \qquad (1)$$

In the presented equation, w denotes the water content expressed as a percentage, m_{wet} corresponds to the mass of the moist specimen (in grams), and m_{dry} represents the mass of the specimen after oven-drying (in grams). The wet unit weight (γ_{wet}) was determined by the ratio m/v, where mmm is the mass of the wet specimen and v its volume. To elucidate the relationship between water content and the dry unit weight (γ_{dry}) of the RCC samples, the dry unit weight was calculated using the following formula:

$$\gamma_{dry} = \frac{\frac{m}{v}}{1+w} \qquad (2)$$

Water content and dry unit weights were computed for all prepared mixtures, followed by the construction of the water content–dry unit weight relationship curve. Utilizing the identified optimum water content, the corresponding optimum water-to-cement (w/c) ratio for the mixture was established.

Subsequently, the optimum w/c ratio was adopted for further experimentation, wherein four cube specimens measuring 150 × 150 mm were fabricated. These specimens were produced adhering to ASTM C1435 (2020) standards, employing a two-layer casting and compaction procedure. Each layer underwent compaction through the application of a 5 kg steel plate load sustained for 20 seconds. After molding, the specimens were allowed to rest at ambient temperature for 24 hours, following which they were demolded and subjected to water curing at 23±2°C for a duration of 28 days.

Specimens were designated as C0.41-1, C0.41-2, C0.41-3, and C0.41-4, where C0.41-1 denotes the control tested at 25°C, and C0.41-2, C0.41-3, and C0.41-4 correspond to samples exposed to elevated temperatures of 300°C, 600°C, and 900°C, respectively. The mix proportions for producing 1 m³ of RCC at the identified optimum w/c ratio are detailed in Table 4.

Mixture	Cement	Water	Aggregate (mm)			
			0-5	5-12	12-22	w/c ratio
C0.41-1 C0.41-2 C0.41-3 C0.41-4	300	123	1240	413	415	0.41

Table 4. Mix proportions for 1 m^3 RCC at the determined optimum w/c ratio (kg/m^3)

Experimental study

Water absorption capacity

To assess the permeability characteristics of the concrete, water absorption testing was performed on 150 mm cubic specimens following the guidelines of ASTM C642. Initially, the specimens were oven-dried at 105°C until a constant weight was attained, after which they were submerged in water to attain full saturation. The water absorption capacity was determined by measuring the weight difference of the specimens before and after immersion.

High-temperature test

High-temperature resistance evaluations were carried out by initially drying the specimens at 105°C for 24 hours following a 28-day curing period, then subjecting them to elevated temperatures of 300°C, 600°C, and 900°C. The heating rate was maintained at 5°C per minute, with specimens held at each target temperature for 180 minutes (see Fig. 3). Subsequent cooling was performed naturally at ambient conditions (23±2°C). Water absorption tests were conducted on both the heat-exposed specimens and the control sample.

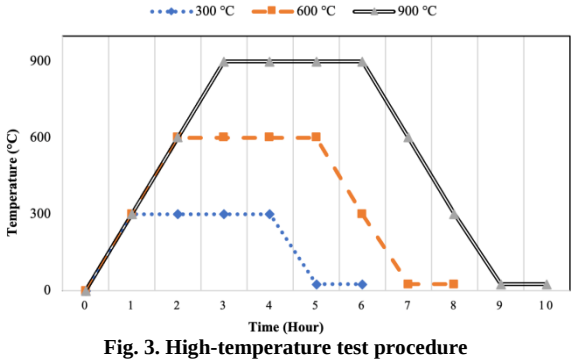


Fig. 3. High-temperature test procedure

III. RESULTS AND DISCUSSION

Table 5 presents the water absorption capacities of both the control specimen and those subjected to high-temperature exposure.

Temperature	25°C	300°C	600°C	900°C
Water absorption capacity (%)	1.47	2.09	4.16	5.85

Table 5. Water absorption capacity test results

Fig. 4 illustrates the relative water absorption capacities of the specimens exposed to elevated temperatures (300°C, 600°C, and 900°C) compared to the control specimen maintained at 25°C.

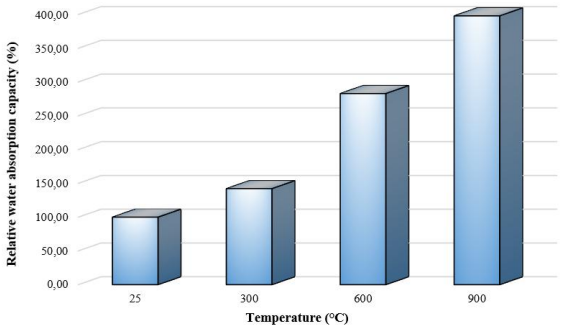


Fig. 4. Relative water absorption capacities compared to the control specimen

Upon analysis of the water absorption capacity of specimens subjected to elevated temperatures (Fig. 4), it was observed that the specimen exposed to 300°C demonstrated a 42% increase in water absorption relative to the control sample. This enhancement is primarily attributed to the evaporation of chemically bound water within the C-S-H gel layers, resulting in the layers contracting and causing volumetric shrinkage [43].

The specimen exposed to 600°C exhibited a 1.83-times increase in water absorption capacity. At this temperature, substantial microstructural damage is believed to occur due to the decomposition of calcium hydroxide ($Ca(OH)_3$) and thermal expansion of the aggregates [44], [45]. Furthermore, as reported in the literature, limestone aggregates undergo fragmentation at these elevated temperatures [45], [46] and the osmotic pressure generated by steam formation is thought to significantly elevate porosity.

For the specimen exposed to 900°C, a 2.98-times increase in water absorption capacity was recorded. At this extreme temperature, irreversible deterioration of the fundamental concrete constituents and complete disintegration of the aggregates (as illustrated in Fig. 5) are considered the principal factors driving this pronounced rise in water absorption.



Fig. 5. Physical degredation of the specimen exposed to 900°C temperature

IV. CONCLUSIONS

The following conclusions were drawn from this study investigating the water absorption capacity of roller-compacted concrete subjected to high temperatures:

1) Mixtures with five different w/c ratios were prepared, and the optimum w/c ratio was determined as 0.41.
2) Water absorption capacity increased significantly with rising temperature, especially after exposure to 600°C.

3) Irreversible degradation and aggregate disintegration occurred in RCC specimens exposed to 900°C.

REFERENCES

[1] Abid, S. R., Abbass, A. A., Murali, G., Al-Sarray, M. L., Nader, I. A., & Ali, S. H. (2022). Repeated impact response of normal-and high-strength concrete subjected to temperatures up to 600 C. *Materials*, *15*(15), 5283.

[2] Guo, J., Tian, W., Cheng, X., & Yun, W. (2024). Study on the evolution of concrete pore structure and moisture transfer mechanism after high temperature based on different sequence NMR technology. *Construction and Building Materials*, *422*, 135739.

[3] Chhorn, C., Hong, S. J., & Lee, S. W. (2018). Relationship between compressive and tensile strengths of roller-compacted concrete. *Journal of Traffic and Transportation Engineering (English Edition)*, *5*(3), 215-223.

[4] Sarsam, S., AL-Rawi, A., & Tawfeeq, S. (2013, February). Assessing Durability of Roller Compacted Concrete Sustainable Pavement. In *Proceedings, 9th International Conference, Concrete for Sustainable Construction, Kingdom of Bahrain* (pp. 11-13).

[5] Deghfel, M., Meddah, A., Beddar, M., & Chikouche, M. A. (2019). Experimental study on the effect of hot climate on the performance of roller-compacted concrete pavement. *Innovative Infrastructure Solutions*, *4*(1), 54.

[6] Pulecio-Díaz, J., Sol-Sánchez, M., & Moreno-Navarro, F. (2024). Effects of relative humidity and temperature on the drying shrinkage of roller-compacted concrete pavements. *Infrastructures*, *9*(2), 22.

[7] Delatte, N., & Storey, C. (2005). Effects of density and mixture proportions on freeze–thaw durability of roller-compacted concrete pavement. *Transportation research record*, *1914*(1), 45-52.

[8] Topličić, Ć. G., Grdić, D., Ristić, N., & Grdić, Z. (2015). Properties, materials and durability of rolled compacted concrete for pavements. *Zastita Materijala*, *56*(3), 345-353.

[9] Mardani-Aghabaglou, A. (2011). *Durability of fly ash incorporating roller compacted concrete* (Publication No. 291166) [Master dissertation, Ege University]. National thesis center of Turkey. https://tez.yok.gov.tr/UlusalTezMerkezi

[10] Mardani, A., Bayqra, S. H., Özen, S., Faqırı, Z. A., & Ramyar, K. (2019). Silindirle sıkıştırılmış betonun dayanıklılık performansı ve boyutsal kararlılığı: Kapsamlı inceleme. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, *7*(3), 1597-1626.

[11] Hejazi, S. M., Abtahi, S. M., & Safaie, F. (2016). Investigation of thermal stress distribution in fiber-reinforced roller compacted concrete pavements. *Journal of Industrial Textiles*, *45*(5), 896-914.

[12] Unverdi, M., Kazemi, R., Kaya, Y., Mardani, N., Mardani, A., & Mirjalili, S. (2025). Predicting compressive and splitting tensile strength of high volume fly ash roller compacted concrete using ANN and ANN-biogeography based optimization models. *Scientific Reports*, *15*(1), 21794.

[13] Khed, V., Gokulanadh, V., & Latha, M. (2020). A Review on Recent Advancements in Roller Compacted Concrete. *International Journal of Inventive Engineering and Sciences (IJIES)*, 5.

[14] Kalhori, M., & Ramezanianpour, A. A. (2021). Innovative air entraining and air content measurement methods for roller compacted concrete in pavement applications. *Construction and building materials*, *279*, 122495.

[15] Shafigh, P., Hashemi, M., Nam, B. H., & Koting, S. (2020). Optimum moisture content in roller-compacted concrete pavement. *International Journal of Pavement Engineering*, *21*(14), 1769-1779.

[16] Abu-Khashaba, M. I., Adam, I., & El-Ashaal, A. (2014). Investigating the possibility of constructing low cost roller compacted concrete dam. *Alexandria Engineering Journal*, *53*(1), 131-142.

[17] Debbarma, S., Ransinchung, G. D., & Singh, S. (2019). Feasibility of roller compacted concrete pavement containing different fractions of reclaimed asphalt pavement. *Construction and Building Materials*, *199*, 508-525.

[18] Chhorn, C., & Lee, S. W. (2018). Influencing compressive strength of roller-compacted concrete. *Proceedings of the Institution of Civil Engineers-Construction Materials*, *171*(1), 3-10.

[19] Chhorn, C., Kim, Y. K., Hong, S. J., & Lee, S. W. (2019). Evaluation on compactibility and workability of roller-compacted concrete for pavement. *International Journal of Pavement Engineering*, *20*(8), 905-910

[20] Wu, Z., Libre, N. A., & Khayat, K. H. (2020). Factors affecting air-entrainment and performance of roller compacted concrete. *Construction and building materials*, *259*, 120413.

[21] Chhorn, C., Hong, S. J., & Lee, S. W. (2017). A study on performance of roller-compacted concrete for pavement. *Construction and Building Materials*, *153*, 535-543.

[22] Mardani-Aghabaglou, A., & Ramyar, K. (2013). Mechanical properties of high-volume fly ash roller compacted concrete designed by maximum density method. *Construction and Building Materials*, 38, 356-364.

[23] Habib, A., Houri, A. A., Habib, M., Elzokra, A., & Yildirim, U. (2021). Structural performance and Finite Element modeling of roller compacted concrete dams: A review. *Latin American Journal of Solids and Structures*, *18*(04), e376.

[24] Zollinger, C. (2015). Recent advances and uses of roller compacted concrete pavements in the united states. *Paving Solutions*.

[25] Harrington, D., Abdo, F., Ceylan, H., Adaska, W., Hazaree, C., & Bektas, F. (2010). Guide for roller-compacted concrete pavements.

[26] Meftah, H., & Arabi, N. (2024). Effects of elevated temperatures' exposure on the properties of concrete incorporating recycled concrete aggregates. *Construction and Building Materials*, *411*, 134612.

[27] Sun, Y., Zhang, H., Shan, L., Zheng, R., Bao, J., Wang, W., & Zhang, P. (2024). Experimental investigation and mesoscale numerical analysis on water absorption in high-temperature-damaged lightweight aggregate concrete incorporating waste foundry sand. *Construction and Building Materials*, *448*, 138239.

[28] Kim, Y. S., Lee, T. G., & Kim, G. Y. (2013). An experimental study on the residual mechanical properties of fiber reinforced concrete with high temperature and load. *Materials and structures*, *46*(4), 607-620.

[29] Liu, Y., Jin, B., Huo, J., & Li, Z. (2018). Effect of microstructure evolution on mechanical behaviour of concrete after high temperatures. *Magazine of Concrete Research*, *70*(15), 770-784.

[30] Zhong, X., Bi, J., Zhao, Y., Wang, C., & Zhang, Y. (2024). Research on the capillary absorption capacity of concrete of different particle sizes after high temperature based on nuclear magnetic resonance technology. *Journal of Building Engineering*, *95*, 110064.

[31] Fernandes, B., Gil, A. M., Bolina, F. L., & Tutikian, B. F. (2017). Microstructure of concrete subjected to elevated temperatures: physico-chemical changes and analysis techniques. *Revista IBRACON de Estruturas e Materiais*, *10*(4), 838-863.

[32] Moghadam, M. A., & Izadifard, R. A. (2020). Effects of steel and glass fibers on mechanical and durability properties of concrete exposed to high temperatures. *Fire Safety Journal*, *113*, 102978.

[33] Mathews, M. E., Kiran, T., Naidu, V. C. H., Jeyakumar, G., & Anand, N. (2021). Effect of high-temperature on the mechanical and durability behaviour of concrete. *Materials today: proceedings*, *42*, 718-725.

[34] Pinto, S. R., Macedo, A. L. A., & Medeiros-Junior, R. A. (2018). Effect of preconditioning temperature on the water absorption of concrete. *Journal of Building Pathology and Rehabilitation*, *3*(1), 3.

[35] Zhang, S. P., & Zong, L. (2014). Evaluation of relationship between water absorption and durability of concrete

materials. *Advances in Materials Science and Engineering*, *2014*(1), 650373.

[36] Karahan, O. (2017). Transport properties of high volume fly ash or slag concrete exposed to high temperature. *Construction and Building Materials*, *152*, 898-906.

[37] Bao, J., Zheng, R., Zhang, P., Cui, Y., Xue, S., Song, Q., & Ma, Y. (2023). Thermal resistance, water absorption and microstructure of high-strength self-compacting lightweight aggregate concrete (HSSC-LWAC) after exposure to elevated temperatures. *Construction and Building Materials*, *365*, 130071.

[38] Behnood, A., & Ziari, H. (2008). Effects of silica fume addition and water to cement ratio on the properties of high-strength concrete after exposure to high temperatures. *Cement and Concrete Composites*, *30*(2), 106-112.

[39] Castro, J., Bentz, D., & Weiss, J. (2011). Effect of sample conditioning on the water absorption of concrete. *Cement and Concrete Composites*, *33*(8), 805-813.

[40] Yoon, M., Kim, G., Choe, G. C., Lee, Y., & Lee, T. (2015). Effect of coarse aggregate type and loading level on the high temperature properties of concrete. *Construction and Building Materials*, *78*, 26-33.

[41] Mendes, A., Sanjayan, J. G., Gates, W. P., & Collins, F. (2012). The influence of water absorption and porosity on the deterioration of cement paste and concrete exposed to elevated temperatures, as in a fire event. *Cement and concrete composites*, *34*(9), 1067-1074.

[42] Kou, S. C., Poon, C. S., & Etxeberria, M. (2014). Residue strength, water absorption and pore size distributions of recycled aggregate concrete after exposure to elevated temperatures. *Cement and Concrete Composites*, *53*, 73-82.

[43] Lugaresi, F., Kotsovinos, P., Lenk, P., & Rein, G. (2022). Review of the mechanical failure of non-combustible facade systems in fire. *Construction and Building Materials*, *361*, 129506.

[44] Biolzi, L., Cattaneo, S., & Rosati, G. (2008). Evaluating residual properties of thermally damaged concrete. Cement and Concrete Composites, 30(10), 907–916.

[45] Wu, B., Yu, Y., & Zhao, X. Y. (2019). Residual mechanical properties of compound concrete containing demolished concrete lumps after exposure to high temperatures. *Fire Safety Journal*, *105*, 62–78.

[46] Tanyildizi, H., Şengür, A., Akbulut, Y., & Şahin, M. (2020). Deep learning model for estimating the mechanical properties of concrete containing silica fume exposed to high temperatures. *Frontiers of Structural and Civil Engineering*, *14*, 1316–1330.

★★★

CARBON EMISSION ASSESSMENT OF 3D PRINTING CONCRETE MIXTURES

[1]HATICE GIZEM SAHIN, [2]ALI MARDANI

Bursa Uludag University, Faculty of Engineering, Deparment of Civil Engineering, Nilufer-Bursa, Turkiye
E-mail: [1]haticegizemsahin@gmail.com, [2]ali.mardani16@gmail.com

Abstract - In this study, carbon emission and energy consumption values of seventeen 3D printable concrete mixtures were investigated. The carbon emission assessment of the mixtures was evaluated according to the use and amount of cement, fly ash, silica fume, limestone aggregate, recycled concrete aggregate, polypropylene fiber, and water reducing admixture. Carbon emission assessment was made by using various embodied carbon and embodied energy values obtained from studies in the literature. As a result, a reduction in CO_2 emission values of the mixtures was measured with the use of silica fume. Also, it was determined that with increasing use of polypropylene fiber, CO_2 emission values increased by 3.6% (by 0.2%), 7% (by 0.4%), and 10.8% (by 0.6%). It was understood that the use of recycled concrete aggregate causes a decrease in the carbon emission values of the mixtures. It was determined that the energy consumption values of 3D printable concrete mixtures have a similar trend as their carbon emission values.

Keywords – Carbon Emissions, Energy Consumption, 3D Printable Concrete, Recycled Concrete Aggregate, Silicafume, Flyash, Polypropylene Fiber, Water Reducing Admixture.

I. INTRODUCTION

Global population growth and the acceleration of urbanization have increased the need for urban infrastructure and therefore the demand for building materials to critical levels [1]. This situation, in particular, makes the environmental impacts of the construction sector even more evident. In fact, it was reported that 36% of global greenhouse gas emissions originate from building and infrastructure construction [2]. In this context, it is clear that the choice of building materials plays a decisive role in the carbon footprint.

The complex life cycle of cement, pozzolanic materials, aggregates, and chemical admixtures used in concrete production makes it difficult to calculate carbon emissions. Therefore, the concept of "embodied carbon" is widely used in the literature to express the total carbon emissions that occur in the process from raw material acquisition to the production stage of a material [3]. Similarly, embodied energy describes the primary energy consumed throughout the life cycle of the material [4]. Hammond and Jones [5] limited this concept to the "Cradle-to-Gate" approach and addressed the energy consumption of the product from the factory to the point of exit.

Compared to traditional construction methods, 3D printing technology significantly reduces carbon emissions by providing material optimization, waste reduction, and energy efficiency [6-8]. This study aims to provide critical data for sustainable material selection by comparatively analyzing the embodied carbon and energy values of the components of 3D printable concrete mixtures.

II. MATERIALS AND METHODS

In this study, the carbon emission and energy consumption values of 17 different 3D printable concrete mixtures were examined in detail. The materials and their proportions used in the composition of the mixtures are shown in Table 1. These mixtures were evaluated according to the amount of cement, fly ash, silica fume, aggregate type (limestone and recycled concrete aggregate-RCA), polypropylene fiber andwater-reducingadmixture.

Mixture	Cement (kg/m^3)	Fly Ash (kg/m^3)	Silica Fume (kg/m^3)	Limestone Aggregate (kg/m^3)	RCA (kg/m^3)	Water (kg/m^3)	Polypropylene Fiber (kg/m^3)	Water Reducing Admixture (kg/m^3)
1	450	300	0	1134.6	0	280	0	8.5
2	450	300	0	1134.1	0	280	0	8.7
3	450	300	0	1133.4	0	280	0	9
4	450	330	0	1074.6	0	280	0	8.5
5	450	350	0	1034.5	0	280	0	8.5
6	450	350	0	1029.4	0	280	3.6	8.5
7	450	350	0	1024.2	0	280	7.1	8.5
8	450	350	0	1019.1	0	280	10.7	8.5
9	450	350	0	1029.4	0	280	3.6	8.5

10	450	350	0	1024.2	0	280	7.1	8.5
11	450	350	0	1019.1	0	280	10.7	8.5
12	450	350	0	1029.4	0	280	3.6	8.5
13	450	350	0	1024.2	0	280	7.1	8.5
14	450	350	0	1019.1	0	280	10.7	8.5
15	450	350	0	0	993.4	280	7.1	3
16	423	350	27	0	981.1	280	7.1	4
17	409.5	350	40.5	0	973.8	280	7.1	5

Table 1. Mixingratios of 3D printable concrete

In calculating carbon emission and energy consumption values, embodied carbon (kg CO_2/kg) and embodied energy (MJ/kg) values per unit weight of each component were taken into account. The secal culations, using the lowest and highest values in the literature (Table 2), were carried out according to the methodology given in Equation 1. Thus, the carbon emission and energy consumption values of the mixtures were obtained.

$$CO_2 = \sum_{i=1}^{n}(W_i x CO_{2i-e}) \quad [1]$$

Where,

CO_2 is the total embodied CO_2value of 1 m^3 of concrete. Itsunit is $kgCO_2/m^3$.

n, is the total rawmaterial in themixture.

W_i is the total amount of material (in kg) requiredtoproduce 1 m^3 of concrete.

CO_{2i-e} is theequivalent CO_2value of material (in kg CO_2/kg)

Mixing Component	Embodied Carbon (kgCO_2/kg)		Embodied energy (MJ/kg)	
	Minimum value	Maximum Value	Minimum value	Maximum Value
Cement	0.804[a]	0.94[b]	4.6[c]	6.15[d]
Fly Ash	0.008[e]	0.027[f]	0[b]	0.1[g]
Silica Fume	0.014[h]	0.024[a]	0.036[i]	0.1[h]
Limestone Aggregate	0.0026[j]	0.017[a]	0.018[k]	0.17[g]
RCA	0.002[e]	0.013[l]	0.066[m]	0.076[k]
Water	0[c]	0.001[e]	0[g]	0.2[c]
Polypropylene Fiber	3.43[n]	5.03[c]	79.8534[o]	94.4[c]
Water Reducing Admixture	0.0000052[f]	2.388[a]	0.0058[m]	18.3[g]

Table 2. Embodied CO2 emission and embodied energy factors used in the study

[a]Thilakarathna et al., [9], [b]Hu et al., [10], [c]Hammond and Jones, [5], [d]Gogginset al., [11], [e]Gan et al., [12], [f]Floweret al., [13], [g]Adesina et al., [14], [h]Kuruşcuet al., [15], [i]Murthyet al., [16], [j]Yanget al., [17], [k]Kurdaet al., [18], [l]Yazdanbakhshet al., [19], [m]Sobuzet al., [20], [n]Korolet al., [21], [o]Galan-Marin et al., [22]

III. EXPERIMENTAL RESULTS AND DISCUSSION

Embodied carbon dioxide refers to the total amount of carbon dioxide released throughout the production processes of a material, from raw material production to the final product [3]. Carbon emission and energy consumption values of the mixtures analyzed in the study are presented comparatively in Figure 1 and Figure 2, respectively, based on 1 m^3 of concrete. The findings support the emphasis made by Kaya et al. [4]. Cement stands out as the most dominant emission source, accounting for 92-98% of the total CO_2 emissions in the mixture. This result is consistent with the high embodied carbon values of cement (0.804–0.94 kg CO_2/kg) in Table 2. Specifically, how the use of cement substitutes can reduce these emissions is one of the focuses of the study.

Keeping the amount of cement constant throughout the mixtures examined within the scope of the study made the effect of cement on carbon emissions more evident, especially in mixtures number 16 and 17 containing silica fume. Experimental results show that these mixtures containing 6% and 9% silica fume reduce CO2 emissions by 4-7% compared to mixture number 15, which uses the same aggregate type but does not contain silica fume. This reduction can be explained by two main properties of silica fume: first, the additional energy requirement in its production is minimal since it is an industrial product; second, it has a much lower embedded carbon value compared to cement [3]. The study by Wang et al. [23] also supports these findings, revealing that the use of silica fume as a partial replacement material for cement significantly alleviates the environmental impacts of concrete production.

Experimental findings reveal that the lowest carbon emission value among the mixtures examined was observed in mixture number 17, which has the lowest cement content and was produced entirely using RCA. The performance of this mixture can be explained due to two critical factors: (1) minimization of the cement amount and (2) lower embedded carbon content of RCA compared to natural aggregates (Table 2). In contrast, the highest emission values were measured in blends 8, 11 and 14 containing 0.6% polypropylene fiber. This is explained by the relatively high

embodied carbon values of polypropylene fibers (3.43-5.03 kg CO_2/kg).

Analysis revealed that mixtures 1-5 did not show any significant difference in CO_2 emission values. This similarity is mainly due to the fact that variations in the mixture components are limited to only minimal changes in the amount of fly ash (in the range of 300-350 kg/m³) and the water-reducing admixture dosage (8.5-9 kg/m³). The data presented in Table 2 show that the embodied carbon values for these two components are at quite low levels (in the range of 0.008-0.027 kg CO_2/kg for fly ash and 0.0000052-2.388 kg CO_2/kg for water-reducing admixture). These low emission factors resulted in final CO_2 emission values remaining within a narrow band (419-420 kg CO_2/m³) despite composition differences between the mixtures. In particular, the fact that fly ash has an embodied carbon content approximately 30-100 times lower than cement played a decisive role in stabilizing emission values in these mixtures.

When examining mixtures containing fiber, it was found that there was a significant increase in CO_2 emissions as the use of polypropylene fiber increased. A 3.6% increase was observed in mixtures containing 0.2% fiber, a 7% increase in mixtures containing 0.4% fiber, and a 10.8% increase in mixtures containing 0.6% fiber. The main reason for this significant difference is that polypropylene fibres have a much higher emissions potential than other components, with an embodied carbon value of 3.43-5.03 kg CO_2/kg. This value is calculated to be 4-6 times higher than cement and 127-628 times higher than fly ash. These findings clearly demonstrate that the amount of fibers used should be carefully optimized to improve mechanical performance and that fiber selection is a critical parameter in sustainable concrete design.

The effects of using RCA on carbon emissions were evaluated by comparing it with mixture number 10, which has the same fiber length and ratio but contains limestone aggregate. The analyses revealed that mixture number 15 containing 100% RCA provided a 2% reduction in CO2 emissions compared to mixture number 10. This limited reduction suggests that the environmental advantages of RCA should be carefully evaluated. As noted by Bostanci et al. [24], this modest decrease in the carbon footprint of RCA is mainly due to the fact that the recycling process itself (extraction, processing and transportation stages) produces additional emissions. Also, the significantly lower amount of water-reducing admixture in mixtures containing RCA can be considered as a secondary factor contributing to this slight reduction in emissions.

Experimental findings revealed a parallel relationship between embodied energy and carbon emissions. As noted by Kaya et al. [4], these two parameters are closely related. As can be seen in Figure 2, the embodied energy values of mixtures 1-5 showed a variation of 6%.This is primarily due to the increase in fly ash content (300-350 kg/m³). Of particular note is the impact of polypropylene fiber use on energy consumption: an energy increase of 5% was observed for blends containing 0.2% fiber, 10% for those containing 0.4% fiber, and 16% for those containing 0.6% fiber. This increase is due to the higher energy requirements of fiber production processes. In contrast, the use of RCA resulted in a 7% decrease in embodied energy values. This can be explained by the more energy-intensive extraction and processing of natural aggregates.

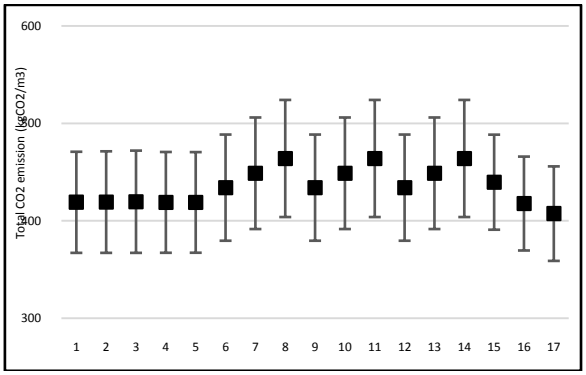


Figure 1. Carbon emission values of the mixtures

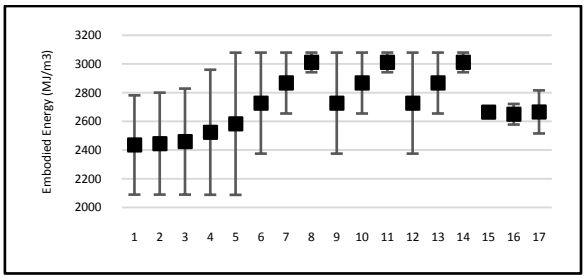


Figure 2. Embodiedenergyvalues of mixtures

IV. CONCLUSION

As a result of the materials used and the analyses performed, the following results were obtained;

1. It was determined that substituting 6-9% silicafum eforcement reduces CO_2 emissions of mixturesby 4-7%.
2. Poly propylenefibers have been found to have a significant impact on the carbon foot print of mixtures. In creases in CO_2 emissions were observed with increases of 3.6% (0.2% fiber), 7% (0.4% fiber), and 10.8% (0.6% fiber) as fiber content increased.
3. When the environmental impacts of using recycled concrete aggregate were evaluated, it was calculated that mixes containing 100% RCA provided a 2% reduction in CO_2 emissions compared to mixes with traditional limestone aggregate.

4. It was determined that the embodied energy and carbon emission values of the mixtures show paralleltrends.

Overall, theresultsobtained in this study demonstrate that thesu stainability of concrete produced with 3D printing technology can be significantly improved through careful selection and optimization of the constituent materials. Inparticular, theuse of alternativebindersinstead of cementandtheutilization of recycle daggregates hold promise for developing green building materials.

ACKNOWLEDGEMENTS

The author swould like to thank the Scientific Research ProjectsUnit of Bursa Uludag University for their support of project number FDK-2024-1959. The first author also thanks the TUBITAK 2211-A program, and the second author thanks TUBA.

REFERENCES

[1] Rossi, C., Reitemeyer, F., Heidrich, O., & Rybski, D. (2024). Comparison of embodied carbon of 3D-printed vs. conventionally built houses. *Findings*.

[2] UNEP. 2021. "Global Status Report for Buildings and Construction: Towards a Zero‐emission, Efficient and Resilient Buildings and Construction Sector." 2021. https://globalabc.org/resources/ publications/2021-global-status-report-buildings-and-construction.

[3] Hashim, A. A., Al-Mosawi, A. I., &Abdulsada, S. A. (2025). Investigating the mechanical properties, durability, microstructure, and embodied CO2 emissions of silica fume-infused sustainable concrete. International Journal of Applied Ceramic Technology, e15136.

[4] Kaya, E., Ciza, B., Yalçınkaya, Ç., Felekoğlu, B., Yazıcı, H., &Çopuroğlu, O. (2025). A Comparative Study on the Effectiveness of Fly Ash and Blast Furnace Slag as Partial Cement Substitution in 3D Printable Concrete. *Journal of Building Engineering*, 112841

[5] Hammond, G., & Jones, C. (2008). Inventory of carbon & energy: ICE (Vol. 5). Bath, UK: Sustainable Energy Research Team, Department of Mechanical Engineering, University of Bath.

[6] Raghu Nath Dharmalingam, V., Santhosh Kumar, A., Kachari, J., Dungrani, M., & Hashemi, A. (2024). Sustainable 3D Printing for Construction: Cement Choices, Structural Components, and Real-World Insights.

[7] Sahin, H., Mardani, A., & Mardani, N. (2024). Performance requirements and optimum mix proportion of high-volume fly ash 3D printable concrete. *Buildings*, *14*(7).

[8] Şahin, H. G., Kaya, Y., Akgümüş, F. E., Mardani, N., Mardani, A., Assaad, J., & Hamad, B. (2025). Degradation of mechanical properties of 3D fiber reinforced printed concrete mixtures exposed to elevated temperatures. *Case Studies in Construction Materials*, *22*, e04506.

[9] Thilakarathna, P. S. M., Seo, S., Baduge, K. K., Lee, H., Mendis, P., &Foliente, G. (2020). Embodied carbon analysis and benchmarking emissions of high and ultra-high strength concrete using machine learning algorithms. Journal of Cleaner Production, 262, 121281.

[10] Hu, W., Zhang, D., Ftwi, E., Ellis, B. R., & Li, V. C. (2023). Development of sustainable low carbon Engineered Cementitious Composites with waste polyethylene fiber, sisal fiber and carbonation curing. Resources, Conservation and Recycling, 197, 107096.

[11] Goggins, J., Keane, T., & Kelly, A. (2010). The assessment of embodied energy in typical reinforced concrete building structures in Ireland. Energy and Buildings, 42(5), 735-744.

[12] Gan, V. J., Cheng, J. C., & Lo, I. M. (2019). A comprehensive approach to mitigation of embodied carbon in reinforced concrete buildings. Journal of Cleaner Production, 229, 582-597

[13] Flower, D. J., & Sanjayan, J. G. (2007). Green house gas emissions due to concrete manufacture. The international Journal of life cycle assessment, 12, 282-288.

[14] Adesina, A. (2020). Performance and sustainability overview of alkali-activated self-compacting concrete. Waste Disposal & Sustainable Energy, 2(3), 165-175.

[15] Kuruşcu, A. O., & Girgin, Z. C. (2014). Efficiency of structural materials in sustainable design. J. Civ. Eng. Archit, 8, 1260-1265.

[16] Murthy, A. R., & Iyer, N. R. (2014). Assessment of embodied energy in the production of ultra high performance concrete (UHPC). International Journal of Students Research in Technology & Management, 2(3), 113-120.

[17] Yang, K. H., Song, J. K., & Song, K. I. (2013). Assessment of CO2 reduction of alkali-activated concrete. Journal of Cleaner Production, 39, 265-272.

[18] Kurda, R., Silvestre, J. D., de Brito, J., & Ahmed, H. (2018). Optimizing recycled concrete containing high volume of fly ash in terms of the embodied energy and chloride ion resistance. Journal of Cleaner Production, 194, 735-750.

[19] Yazdanbakhsh, A., Bank, L. C., Baez, T., & Wernick, I. (2018). Comparative LCA of concrete with natural and recycled coarse aggregate in the New York City area. The International Journal of Life Cycle Assessment, 23, 1163-1173.

[20] Sobuz, M. H. R., Datta, S. D., Akid, A. S. M., Tam, V. W., Islam, S., Rana, M. J., ... & Sutan, N. M. (2024). Evaluating the effects of recycled concrete aggregate size and concentration on properties of high-strength sustainable concrete. Journal of King Saud University-Engineering Sciences, 36(3), 216-227.

[21] Korol, J., Hejna, A., Burchart-Korol, D., & Wachowicz, J. (2020). Comparative analysis of carbon, ecological, and water footprints of polypropylene-based composites filled with cotton, jute and kenaf fibers. Materials, 13(16), 3541.

[22] Galan-Marin, C., Rivera-Gomez, C., & Garcia-Martinez, A. (2016). Use of natural-fiber bio-composites in construction versus traditional solutions: Operational and embodied energy assessment. Materials, 9(6), 465.

[23] Wang, Y. S., Cho, H. K., & Wang, X. Y. (2022). Mixture optimization of sustainable concrete with silica fume considering CO2 emissions and cost. Buildings, 12(10), 1580.

[24] Bostanci, S. C., Limbachiya, M., & Kew, H. (2018). Use of recycled aggregates for low carbon and cost effective concrete construction. *Journal of Cleaner Production*, *189*, 176-196.

★ ★ ★

EFFECT OF USING UV-MODIFIED WASTE HEMP FIBER ON CERTAIN FRESH AND HARDENED PROPERTIES OF CEMENTITIOUS SYSTEMS

[1]YAGMUR BASAR, [2]ALIYE AKARSU OZENC, [3]ALI MARDANI, [4]SEMIHA EREN

[1,3]Bursa Uludag University, Faculty of Engineering, Department of Civil Engineering
[2,4]Bursa Uludag University, Faculty of Engineering, Department of Textile Engineering
E-mail: [1]yagmurrbasarr@gmail.com, [2]aakarsu@uludag.edu.tr, [3]ali.mardani16@gmail.com, [4]semihaeren@uludag.edu.tr

Abstract - This study investigated the effect of using UV-modified waste hemp fibers on the performance characteristics of cement-based mortars. Hemp fibers with a length of 6 mm were surface modified using UV modified for two different durations (30 and 60 minutes) and replaced 0.5% of the aggregate by volume. In all mixtures, the water-to-cement ratio was kept constant at 0.52 and the flow value at 180±20 mm, and a high-performance water-reducing admixture based on poly carboxy late ether was used. It was observed that the addition of hemp fibers to the mixtures negatively affected their flow performance. This is believed to be due to the high cellulose content and porous structure of hemp fiber. It was determined that the need for admixtures increases in mortar mixtures containing hemp. The need for water-reducing admixtures in the mixtures was not affected by fiber surface modification. A significant decrease in both compressive and flexural strength was observed in the mixtures with fiber addition. This is attributed to an increase in the void volume within the matrix due to fiber agglomeration. The UV surface modification process applied to mitigate mechanical strength losses was observed to enhance the fiber-matrix interface by increasing surface roughness, thereby improving the compressive and flexural strength of the mixtures. The study emphasizes the necessity of chemical and physical modification processes to improve the industrial performance of hemp waste and mitigate strength losses.

Keywords - Cementitious Systems, Waste Hemp Fiber, UV Surface Modification, Flow Performance, Compressive and Flexural Strength

I. INTRODUCTION

In recent years, there has been growing interest in sustainable building materials in the construction industry. As a result, the use of natural fibers as reinforcing agents in cement-based composite materials has gained importance [1-3]. In particular, the reuse of waste fibers helps reduce negative environmental impacts. Additionally, it provides economic benefits.

The hemp plant stands out among fiber sources due to its high cellulose content, biodegradable structure, and rapid growth rate [4]. The stems of the hemp plant have a hard and strong structure due to the fibers that support the plant's upright position. Thanks to these properties, hemp fibers can be used as reinforcement in composite structures [5]. However, the low lignin content of hemp fibers results in poor adhesion, while their porous morphology and high-water absorption capacity can lead to poor processability and mechanical strength issues in cement-based composites [6]). In this context, applying modifications to the fiber surface has emerged as an effective method to address these issues and enhance matrix-fiber interaction [7-9].

In recent years, ultraviolet (UV) irradiation has gained popularity as a chemical-free and environmentally friendly surface modification method [10-11]. It is believed that the structural changes caused by UV treatment on the fiber surface have a positive effect on fiber-cement matrix adhesion and, consequently, on the overall performance of cement matrix composites [12].

This study aims to enhance the acceptability of natural fiber-reinforced cement matrix composites for industrial use while reducing the performance degradation of fiber-reinforced cement composites by modifying the surface of hemp fibers using UV-C light, an environmentally friendly method.

II. MATERIALS AND METHODS

2.1 Materials

In this study, CEM I 42.5R Portland cement was used in accordance with EN 197-1 standard. The chemical composition and physical and mechanical properties of the cement supplied by the manufacturer are presented in Table 1.

Oxides	(%)
SiO_2	18
Al_2O_3	4.75
$Fe2O_3$	3.58
CaO	63

MgO		1.4
$Na_2O+0,658K_2O$		0.7
SO_3		3.11
Specific gravity		3.06
Specific Surface Area (cm^2/g)		3441
Compressive Strength (MPa)	7-Day	42.8
	28-Day	51.8
Setting Time(min)	Initial	170
	Final	240

Table 1. Some properties of Portland Cement

In the scope of the study, river sand aggregate with a 0-4 mm sieve range, a specific gravity of 2.55 and a water absorption capacity of 2.34% according to the TS EN 1097-6 standard was used. In the mortar mixtures, a single type of polycarboxylate-ether based high-range water reducer was used in order to reach the target flow value of 180±20 mm. Some of the properties of the additive provided by the manufacturer are summarized in Table 2.

Density (g/cm^3)	Solid Content (%)	pH	Chlorine Content (%)	Alkaline Ratio, (%)
1,1	50±2	6±1	<0,1	<10

Table 2. Some properties of high-range water-reducing admixtures

In all fiber mixtures, 6 mm length hemp fiber was used in a constant ratio. Some properties of the hemp fiber used are shown in Table 3.

Density (g/cm^3)	Lenght (mm)	Tensile Strenght (MPa)	Modulus of Elasticity (MPa)
1,5	6,0	500	12,7

Table 3. Some physical and mechanical properties of hemp fiber

2.2 Preparation of mixture

Hemp fibers were subjected to UV surface modification in order to investigate the effect of the surface modification process on cementitious systems. In addition to the control mixture, three different mortar mixtures were prepared with 0.5% unprocessed hemp fiber and modified hemp fiber added to the control mixture. The water/cement ratio was kept constant at 0.52 and the flow value at 180±20 mm for all mixtures. The dosage of water-reducing admixture was optimized for each mixture to achieve the desired flow value. Mortar mixture calculations were performed for a volume of 1 m^3. The quantities of materials used in the production of the mortar mixtures are presented in Table 4. The naming of the fiber mixtures was based on the type of fiber and the UV treatment time. For example, the mixture using untreated hemp fiber is denoted as HF, while the mixture using 30-minute UV surface-modified fiber is named UV30-HF.

Mixture	Cement	Water	Aggegate	PCE*	Fiber	Flow
Control	450	249.4	1534.0	0.6	-	188
HF	450	249.3	1522.8	2.1	7.4	185
UV3O-HF	450	249.3	1522.8	2.4	7.4	160
UV60-HF	450	249.3	1522.8	2.8	7.4	175

Table 4. The amount of material used in the production of the mortar mixture (kg/m3) and the flow values (mm)

*****Cement By Weight

2.3. Method

The flow values of mortar mixtures were determined in accordance with ASTM: C1437 standard.

The ASTM C1437 standard test method is used to determine the fluidity or flow diameter of self-compacting concrete. Generally, the test involves placing a sample of the material in a pile cone, then removing it and allowing it to flow out on a flat surface. The resulting flow diameter is measured and used as an indicator of the material's flow ability.

The compressive strength and flexural strength of mortar mixtures have been determined in accordance with the EN 196-1 standard.

The EN 196-1 standard test method is used to determine the flexural and compressive strengths of cement mortars. The test involves placing the mortar, prepared at standard ratios, into molds and curing it under specified conditions. At specified ages, the specimens are first subjected to flexural testing, followed by compressive strength testing on the separated pieces.

Fiber surface modification

For the UV process used in the surface modification of hemp fibers, an apparatus containing 254 nm UV-C lamps was used. This apparatus is equipped with a total of 18 lamps and provides a combined power output of 470 watts. These lamps are placed on both sides and on top of the UV cabinet. The dimensions of the UV chamber used in the experiments were designed to be 100 x 70 x 138 cm. The UV chamber used for hemp fiber surface modification is shown in Figure 1.



Figure 1. UV cabinet

III. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Flow Performance

The amount of water-reducing admixture required to achieve the target flow value of the mixtures is shown in Figure 2.

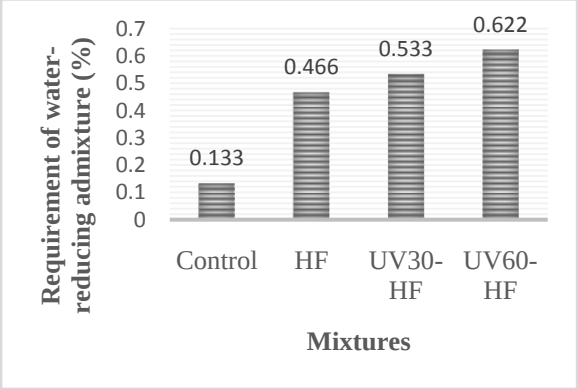


Figure 2. Water-reducing admixture requirements for mixtures

According to the data presented in Figure 2, it has been determined that the addition of hemp fiber significantly increases the amount of water-reducing admixture required for mortar mixtures to reach the target flow value, regardless of UV treatment.

As seen in Figure 2, the requirement for water-reducing admixture was observed to be 3–4.7 times higher with hemp fiber addition compared to the control mixture.

The increase in additive requirement is thought to stem from the high-water absorption capacity of the fibers, which increases the internal friction coefficient of the mixture and creates a three-dimensional network structure that raises viscosity [6,13]. The porous structure and high cellulose content of hemp fibers increase their sensitivity to moisture, and their hydrophilic nature, which gives them a high water absorption capacity, can negatively affect their performance in various applications [14,15]. Cellulose, being a hydrophilic (water-attracting) material, absorbs water in the mixture, reducing the amount of free water [16,17]. The fibers interact with each other during mixing, causing agglomeration. This negatively affects the processability of the mixture, leading to a decrease in flow values. It has been determined that the need for additives in fiber-containing mixtures does not cause a significant change in the need for additives, independent of the modification process duration.

3.2 Compressive and Flexural Strength

The 7-day compressive and flexural strength results of the mortar mixtures are shown in Figure 3. Regardless of the modification process, it was found that the addition of hemp fibers had negative effects on both compressive and flexural strength. The compressive strength values of the fiber-reinforced mixtures were found to be lower than those of the control mixture. This is thought to be due to the hemp fibers not mixing homogeneously, causing the fibers to interact with each other, form clumps, and create voids. Similarly, in a study conducted by Mardani Aghabaglou [18], it was emphasized that the presence of excessive fibers in the system increases the risk of clumping in the matrix and negatively affects strength due to the increase in void volume. However, it is thought that the porous structure, combined with the high water absorption capacity, causes the mixture to become cohesive, leading to the formation of voids during mixing due to air entrainment of the fibers.

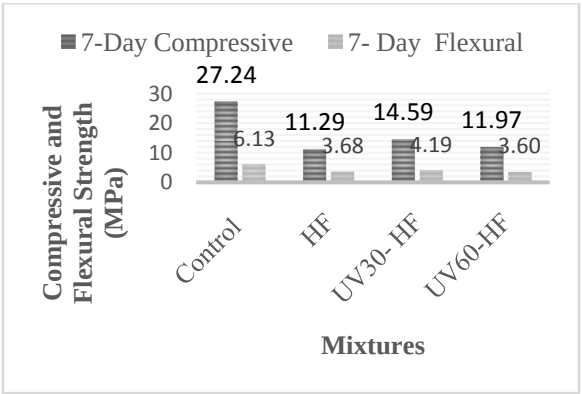


Figure 3. 7-day compressive and flexural strength values of mixtures

The compressive strength of the HF mixture was determined to be 11.29 MPa. The compressive strength of the UV30-HF mixture, which underwent 30 minutes of UV treatment, increased to 14.59 MPa, resulting in a 29.23% improvement. This is thought to be due to the improved adhesion between the fibers and the matrix resulting from the modification. It is believed that the surface roughness was increased with the UV surface modification. Many studies have emphasized that the adhesion between the fibers and the matrix depends significantly on both the properties of the matrix and the properties of the fibers [19]. The compressive strength of the UV60-HF mortar mixture, which underwent a 60-minute UV modified, increased

by approximately 6.02%, reaching 11.97 MPa. This is thought to be due to damage to the structural integrity of the fibers as a result of the increased treatment time. The flexural strength of the HF mixture was measured as 3.68 MPa. To strengthen the fiber-mortar matrix adhesion and increase the strength and durability of the fiber, a 30-minute UV modified was applied to the sample, resulting in an increase to 4.19 MPa, representing an approximate 13.86% increase. The bridging effect of fibers with a roughened surface due to modification [20,21] prevented crack propagation and reduced micro-crack formation, leading to an improvement in the flexural strength of the mixtures. Regardless of the modification process, it was observed that the addition of fibers to the mixture reduced the flexural strength. This situation is thought to be due to the fibers not mixing homogeneously in the matrix, resulting in an increase in the void volume as the fibers become entangled with each other[22]. As the modification time increased, the flexural strength of the sample containing hemp fiber modified with 60 minutes of UV processing decreased to 3.60 MPa, showing a decrease of approximately 2.17% compared to the untreated condition.

The findings revealed that a 30-minute UV modified time had a positive effect on mechanical properties, improving both flexural and compressive strength. The 30-minute UV surface modification modified strengthened the fiber-matrix interface, thereby increasing the compressive and flexural strength of the composites. However, when the UV modified time was increased to 60 minutes, it was observed that the structural integrity of the fibers was compromised, leading to significant decreases in mechanical properties. Based on these findings, enhancing the performance of hemp fibers through surface modification is considered an important method for developing environmentally friendly, durable, and economical cement-based composites.

IV. CONCLUSION

The findings obtained from the materials used and experiments conducted within the scope of the study are summarized below:

It was observed that adding fiber to the mixtures increased the demand for water-reducing additives in order to achieve the target workability value.
It was determined that the additive requirement in fiber-reinforced mixtures does not cause a significant change in the additive requirement, independent of the modification process duration.
A significant decrease in both compressive and flexural strength was observed in mixtures with fiber addition.
A decrease in compressive and flexural strength was observed in mixtures with fiber addition, independent of the modification process.
It was observed that the UV surface modification process positively affected the compressive and flexural strength of mortar mixtures.
It was observed that the effect of the UV surface modification process on the compressive and flexural strength of mortar mixtures varied depending on the duration of the process.
In mortar mixtures containing hemp fiber subjected to 30 minutes of UV surface modification, a 29.23% increase in compressive strength was observed compared to the unmodified mixture.
In mortar mixtures containing hemp fiber subjected to 60 minutes of UV surface modification, a 6.02% increase in compressive strength was observed.
As a result of the 30-minute UV treatment, a 13.86% increase in flexural strength was observed.
However, in the sample subjected to 60 minutes of UV surface modification, flexural strength showed a decrease of approximately 2.17% compared to the unmodification sample.

ACKNOWLEDGEMENTS

The authors would like to thank Bursa Uludag University BAP unit and Turkish Academy of Sciences (TUBA) for their support of the project numbered FPDD-2025-2210.

REFERENCES

[1] Torgal, F. P., & Jalali, S. (2011). Natural fiber-reinforced concrete. Fiber and composite materials for civil engineering applications (pp. 154–167). Woodhead Publishing.
[2] Chandar, S. P., & Kumar, S. S. (2022). Mechanical properties of fiber-reinforced concrete – natural fibers: A review. Materials Today: Proceedings, 68, 2066–2071.
[3] Özen, S., Benlioğlu, A., Mardani, A., Altın, Y., & Bedeloğlu, A. (2024). Effect of graphene oxide-coated jute fiber on the mechanical and durability properties of concrete mixtures. Construction and Building Materials, 448, 138225.
[4] Niyigena, C., Amziane, S., Chateauneuf, A., Arnaud, L., Bessette, L., Collet, F., ... & Walker, P. (2016). Variability of mechanical properties of hemp concrete. Materials Today Communications, 7, 122-133.
[5] Shahzad, A. (2012). Hemp fiber and composites – a review. Journal of Composite Materials, 46(8), 973-986.
[6] Çomak, B., Bideci, A., & Bideci, Ö. S. (2018). Effects of hemp fibers on the properties of cement-based mortar. Construction and Building Materials, 169, 794-799.
[7] Pehanich, J. L., Blankenhorn, P. R., & Silsbee, M. R. (2004). Effects of wood fiber surface treatment level on selected mechanical properties of wood fiber-cement composites. Cement and Concrete Research, 34(1), 59-65.
[8] Wei, J., & Meyer, C. (2014). Improvement of sisal fiber degradation resistance in concrete through fiber surface treatment. Applied Surface Science, 289, 511-523.
[9] Kim, J. H., Han, J. H., Hong, S., Kim, D. W., Park, S. H., Wee, J. H., ... & Kim, Y. A. (2021). Effect of plasma surface modification on the tensile properties of carbon fiber-reinforced cement composites. Carbon Trends, 3, 100030.
[10] Liu, X. D., Sheng, D. K., Gao, X. M., Li, T. B., & Yang, Y. M. (2013). UV-assisted surface modification of PET fiber for adhesion improvement. Applied Surface Science, 264, 61-69.
[11] Eren, S., & Özenç, A. A. (2023). Investigation of the bleaching of cotton fabrics with UV-TiO2.
[12] Malchiodi, B., Pelaccia, R., Pozzi, P., & Siligardi, C. (2023). Three sustainable polypropylene surface treatments for

optimizing the compatibility of PP fibers and cement matrix in fiber-reinforced concrete. Ceramics International, 49(14), 24611-24619.

[13] Kaplan, G., & Bayraktar, O. Y. (2021). The effect of hemp fiber usage on the mechanical and physical properties of cement-based mortars. Res. Eng. Struct. Mater, 7, 245-25

[14] Francois, C., Plasseraud, L., Pourchet, S., Boni, G., Placet, V., Fontaine, S., ... & Champion, D. (June 2017). A study on an innovative processing method for hemp fibers under supercritical fluid conditions and the resulting properties. National Conference on Composites 2017.

[15] Basar, Y., Caparoglu, N., Mardani, A., (2025), Effect of Hemp Waste Usage on Some Fresh and Hardened State Properties of Blast Furnace Slag Cement Systems. International Üsküdar Scientific Research Congress, Istanbul, Turkey, March, 2025

[16] Islam, S., & Hasan, B. (2025). A general overview of the effects of water and moisture absorption on the performance of hemp fiber and composites. SPE Polymers, 6(1), e10167.

[17] Kidalova, L., Stevulova, N., & Terpakova, E. (2015). The effect of water absorption on selected properties of hemp waste composites. Pollack Periodica, 10(1), 123–132.

[18] Mardani-Aghabaglou, A., Altun, M. G., & Yılmaz, G. (2017) The Effect of Polypropylene Fiber Usage Ratio on the Strength of Concrete Mixtures.

[19] Şahin, H. G., Akarsu Özenç, A., Saka Dinç, Z., Mardani, A., & Eren, S. (2025). Investigation of the fresh and hardened properties of 3D printable concrete containing ozone-modified carbon fiber. Journal of Sustainable Cement-Based Materials, 14(3), 534-548

[20] Altun, M. G., Süleyman, Ö. Z. E. N., & MARDANİ-AGHABAGLOU, A. (2018). The effect of polypropylene fiber usage on the drying shrinkage of natural hydraulic lime mortars. Sakarya University Journal of Science, 22(2), 427-435.

[21] Mardani-Aghabaglou, A., Yüksel, C., Hosseinnezhad, H., & Ramyar, K. (2016). Performance of steel microfiber-reinforced mortar mixtures containing plain, dual, and triple cement systems. Green Building Journal, 11(4), 109–130.

[22] Latifi, M. R. (2020). Effect of macro synthetic polypropylene fiber usage on the fresh and hardened state properties of concrete mixtures (master's Thesis, Bursa Uludağ University (Turkey)).

★★★

EFFECT OF WASTE STEEL FIBER LENGTH AND UTILIZATION RATE ON THE FLOW PERFORMANCE OF BLAST FURNACE SLAG 3D PRINTABLE CONCRETE MIXTURES

[1]FATIH EREN AKGUMUS, [2]HATICE GIZEM SAHIN, [3]ALI MARDANI

[1]Department of Civil Engineering, Bursa Uludag University, Nilufer-Bursa, Turkey, MSc Student,
[2]Department of Civil Engineering, Bursa Uludag University, Nilufer-Bursa, Turkey, Ph.D Student,
[3]Department of Civil Engineering, Bursa Uludag University, Nilufer-Bursa, Turkey
E-mail: [1]fatiheren1177@gmail.com, [2]haticegizemsahin@gmail.com, [3]ali.mardani16@gmail.com/alimardani@uludag.edu.tr

Abstract - Additive manufacturing has enabled the widespread adoption of 3D printable concrete (3DPC) mixtures in the construction industry due to their significant advantages over conventional methods. Compared to traditional formwork systems, 3DPC offers faster production times, reduced labor demands, improved workplace safety, and enhanced design flexibility. However, the absence of coarse aggregates and the high proportion of fine materials and binders in these mixtures often result in inferior drying-shrinkage performance. Furthermore, the elevated binder content compromises their sustainability and economic viability relative to traditional concrete. To address these limitations, recent studies have explored the incorporation of fibers, pozzolanic materials, and industrial byproducts to enhance dimensional stability, ecological balance, and cost efficiency. In this study, blast furnace slag (BFS) was used as a partial replacement for cement at 0%, 25%, 50%, and 75% of the total binder volume to mitigate the environmental impact of 3DPC mixtures. Additionally, straight steel fibers sourced from waste tires, with lengths of 5, 10, and 15 mm, were incorporated at volumetric ratios of 0%, 0.5%, and 1% to improve drying-shrinkage resistance.

Keywords - 3D printable concrete, blast furnace slag, flow, sustainability, waste tire fiber.

I. INTRODUCTION

Three-dimensional printable concrete (3DPC) technology represents an innovative additive manufacturing approach that facilitates moldless construction of complex structures through automated layer-by-layer deposition of cementitious materials. This emerging methodology has gained significant traction in the construction sector due to its transformative potential. The technology offers compelling advantages over conventional construction techniques, including accelerated production cycles, enhanced worker safety through reduced on-site hazards, optimized material utilization, and unprecedented architectural freedom in design realization [1,2].

Despite these benefits, the application of 3D printing technology in construction remains in a nascent stage of development. A critical challenge lies in the absence of standardized protocols, as current industry practices lack established acceptance criteria or comprehensive regulatory frameworks specifically tailored for 3DPC [3]. Conventional concrete standards prove insufficient for addressing the unique rheological and mechanical requirements of 3D-printed concrete systems, necessitating the development of specialized guidelines. This knowledge gap has prompted extensive empirical research efforts aimed at optimizing both fresh-state properties (e.g., extrud ability and build ability) and hardened-state performance characteristics of 3DPC mixtures [4].

Current research emphasizes that 3DPC mixtures must satisfy specific fresh-state performance criteria, which are principally categorized into three key parameters: extrudability [5–8], buildability [9,10], and shape stability [11,12]. A notable distinction between 3DPC and conventional high-strength concrete lies in their binder composition. While traditional mixtures typically contain 471–495 kg/m³ of cement, 3DPC mixtures require significantly higher cement contents (540–579 kg/m³), raising both economic and environmental concerns [13].

To address these challenges, researchers have investigated partial replacement of Portland cement with supplementary cementitious materials (SCMs), including fly ash, granulated blast furnace slag, silica fume, and limestone dust [14]. Although these mineral admixtures enhance workability and long-term mechanical properties, mirroring their effects in conventional concrete, they often compromise early-age strength development. Therefore, it has been stated that there are certain limitations regarding the use of mineral admixtures [15].

The escalating global consumption of plastic products has raised significant environmental concerns due to their persistent waste accumulation and ecological impacts [16]. This trend has led to the generation of substantial plastic waste volumes, with improper disposal posing severe risks of environmental contamination. Notably, Torres et al. [17] documented how the COVID-19 pandemic exacerbated this issue through the surge in disposable mask usage, further intensifying plastic pollution challenges. Parallel

concerns exist for the automotive sector, where widespread tire use generates millions of non-biodegradable waste tires annually [18].

In response to these sustainability challenges, innovative recycling approaches have emerged, including the incorporation of processed tire-derived fibers into fiber-reinforced concrete [19]. While existing literature extensively explores the application of waste tire fibers in conventional mixtures, a critical research gap persists regarding their utilization in 3DPC systems.

This study investigates sustainable modifications to 3DPC mixtures through two key approaches: partial cement replacement with blast furnace slag at substitution rates of 0%, 25%, 50%, and 75% by weight, and incorporation of recycled waste tire fiber at volumetric fractions of 0%, 0.5%, and 1%. To evaluate fiber geometry effects, three distinct fiber lengths (5, 10, and 15 mm) were examined. The experimental design specifically focused on quantifying the influence of these variables on the flow performance, a critical parameter governing 3DPC printability.

II. MATERIALS AND METHODS

A. Materials

The chemical, physical and mechanical properties of CEM I 42.5R Portland cement and blast furnace slag used obtained from their manufacturer are shown in Table 1.

Oxides (%)		**Cement**	**BlastFurnaceSlag**
SiO_2		18	35,5
Al_2O_3		4,75	12,4
Fe_2O_3		3,58	1,5
CaO		63	38,9
MgO		1,4	5,05
Na_2O+0,658 K_2O		0,7	1,07
SO_3		3,11	1,67
Specificgravity		3,06	2,5
SpecificSurfaceArea (cm^2/g)		3441	4950
CompressiveStrength (MPa)	7-day	42,8	-
	28-day	51,8	-
Pozzolanic Activity Index (%)	28-day	-	80
	90-day	-	90
Setting Time (min)	İnital	170	-
	Final	240	-

Table 1. Chemical composition, physical and mechanical properties of binder materials

Someproperties of the water reducing admixture used to ensure the required work ability in 3DPC mixtures, shared by the manufacturer, are shown in Table 2.

Admixture	Density (g/cm^3)	Solid Content (%)	pH	Chlorine Content (%)	Alkaline Content, Na_2O (%)
Polycarboxylate-etherbasedhighrangewaterreducing	1,060	32	2-5	<0,1	<10

Table 2. Some properties of water-reducing admixtures

The river sand aggregates with a maximum particle size (Dmax) of 2 mm was used. Physical characterization according to EN 1097-6 revealed the aggregates had a specific gravity of 2.54 and water absorption capacity of 0.4%.

For fiber reinforcement, steel fibers obtained from recycled waste tires were incorporated at two volumetric fractions (0.5% and 1%) with three different lengths (5, 10, and 15 mm) to evaluate size-dependent effects. Some properties of the fibers used are given in Table 3. Additionally, images of the scissors and cut waste fibers used to cut the waste fibers to the appropriate length are shown in Figure 1-a and Figure 1-b, respectively.

Fiber Type	Fiber Length (mm)	Tensile Capacity (MPa)	Modulus of Elasticity (MPa)	SpecificGravity
Steel	5, 10, 15	1500	200000	7.8

Table 3. Someproperties of wastesteel fiber



Figure 1. (a) Usedscissorsand (b) cutwaste fiber images

B. Mixing Ratios

The mixture design for 3DPC mixtures in this study incorporated the critical parameters for extrudability, buildability, and shape stability established by Şahin et al. [4]. Following their recommended methodology, extrudability was evaluated based on the mixture's ability to pass through the printing nozzle without clogging, while buildability was assessed through successful deposition of five consecutive layers without surface deformations. Mixtures meeting these criteria were further examined for shape stability, with those demonstrating values exceeding 95% deemed suitable for 3D printing applications. The water/binder ratio was kept constant at 0.40 in all mixtures. The experimental program included 28 different mixtures, comprising a control mixture andfiber-reinforced variants.Waste steel fiber were incorporated at two volumetric fractions (0.5% and 1%) and three lengths (5, 10, and 15 mm). The amount of material used in the production of 1 m^3 of 3DPC mixtures is shown in Table 4. Fibrous mixtures are categorized based on the BFC utilization ratio, fiber utilization ratio, and fiber length. For example, a mixture containing no BFC and using 0.5% waste steel fiber in a 5 mm length is designated as K-0.5-0.5, while a mixture containing 25% BFC andusing 1% waste

Mixture	Cement (kg/m^3)	BFC (kg/m3)	SilicaFume (kg/m3)	Aggregate (kg/m3)	FiberUsageAmount (kg/m3)	WaterReducingAdmixture (kg/m^3)
K	700	0	0	1211.3	0	2
25	525	143	0	1212.5	0	1.5
50	350	285.9	0	1216.1	0	0
75	175.2	395	28.9	1215.5	0	0
K-0,5-0,5	700	0	0	1198.6	39	2
K-1-0,5	700	0	0	1185.8	78	2
25-0,5-0,5	525	143	0	1199.8	39	1.5
25-1-0,5	525	143	0	1187	78	1.5
50-0,5-0,5	350	285.9	0	1203.4	39	0
50-1-0,5	350	285.9	0	1190.6	78	0
75-0,5-0,5	175.2	395	28.9	1202.8	39	0
75-1-0,5	175.2	395	28.9	1190	78	0
K-0,5-1	700	0	0	1198.6	39	2
K-1-1	700	0	0	1185.8	78	2
25-0,5-1	525	143	0	1199.8	39	1.5
25-1-1	525	143	0	1187	78	1.5
50-0,5-1	350	285.9	0	1203.4	39	0
50-1-1	350	285.9	0	1190.6	78	0
75-0,5-1	175.2	395	28.9	1202.8	39	0
75-1-1	175.2	395	28.9	1190	78	0
K-0,5-1,5	700	0	0	1198.6	39	2
K-1-1,5	700	0	0	1185.8	78	2
25-0,5-1,5	525	143	0	1199.8	39	1.5
25-1-1,5	525	143	0	1187	78	1.5
50-0,5-1,5	350	285.9	0	1203.4	39	0
50-1-1,5	350	285.9	0	1190.6	78	0
75-0,5-1,5	175.2	395	28.9	1202.8	39	0
75-1-1,5	175.2	395	28.9	1190	78	0

Table 4. Materials and mixing ratios used in 3DPC mixtures

C. Preparation of Mixtures and Method

The study produced 3DPC mixtures that met the essential requirements of extrudability, constructability, and shape stability. The mixing process followed a carefully designed workflow as depicted in Figure 2 and consisted of three key stages. First stage, the dry components, Portland cement, blast furnace slag, aggregate, and waste steel fiber, were thoroughly blended in a mixer at 62.5 rpm for 30 seconds to achieve uniform distribution. Next, water and necessary water-reducing admixtures were incorporated while continuing tomix at 62.5 rpm for 1 minute. Finally, the complete mixture underwent high-speed mixing at 125 rpm for 2 minutes to attain optimal homogeneity and rheological properties before being prepared for layer-by-layer compaction. This approach guaranteed consistent material properties throughout all experimental batches while

maintaining the precise control needed for 3D printing applications. The three-stage mixing protocol was specifically designed to address the unique requirements of fiber-reinforced 3DPC mixtures, particularly focusing on achieving proper fiber distribution without compromising the workability essential for extrusion-based printing.

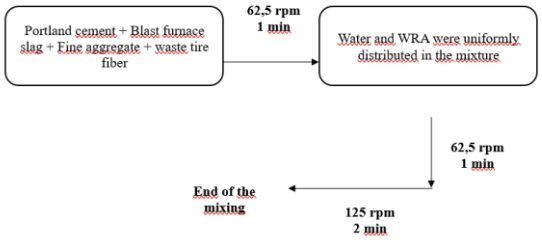


Figure 2. Preparationprocess of themixtures

Flow Test

Theflowvalue of theprepared 3DPC mixtureswasmade in accordancewiththe ASTM C1437-20 standard (Figure 3).



Figure 3. Flow test

III. EXPERIMENTAL RESULTS AND DISCUSSION

Flow Performance

The flow values of the 3DPC mixtures produced within the scope of the study are given in Table 5. The flow performance of mixtures significantly varied depending on composition parameters. Experimental results demonstrated flow values ranging from 162.5 mm to 185 mm, with the 25-1-1.5 mixture (25% BFC, 1% 15mm fibers) showing optimal flow characteristics and the 75-0.5-1.5 mixture (75% BFC, 0.5% 15mm fibers) exhibiting the most restricted flow. These findings align with the established printable concrete flow range of 130-210 mm reported by Zhang et al. [20], confirming all mixtures as suitable for extrusion-based deposition.

A notable trend emerged regarding admixture requirements: control mixtures without BFC required 2 kg/m³ of water-reducing admixture, while BFC-containing mixtures showed reduced demand, 1.5 kg/m³ for 25% replacement and complete elimination for 50-75% replacements. This progressive decrease in chemical admixture need with increasing BFC content correlates with findings by Özbay et al. [21], who attributed such behavior to three primary mechanisms:

Thermal and Hydration Effects

The lower hydration reactivity of blast furnace slag (BFS) compared to Portland cement generates less exothermic heat during initial setting [22]. This moderated thermal profile reduces early-age water evaporation, thereby maintaining mixture workability over extended periods. The slower reaction kinetics also delay stiffening, effectively extending the open time for printing operations without requiring additional water-reducing chemicals.

Particle Morphology and Lubrication

Micro structural analyses reveal that BFS particles exhibit more spherical geometries than angular cement grains [23]. This morphological advantage reduces inter particle friction within the fresh matrix, creating a ball-bearing effect that enhances flow characteristics. The resultant improvement in particle mobility diminishes the need for synthetic lubricants typically provided by conventional super plasticizers.

Surface Chemistry Interactions

With a specific surface area of 4950 cm²/g versus cement's 3441 cm²/g (Table 1), BFS provides greater adsorption sites for polycarboxylate-based admixtures [24]. This enhanced surface interaction promotes more efficient dispersion of cementitious particles at lower admixture dosages. The finer BFS particles also contribute to better paste phase continuity, further optimizing rheological performance through improved particle packing density.

The incorporation of silica fume (6% by volume) in mixtures with 75% BFC replacement proved essential for achieving optimal printability parameters. As demonstrated by Şahin et al. [24], the ultra-high specific surface area (~20,000 m²/kg) of silica fume provides two critical functions: it naturally increases the thixotropic behavior of the mixture through enhanced particle interactions, it precisely adjusts the viscosity to maintain shape stability without compromising extrudability. This dual effect addresses the potential over-fluidization that could occur with high BFC content while simultaneously supporting buildability through controlled structural buildup.

Notably, the study revealed that fiber reinforcement parameters (0.5-1% volume fraction, 5-15 mm lengths) exhibited negligible influence on admixture requirements. This suggests that the dominant

rheological control stems from the carefully balanced binder system (BFC-silica fume-cement ternary blend), with fiber additions primarily affecting hardened-state properties rather than fresh-state workability. The independence of admixture demand from fiber characteristics indicates that the developed matrix successfully decouples flow performance from fiber reinforcement, enabling separate optimization of printability and mechanical performance, a significant advantage for mix design flexibility in 3D concrete printing applications.

Mixture	Flowvalue (mm)
K	182,5
25	182,5
50	177,5
75	175
K-0,5-0,5	172,5
K-1-0,5	177,5
25-0,5-0,5	182,5
25-1-0,5	180
50-0,5-0,5	172,5
50-1-0,5	180
75-0,5-0,5	170
75-1-0,5	162,5
K-0,5-1	177,5
K-1-1	170
25-0,5-1	177,5
25-1-1	180
50-0,5-1	177,5
50-1-1	177,5
75-0,5-1	175
75-1-1	170
K-0,5-1,5	165
K-1-1,5	177,5
25-0,5-1,5	182,5
25-1-1,5	185
50-0,5-1,5	172,5
50-1-1,5	172,5
75-0,5-1,5	162,5
75-1-1,5	162,5

Table 5. Flowvalues of 3DPC mixtures

IV. RESULTS

In this study, which investigated the effect of BFC utilization ratio, fiber utilization ratio and length change on the flow value in 3DPC mixtures, the following results were obtained.

1. All tested mixtures demonstrated flow values within the 162.5–185 mm range, conforming to the established printable concrete threshold of 130–210 mm reported in the literature. This consistency confirms the suitability of the developed mixtures for extrusion-based deposition processes, with optimal flow achieved in the 25% BFS–1% fiber (15 mm) combination (185 mm)
2. A strong inverse correlation emerged between BFS content and water-reducing admixture demand: control mixtures required 2 kg/m³, decreasing to 1.5 kg/m³ at 25% replacement, and reaching complete elimination at 50–75% BFS substitution.
3. Waste fiber characteristics (0.5-1% volume fraction, 5-15 mm lengths) showed negligible influence on fresh-statead mixture requirements. .

ACKNOWLEDGEMENTS

The authors would like to thank the Scientific and Technological Research Council of Turkey for supporting project number 124M212 and Bursa Uludağ University Science and Technology Center (BAP) for supporting project number FYL-2025-2130. The first author would like to thank the TÜBİTAK 2210-A program, the second author would like to thank the TÜBİTAK 2211-A program, and the third author would like to thank the Turkish Academy of Sciences (TÜBA).

REFERENCES

[1] Hassan, A., Alomayri, T., Noaman, M. F., & Zhang, C. (2025). 3D printed concrete for sustainable construction: A review of mechanical properties and environmental impact. Archives of Computational Methods in Engineering, 1-31.

[2] Mohamed, O., Mishra, A., & Isam, F. (2025, August). An overview of 3D printed concrete for building structures: Material properties, sustainability, future opportunities, and challenges. In Structures (Vol. 78, p. 109284). Elsevier.

[3] Zhang, C., Hou, Z., Chen, C., Zhang, Y., Mechtcherine, V., & Sun, Z. (2019). Design of 3D printable concrete based on the relationship between flowability of cement paste and optimum aggregate content. Cement and Concrete Composites, 104, 103406.

[4] Şahin, H. G., & Mardani-Aghabaglou, A. (2022). Assessment of materials, design parameters and some properties of 3D printing concrete mixtures; a state-of-the-art review. Construction and Building Materials, 316, 125865.

[5] Zhi, P., Wu, Y. C., Yang, Q., Kong, X., & Xiao, J. (2022). Effect of spiral blade geometry on 3D-printed concrete rheological properties and extrudability using discrete event modeling. Automation in Construction, 137, 104199.

[6] Jayathilakage, R., Rajeev, P., & Sanjayan, J. G. (2020). Yield stress criteria to assess the buildability of 3D concrete printing. Construction and Building Materials, 240, 117989.

[7] Chen, Y., Chaves Figueiredo, S., Yalçinkaya, Ç., Çopuroğlu, O., Veer, F., & Schlangen, E. (2019a). The effect of viscosity-modifying admixture on the extrudability of limestone and calcined clay-based cementitious material for extrusion-based 3D concrete printing. Materials, 12(9), 1374.

[8] Chen, Y., Li, Z., Chaves Figueiredo, S., Çopuroğlu, O., Veer, F., & Schlangen, E. (2019b). Limestone and calcined clay-based sustainable cementitious materials for 3D concrete printing: a fundamental study of extrudability and early-age strength development. Applied Sciences, 9(9), 1809.

[9] Wu, Y., Liu, C., Liu, H., Zhang, Z., He, C., Liu, S., ... & Bai, G. (2021). Study on the rheology and buildability of 3D printed concrete with recycled coarse aggregates. Journal of Building Engineering, 42, 103030.

[10] Jayathilakage, R., Sanjayan, J., & Rajeev, P. (2020a). Characterizing extrudability for 3D concrete printing using discrete element simulations. In Second RILEM International Conference on Concrete and Digital Fabrication: Digital Concrete 2020 2 (pp. 290-300). Springer International Publishing.

[11] Lee, J. H., & Kim, J. H. (2022). Matric suction and its effect on the shape stability of 3D printed concrete. Cement and Concrete Research, 159, 106864.

[12] Kazemian, A., Yuan, X., Meier, R., Cochran, E., &Khoshnevis, B. (2017, June). Construction-scale 3D printing: shape stability of fresh printing concrete. In

International Manufacturing Science and Engineering Conference (Vol. 50732, p. V002T01A011). American Society of Mechanical Engineers.

[13] Khan, S. A., Koç, M., & Al-Ghamdi, S. G. (2021). Sustainability assessment, potentials and challenges of 3D printed concrete structures: A systematic review for built environmental applications. Journal of Cleaner Production, 303, 127027.

[14] Ma, G., & Wang, L. (2018). A critical review of preparation design and workability measurement of concrete material for largescale 3D printing. Frontiers of Structural and Civil Engineering, 12(3), 382-400.

[15] Marchon, D., Kawashima, S., Bessaies-Bey, H., Mantellato, S., & Ng, S. (2018). Hydration and rheology control of concrete for digital fabrication: Potential admixtures and cement chemistry. Cement and Concrete Research, 112, 96-110. https://doi.org/10.1016/j.cemconres.2018.05.014

[16] Björkner, B., Frick-Engfeldt, M., Pontén, A., &Zimerson, E. (2011). Plastic materials. Contact dermatitis, 695-728.

[17] Torres, F. G., & De-la-Torre, G. E. (2021). Face mask waste generation and management during the COVID-19 pandemic: An overview and the Peruvian case. Science of the total environment, 786, 147628.

[18] Li, G., Garrick, G., Eggers, J., Abadie, C., Stubblefield, M. A., & Pang, S. S. (2004). Waste tire fiber modified concrete. Composites Part B: Engineering, 35(4), 305-312.

[19] YILDIRIM, Z. B., KARACASU, M., & OKUR, D. V. (2018). Atık Lastik ve Cam Lif ileModifiyeEdilmişBitümünAsfalt Betonu Performansına Etkileri. Afyon Kocatepe Üniversitesi Fen Ve MühendislikBilimleriDergisi, 18(3), 1019-1027.

[20] Zhang, C., Nerella, V. N., Krishna, A., Wang, S., Zhang, Y., Mechtcherine, V., & Banthia, N. (2021). Mix design concepts for 3D printable concrete: A review. Cement and Concrete Composites, 122, 104155.

[21] Özbay, E., Erdemir, M., & Durmuş, H. İ. (2016). Utilization and efficiency of ground granulated blast furnace slag on concrete properties–A review. Construction and Building Materials, 105, 423-434.

[22] Park, C. K., Noh, M. H., & Park, T. H. (2005). Rheological properties of cementitious materials containing mineral admixtures. Cement and concrete research, 35(5), 842-849. https://doi.org/10.1016/j.cemconres.2004.11.002

[23] He, T., Li, Z., Zhao, S., Zhao, X., & Qu, X. (2021). Study on the particle morphology, powder characteristics and hydration activity of blast furnace slag prepared by different grinding methods. Construction and Building Materials, 270, 121445.

[24] Şahin, H. G., Mardani, A., &Beytekin, H. E. (2024). Effect of silica fume utilization on structural build-up, mechanical and dimensional stability performance of fiber-reinforced 3D printable concrete. Polymers, 16(4), 556.

★★★

PREGNANCY HEALTH EDUCATION IN OMAN: THE NECESSITY FOR ENHANCED INITIATIVES FOCUSED ON WOMEN'S HEALTH.

[1]ASMA SAIF YAHYA AL-HADABI, [2]DR SHARIFAH SHAFINAZ BINTI SH ABDULLAH

[1]RN, RM, MSc, Nursing and midwifery Tutor Sultanate of Oman. Current PhD student at Universiti Teknologi Mara (UiTM, PunakAlam, Selangor Malaysia)
[2]Senior Lecturer at MARA University of Technology
E-mail: asm39560@gmail.com

Abstract - World Health Organization (WHO), which stands for the growing recognition of the importance of antenatal care (ANC) to world health. Health education during pregnancy aims to do the following: reassure and support expectant mothers; educate and guide them through the prenatal period; identify and treat any minor complications that may develop; and provide efficient and effective screenings throughout the pregnancy. Investigations of current gap in practices within the Oman health care system over the past few decades have made it very evident that more coordinated educational activities are necessary to ensure high quality, individual happiness, and societal satisfaction through the use of technology. A new approach to pregnancy education that takes advantage of mobile application to cater to women when and when they are most comfortable.

Keywords - Antenatal Care (ANC), Pregnancy, Health Education, Oman Health Care System, Gaps in Practice, Innovation, Mobile application.

I. INTRODUCTION AND BACKGROUND

A routine, specialized treatment that is provided to pregnant women and their unborn children in order to guarantee a healthy pregnancy, delivery, and postpartum period is referred to as antenatal care (ANC). The American National Congress (ANC) was founded in Paris in 1788 and relocated to Boston, Massachusetts, in the first decade of the 20th century. It focused on determining whether or not the woman was pregnant and planned the time and location of the delivery (Demirci et al., 2023). It is essential for health promotion and prevention in maternal health services, according to the World Health Organization (WHO), that antenatal care provides safe motherhood. (WHO, 1997) The objective of this multinational effort is to reduce the rates of illness and mortality among mothers and newborns. The modern American Nurses Association acknowledges that pregnant women face distinct health "challenges and needs" and works to address these issues in order to assist them in having a healthy pregnancy. The Context of the Research This section provides an overview of the history and development of health care services in Oman and around the world. In addition, the third segment is going to focus on a pregnant health education service, as well as the existing scenario regarding the ANC gap in practice in Oman.

1. Health Education for Antenatal Care Around the World

Health Education for Antenatal Care (ANC) on a Global Scale: Although physical preparation is the primary emphasis of prenatal programs around the world, the social and psychological aspects of pregnancy, delivery, and the postpartum period are no less difficult. The majority of pregnant women, though, find that attending prenatal classes helps them prepare for the mental and physical changes that are to come. Breastfeeding knowledge and self-efficacy are enhanced by both online and in-person learning, according to research (Pilus et al. 2022). Specialized prenatal seminars can help first-time moms feel more prepared for the birth process. The confidence of pregnant women is increased and complications like cesarean sections are decreased through these training programs (Striebich et al. 2018; Yörük &Acikgoz 2023). Lothian (2016), Levett et al. (2020), Vanderlaan (2021), Janicka-Kubiak (2022), and Grussua& Quatraro (2020) all agree that prenatal education, when practiced regularly and with purpose, is beneficial to the health of both mother and child.

To help parents in industrialized nations get ready for all the changes that pregnancy brings, specialist experts offer pre-pregnancy and prenatal education throughout ANC. Individuals or small groups typically accomplish this. Several studies have shown that high-quality, preventative healthcare practices reduce the risk of illness and death for mothers and their children (Gagnon & Sandall, 2007; Homer, 2011; Hatamleh et al., 2019 Oktariana, 2020). O'Sullivan et al. (2014), Brixval et al. (2016), and Shand (2022) all found that while organized ANC health education sessions were effective in many developed countries, some countries have not implemented them yet.

2. The current healthcare system in Oman

Oman, a member of the Gulf Cooperation Council, is formally designated as the Sultanate of Oman. Muscat is the capital of Oman. The country's 11

governorates comprise 63 districts, sometimes known as "wilayat" (Annual Health Report, 2022). The oil sector of Oman has facilitated its transformation into a high-income powerhouse following five decades of accelerated expansion. In 1970, His Majesty Sultan Qaboos Bin Said reformed the nation's healthcare, educational, and human resources institutions. Oman's population of 5 million comprises 3 million native-born Omani residents and 2 million foreign nationals, including a substantial expatriate component (National Center of Statistics and Information, 2022). Omani legislation is founded on Sharia, with Islam as the official religion (Alhejji, 2018). Figure 1.1 illustrates Oman's geographical position in Asia, while figure 1.2 delineates its 11 governorates.



1.1 illustrates Oman's geographical position in Asia

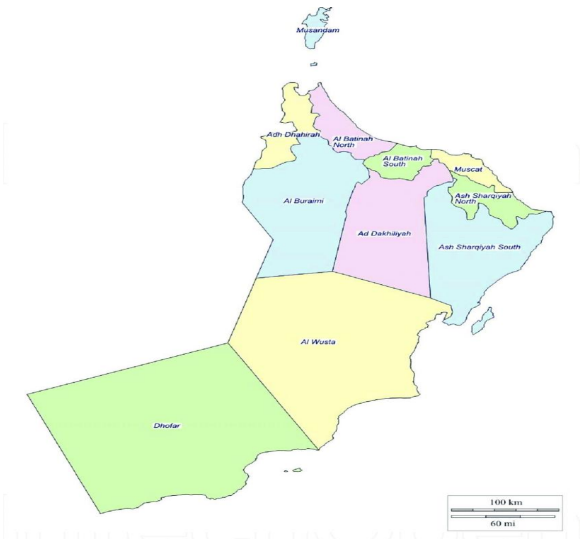


figure 1.2 Oman's 11 governorates

Prior to 1970, Oman's healthcare system was underdeveloped, underfunded, and only had two hospitals. The average life expectancy was 49.3 years, with high rates of maternity and child mortality, and the bulk of the population relied on traditional healers. Sultan Qaboos Bin Said, who took control in 1970, improved healthcare and infrastructure to meet the country's growing population. The rapid expansion of healthcare services in Oman over the last 50 years has increased life expectancy to 77 years. The Ministry of Health oversees primary, secondary, and tertiary healthcare services. Table 1.1 summarizes the Oman Ministry of Health's (MoH) 50-year progress (MoH, 2022).

Year	1970	2000	2022
Population	658,000	2,402,000	4,934,000
Hospitals	2	49	50
Extended Health Centers	0	9	21
Health centers with bed	0	57	52
Health Centers without Beds	19	52	140
Life Expectancy at birth (Omani)	49.3	73.38	77

Table 1.1: Health care services in Oman Over 5 decades. Source: Summary from MoH, Annual Health report 2022

Approximately 15,000 individuals in Oman obtain prenatal and postnatal care, vaccinations, general medical services, and additional support from primary health care (PHC) facilities, commonly referred to as health centers or polyclinics. By 2022, Oman has around 140 health centers and 21 extended centers, with larger cities hosting multiple facilities. SHC institutions, often district or governorate hospitals, provide treatment for patients referred from PHCs requiring more comprehensive medical care, including surgical procedures. Tertiary Health Care (THC) institutions, sometimes referred to as national hospitals, manage high-risk scenarios, complex operations, and specialized medical care. The referral system integrates primary, secondary, and tertiary hospitals, consolidating all specialists in Muscat and prolonging wait times. Figure 1.1: classify Oman-MoH health care institutions and referral systems.

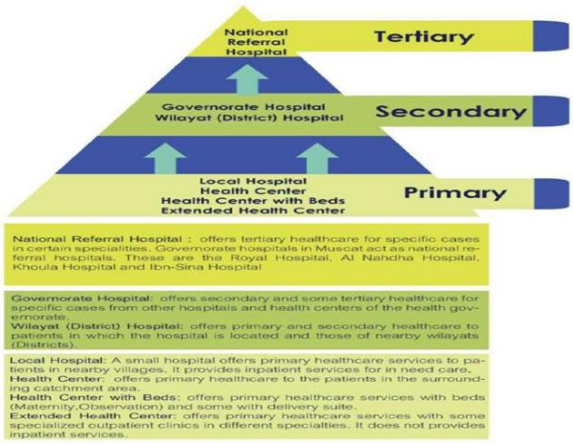


Figure 1.1: Referral system flow in Oman Health care institutions

As a part of Vision 2040–2050, Oman's healthcare system has been heavily integrated with technology to streamline procedures, improve data management, and increase efficiency. The care that patients receive has improved. After launching a prototype version in 1994, the Health Information System (HIS) was upgraded to AlShifa 3+ in 2008 by the Ministry of Health (MoH), allowing more than 200 healthcare facilities to be connected to it. Healthcare

information systems (HIS) enhance healthcare provider communication, paper usage, and patient record management (Al-Gharbi et al., 2014). Al Kiyumi (2021), the e-Health Portal (2021), e-Health Portal (2022), and Abri (2023) all point to the usefulness of digital services like tele-counseling and e-referrals, which E-Oman supports.

Ever since the 1970s, Oman's healthcare system has been working to enhance the health of women. The majority of women were responsible for the upbringing of children and the care of the elderly prior to the early 1970s, when advocates for women's rights granted them the opportunity to attend college and work in the private and public sectors. This resulted in Oman's Total Fertility Rate (TFR) decreasing from 10.13 in 1985 to 3.2 in 2022. This was accomplished by the implementation of birth spacing laws and the empowerment of women beginning in 1990.

Article 15 of Oman's Child Law says that all pregnant women must get free care before, during, and after giving birth. This is to make sure that all children are treated fairly. Ultrasounds, screens, and diagnostic tests are all common in Omani ANC facilities (Al-Jarida& Al-Rasmiya, 2014). These doctors and nurses rarely get training in women's health and giving birth. Al-Hadabi (2017) says that Oman's Ministry of Health (MoH) promotes women to register early and keeps MHRs for each woman, which is in line with WHO guidelines. People say that clinics don't teach enough about health. Reports say that the MHR's health teaching part is not taken seriously. According to the 2018 Women's Report (Al Maqbali), nurses have to quickly register pregnant women and do extra paperwork in the clinics, leaving them with little time to talk to women and answer their questions. Women don't always read brochures that are special to each trimester (Almalik & Mosleh 2017; Al Maqbali 2018; AlDughaishi et al. c 2023). For training information, the MoH switched from printed books to MHR par cods (QR codes) in 2023. Figure 1.4 on page 23 of MHR shows health education topics. This improvement cut down on costs, but the content is long and doesn't have any live help, so women might not be interested.



Figure1.4: Health Education page 23 in Maternal Health Record-Oman

3. Present status of healthcare services in Oman concerning antenatal education and the existing practice gap

In Oman's healthcare system, which is now in need of a well-organized program for educating persons about birth, a number of research studies have been conducted to investigate the efficacy of antenatal preparation programs. Some pregnant women have inadequate comprehension, bad attitudes toward labor, and increased anxiety about the birthing process as a result of the lack of information that is available to them. According to the Ministry of Health (2019) and Almalik and Mosleh (2017), this has resulted in an increase in the number of requests for cesarean sections (CS) that are not justified by acceptable medical justifications. The length of hospital stays and other medical treatments that are paid by the government would be extended as a result of this, which would contribute to an increase in the costs that are incurred by the healthcare system. Oman does not have a formal or validated antenatal education program (Al Maqbali, 2018; Al Dughaishi et al., c 2023). This is despite the fact that numerous studies have been conducted all over the world to investigate the effectiveness of childbirth classes on a variety of aspects, including women's childbirth experience, maternal and neonatal well-being, women's satisfaction, and childbirth outcomes.

Omani prenatal health education has to be improved to meet the demands of women and the standards set by medical professionals. The lack of a comprehensive guideline in the educational program of the Ministry of Health that serves the Omani community and the scarcity of trained medical professionals are two key issues with Oman's healthcare system when it comes to pregnancy education (MOH, 2019; Almalik & Mosleh, 2017; Al Dughaishi et al., 2023; Al Dughaishi et al. b 2023; AlBalushi et al., 2023).

Consequently, in light of compelling evidence and research concerning the deficiencies and pressing needs for antenatal care (ANC) preparation classes in Oman and Gulf nations, alongside numerous recommendations highlighting the importance of instituting structured ANC preparation classes for Omani women, this proposed study seeks to develop the New Structured Antenatal Educational Program (NSAEP) (MOH, 2019; Almalik & Mosleh, 2017; Al Dughaishi et al., 2023; Al Dughaishi et al. b 2023; Amal et al., 2023; Zalikha et al., 2024). The NSAEP program seeks to deliver comprehensive education to primigravida women in their third trimester, intending to equip them physically and psychologically for labor and lactation. The proposed study introduces a comprehensive childbirth education program aimed at equipping pregnant women with the necessary knowledge to manage the changes occurring during the third trimester of

pregnancy and ultimately enhance pregnancy outcomes. Therefore, it is essential to assess the effectiveness of this childbirth education program in improving the knowledge and readiness of primigravida women for labor.

Additionally, further research is required to explore women's perspectives on the impact of birthing preparation classes on their readiness for parenting. To align with the digitalization initiatives in Oman's vision for 2040-2050, enhancing maternal health education is essential to meet the needs of a digitally inclined generation of mothers. Research at both global and local levels indicates that pregnant women utilize mobile devices and internet access to obtain information and alleviate uncertainties (Hatamleh et al., 2023; Al Dughaishi et al., 2023 a). Healthcare providers must align with community demands and expectations to effectively implement digital services. Providing women with valid, evidence-based, and reliable health information that is accessible at any time and from any location is advantageous, in contrast to the unreliable information available on the internet.

The World Health Organization has long pushed for women to have access to comprehensive prenatal, labor, and postnatal records in order to guarantee a positive delivery experience. A well-structured program is necessary to promote ANC education in Oman, as demonstrated in the essay. Al Dughaishi et al. (2023), Al Dughaishi et al. (2023), and AlBalushi et al. (2023) highlight the importance of new pregnancy education programs in Oman to help women prepare for childbirth. Both the mother and her unborn child benefit greatly from prenatal education programs that target the third trimester. Due to the absence of a formal pregnancy education program in Oman's healthcare system, health care providers there should examine, design, and evaluate a program to improve women's and babies' health during the third trimester of pregnancy. Patient satisfaction is a key indicator of quality health treatment, particularly during pregnancy. In order to make pregnant women happy, it's important to cater to their needs and desires (MOH, 2019; Almalik & Mosleh, 2017; Al Dughaishi et al. b 2030).

Numerous studies have been undertaken worldwide to assess the effectiveness of antenatal preparation classes for first-time mothers. It is noteworthy that these studies were conducted mainly in foreign and Western countries, which exhibit considerable cultural and contextual differences relative to the health environment in Oman. Moreover, most previous global studies have focused on only one or two dimensions of maternal health. This proposed study seeks to assess various outcomes related to pregnancy, labor, and the postnatal period. This proposed e-platform represents the inaugural service in Oman specifically tailored for women, offering extensive information and resources to facilitate a secure labor and childbirth experience. The proposed educational curriculum is specifically designed for Omani women, considering the cultural beliefs and traditions of Oman. The NSAEP will serve as an electronic platform by integrating educational sessions into the existing MoH Al-Shifa application, which has been in operation in Oman for several years. This proposed study will investigate the integration through a randomized controlled trial approach. The following chapter will examine the development of an NSAEP. A viable approach to mitigate the current shortage of specialized workers in Oman is the establishment of a nationwide pregnancy educational program.

II. CONCLUSION

The provision of information, reassurance, and support, as well as the identification and resolution of minor issues, screening, and information provision, are all advantages of health education during pregnancy. The modern American Nurses Association recognizes that pregnant women encounter unique health "challenges and needs" that must be addressed to guarantee their safety. Given the evolution of the health care system in Oman over the past few decades, it is imperative to coordinate educational initiatives to ensure that all medical treatment recipients receive the utmost quality of care. Consequently, cooperation with other departments within the Ministry of Health in Oman has the potential to improve the overall quality of women's services, thereby reducing mortality and morbidity rates and ensuring secure motherhood worldwide. You can accomplish this task with the assistance of technology. Mobile applications facilitate the provision of distinctive pregnancy education to women.

REFERENCES

[1] AlDughaishi, M., Matua, G., Seshan, V. (2023) b. Antenatal Education Services in Oman: A Descriptive Qualitative Inquiry of Healthcare Provider's Perspective. SAGE Open Nursing. Volume 9: 1–12. A

[2] AlDughaishi, M., Matua, G., Seshan, V. (2023) a. A Qualitative Inquiry of Women's Perspective of Antenatal Education Services in Oman. SAGE Open Nursing Volume 9: 1–12. B

[3] AlDughaishi, M. Y., Seshan, V., & Matua, G. A. (2023) c. Challenges and Strategies for Providing Effective Antenatal Education Services in Oman's Public Healthcare System: Perspectives of service providers and pregnant women. Sultan Qaboos University Medical Journal, 1(1). https://doi.org/10.18295/squmj.5.2023.032. C

[4] Al Maqbali, F. (2018). Navigating Antenatal Care in Oman: A Grounded Theory of Women's and Healthcare Professionals' Experiences. The University of Manchester (United Kingdom). ProQuest Dissertations Publishing, 2019. 27775318.

[5] Almalik, M. M., & Mosleh, S. M. (2017). Pregnant women: What do they need to know during pregnancy? A descriptive study. Women and Birth, 30(2), 100-106.

[6] AlBalushi A. A, Al-Asmi A, Al-Shekaili W, Kayed RR, Islam MM, Ganesh A, Al-Adawi S. Medical malpractice in Oman: A 12-year retrospective record review. PLoS One. 2023 Aug 23;18(8):e0290349. doi: 10.1371/journal.pone.0290349. PMID: 37611051; PMCID: PMC10446241.

[7] Amal Al Hadi, Dawson, J., Paliwoda, M., Walker, K., & New, K. (2023). Healthcare Providers' Views of Information, Support, and Services Offered to Women in the Postnatal Follow-up Care Period in Oman: A Qualitative Study. PubMed, 11(1), 2–13. https://doi.org/10.30476/ijcbnm.2022.96663.2140

[8] Brixval, C. S., Thygesen, L. C., Axelsen, S. F., Gluud, C., Winkel, P., Lindschou, J., ... & Bryman, A. (2006). Paradigm peace and the implications for quality. International journal of social research methodology, 9(2), 111-126.

[9] Demirci, A. D., Kochan, M., &Kabukcuoglu, K. (2023). Effect of antenatal education on childbirth self-efficacy: A systematic-review and meta-analysis. Current Psychology, 1-11.

[10] Gagnon, A. J., & Sandall, J. (2007). Individual or group antenatal education for childbirth or parenthood, or both. Cochrane database of systematic reviews, (3).

[11] Hatamleh, R., Abujilban, S., &Abuhammad, S. (2019). The effects of a childbirth preparation course on birth outcomes among nulliparous Jordanian women. Midwifery, 72, 23-29.

[12] Hatamleh, R., Abujilban, S., & Joseph, R. (2023). Using social media platforms to enhance the delivery of a childbirth education program. The Journal of Perinatal & Neonatal Nursing, 37(1), 36-43.

[13] Homer, C. S. (2011). The 'Ready for Child'structured antenatal training programme increases likelihood of mother's arriving at the maternity ward in active labour and decreases use of epidural analgesia. Evidence-Based Nursing, 14(1), 16-17. doi:10.1136/ebn1127.

[14] Ministry of Health (2019). Sultanate of Oman. Annual Health Report (Online). Available: https://www.moh.gov.om/en/web/statistics/annual-reports (Accessed 20 December, 2023).

[15] Oktariana, D. (2020, November). Efforts to Maintain the Health of Pregnant Women through Antenatal Care Education. In Conferences of Medical Sciences Dies Natalis Faculty of Medicine Universitas Sriwijaya (Vol. 2, No. 1, pp. 45-50).

[16] O'Sullivan, C; O'Connell, R and Devane, D. (2014). A Descriptive Survey of the Educational Preparation and Practices of Antenatal Educators in Ireland. The Journal of Perinatal Education. 23(1), 33–40

[17] World Health Organization. (1997) Family and reproductive health coverage of maternity care.

[18] Zalikha Al-Marzouqi, Ruqiya Al-Za'abi, & Al-Dhoani, A. (2024). Health-care professionals' barriers to anemia prevention among pregnant women in Oman. Deleted Journal, 3(2), 62–71. https://doi.org/10.4103/abhs.abhs_98_23

★★★

THE IMPACT OF THE SOCIAL CONTEXT ON STUDENT ATTITUDES AND PERFORMANCE: A CASE STUDY IN A SOUTH AFRICAN UNIVERSITY

CINDY RAMHURRY

University of Johannesburg, Johannesburg. South Africa
E-mail: cindyr@uj.ac.za

Abstract - An implicit theme underlying academic research is that student attitudes play a significant part in student learning and performance yet remains a relatively under-researched topic. Acknowledging the theoretical notion offered by Fontana (1995) that there is a strong correlation between attitudes and academic performance, this article explores such a relationship in a Communication Skills module offered in 2024 within an Engineering Degree programme at a South African University. The aim of the article is to highlight psycho-social factors which show a higher correlation between students' attitudes and their performance. Using a qualitative approach, data were gathered using focus group interviews with a set of 20 students enrolled in the Communication Skills course. Thematic analysis was used to identify salient themes from these discussions. The discussions revealed that the psycho-social factors with higher correlations include group work and mutual support. Findings also showed that self-image and self-confidence were the two most clearly valued attitudes. The paper argues that the psycho-social context has an important influence on students' attitudes. The paper argues that the positive impact of social interaction on students' attitudes may have potential for academics in transforming their practices and decision-making within the classroom.

Keywords - Academic Performance, Higher Education, Foucault, Governmentality, Subjectivity.

I. INTRODUCTION

Using a case study approach, this paper explores the impact of the social context on the relationship between student attitudes and performance in a South African University. It particularly employs theory on perception and learning to provide an interpretation of this relation. Employing a theoretical framework that centralises attitudes and the psycho-social context, this article highlights some of the tensions evident in academic performance in a South African university.

In addition to the core modules offered in most programmes in universities across the world, students are offered a course in Communication Skills. In most cases this is split into two parts. The rationale behind offering this module is two pronged. Firstly, the module equips students with academic writing skills. Secondly, module students are taught business writing and communication skills which are necessary both before and after they complete their programmes of study. In the case in question, despite the importance of the module, academics who teach Communication Skills often report poor performance in the module by students pursuing professions such as finance, health sciences and engineering.

Most of the academics attribute this poor performance to factors both external and internal to students. The external factors include students' poor language skills, especially in contexts where the language of instruction is the students' second or third language; the level of institutional support offered to students and the non-availability of learning infrastructure and resources such as libraries, books and computers. The internal factors include students' aptitudes for the course, their perceptions of the value of what they learn in the module and levels of motivation. Considering the poor performance in Communication Skills module, especially by students pursuing programmes in engineering, it is critical to investigate the students' perceptions of this module.

An understanding of these perceptions might help to shed light on the strategies and techniques they employ in studying the content of the module. This might also help to establish the learning strategies and techniques which they employ in the module. To the knowledge of the researchers, this is an areain which little research has been carried out, especially in South Africa. The following research question guides this study: What is the impact of the social context on the relationship between student attitudes and performance?

II. LITERATURE REVIEW

A considerable amount of literature on South African higher education attributes students' poor performance across different modules at tertiary level to their high school learning backgrounds and ultimately, the legacy of apartheid. For example, in linking university students' poor performance to the problems in South African basic education, Nongxa (2010:9) says, it is common cause that schooling is in dire straits in many areas and has been for years. Although we are the wealthiest economy on the continent, our schooling success is among the worst. We continue to be placed towards the bottom of comparative measures of achievement.

Similarly, drawing a link between the challenges in basic education and those in tertiary education in South Africa, Sewlall (2010: 13) says, "Tertiary institutions in the country- with the exception of the elite ones- are becoming dumping grounds for barely literate students who fill our classes in their hundreds…" Lamenting the problems she faced in her first year because of under-preparedness, her wealthy socio-economic background and private schooling notwithstanding, Mthethwa (2013:22), says, "Our secondary education system needs to find better ways of preparing matriculants for university life."

Under-preparedness is a widely acknowledged predictor of poor performance by students, especially at first-year level. However, studies conducted within the field of higher education on the international scene indicate that, in addition to students' high school experiences, their perceptions of what they will be studying, and their opinions of their study environment have an influence on their approaches to learning, strategies for studying and motivation to study (Covington in Jungert 2007, Entwistle & Smith 2002). Success rates at university as a result, are also said to be attributable to a combination of a multiplicity of psycho-social and institutional factors (Brier & le Roux 2012; Glimour, Christie &Soudien 2012; Troike in Riveria 1984). Ultimately, psycho-social factors influence students' performance in various subject areas.

A. Perception and learning

Various theories have been put forward by scholars mainly in the field of psychology to explain the factors that affect our perceptions and the values that we then go on to place on each of these phenomena. Lindsey and Norman (1977) define perception as "The process by which organisms interpret and organise sensation to produce a meaningful experience of the world." Similarly, Travers (1982:29) defines perception as, "…the process through which the living organism maintains contact with the environment." Travers (1982:29) goes on to say, "Perception always involves immediate experience, which can be explained as immediate exposure to any particular source of information in the environment." An implication is that perception is largely dependent on what has already been learnt. Travers (1982) goes on to argue that an individual's attitude is the result of his or her perception and this explains why two people with different perceptions see the same thing or concept differently resulting in them having different attitudes towards that thing or concept. Students who have different perceptions of the value of a module will therefore necessarily have different attitudes towards the module. For example, an Engineering student who perceives Communications Skills as a 'need-to-do' module will have a different attitude towards the module than one who views it as just a 'nice-to-do' module.

According to the Social Learning theory, attitudes go a long way in influencing learners' views of the material to be learnt. Fontana (1995: 227) defines attitudes as "…the relatively enduring orientations that individuals develop towards the various objects and issues they encounter during their lives, and which they express verbally as opinions." Fontana (1995) maintains that attitudes contain elements of value, belief, as well as varying degrees of factual knowledge (or what the holder believes to be factual knowledge and possess both cognitive and behavioral as well as affective aspects. Based on this, one can conclude that university students' attitudes towards what they have to learn manifest themselves in the value they attach to different subjects; their beliefs about the subjects as well as the extent to which they are willing to exert themselves intellectually in the process of learning the subjects. Chances are high that students' attitudes towards what they have to learn will be positive in cases where they place value in the subjects in question or where they believe in the short- or long-term utilitarian or intrinsic value of the subjects. The reverse is likely to be true in cases where students do not see value in what they are learning and do not possess a cognitive, behavioral and affective appreciation of it. In the case of Communication Skills, if Engineering students perceive it to have value in their lives.

Fontana (1995) adds that attitudes may be conscious or unconscious and it is the balance in this conflict that often determines the final position that we take on a particular issue. In the case of academic courses what this means is that students may consciously decide to adopt a particular attitude towards a particular subject out of, for example, what they believe to be the value of the subject in their lives. They can, however, also unconsciously develop an attitude towards a subject. This could be because of some elements within the learning environment, the quality of teaching which they receive or the influence of their peers. If, for example, a student's classmates all have a positive attitude towards a particular subject, it increases the chances of the student also developing a positive attitude towards the subject. The reverse can be true in a situation where the student finds themselves in a group with negative attitudes towards a particular subject.

There are four functions of attitudes according to Fontana (1995). Firstly, they can be instrumental (prompted by an individual's desire to see things arranged in a particular way to suit his or her needs). Secondly, they can be knowledge-based (governed by one's need to make sense of the world and his or her life). Thirdly, they can be value-expressive (associated with one's moral beliefs and self-concept)

and lastly, they can be socially adjustive (generated by one's desire to feel part of a larger social or political community). It is clear from these functions that attitudes influence the way learners see educational programmes. For example, the instrumental function shapes the use-value that learners see in an educational programme and the knowledge-based function influences the learners' ability to use the content of an educational programme to make sense of the world around them. The value-expressive function determines the extent to which learners develop certain beliefs and values on the basis of the knowledge acquired from an educational programme while the socially adustive function influences the extent to which learners see an educational programme as helping them to integrate into the community that they are part of.

Another important aspect of attitudes highlighted by Fontana (1995) is that, for most people, on most issues, they are not cast in concrete. They may change on the basis of changes in the environment in which individuals find themselves. This has implications for teaching and learning in that positive rewards for what learners are doing well in usually engenders positive attitudes. According to Fontana (1995) there are four basic ways in which such positive changes in attitudes on the part of learners can be achieved. Firstly, the modeling of activities by a figure they look up to, imply that educators must be role models in their subject areas. Secondly and closely related to modeling, is the need for educators to set examples for learners, especially in terms of social conduct. This may, for example, imply the need for fair-mindedness and being considerate on the part of the educator. Thirdly, positive changes in attitudes need to be reinforced by the educator and last, is the need to recognize that learners respond readily to enthusiasm in others. If this enthusiasm is not forced on them, learners are likely to be fired by it and want to participate in activities associated with it. This implies a need to inculcate in students the ability to motivate each other to work hard.

B. Students' approaches to learning

In addition to influencing students' attitudes towards their modules, perceptions and attitudes also have an influence on students' approaches to learning. This is an area in which there has been considerable research since the late 1970's. The pioneering work was carried out by Marton and Saljo (1976) who came up with the concepts of deep and surface learning. Entwistle (2000:3) defines deep learning as, "…the critical analysis of new ideas linking them to already known concepts and principles and leads to understanding and long-term retention of concepts so that they can be used for problem solving." Thus, with respect to Communication Skills, use of a deep approach would, for example, enable students to effectively apply their academic writing skills to new writing tasks. Deep learning also promotes understanding of concepts and enables students to apply these concepts in real life. Use of this approach would, for instance, enable Engineering students to apply their knowledge of conflict resolution skills gained from Communication Skills to solve a project-related dispute. When students employ the deep learning approach, they also engage in active learning. This involves relating ideas and looking for patterns and principles on the one hand and using evidence and examining the logic of the argument, on the other. In addition, the student who uses the deep approach to learning can monitor the development of his or her own understanding (Entwistle, McCune and Walker, 2000).

In the surface approach completion of a task is an end in itself for a student. The student is therefore not concerned with the interrelatedness of the ideas to be learnt because he or she sees the course as being made up of disparate bits of information. This leads to a restricted learning process and often routine memorization of facts (Entwistle, 2000). A student who adopts this approach therefore also resorts to superficial retention of material for tests and examinations. The approach does not therefore promote understanding or long-term retention of knowledge and information. From the two concepts of deep learning and surface learning emerged a third concept- the strategic approach to learning. In this approach, according to Entwistle (2000), the student's intention is to achieve the highest possible grades. The student does this through utilization of organized study methods and good time management skills. In addition, the student monitors his or her own study methods to check their suitability to the assessment process. The student therefore benefits from metacognitive alertness and self-regulation.

III. METHODOLOGY

Research in the field of communication appears to be now dominated by qualitative studies, reflecting a positive response to an earlier gap voiced by several scholars. There has been a shift from the quantitative focus of the 1900's which looked largely at behavioral components of communication, while qualitative studies were given minimum attention. As pointed out by Bertelsen et al. (2009), communication scholars have now also recognized the need to qualitatively evaluate current communication curriculum in terms of its contribution to meeting the needs of students and the demands of the workplace.

The current study therefore adopted a qualitative approach in recognition of the possibilities that it provides for a deeper understanding of Engineering students' perceptions of the Communication Skills module. This might in turn help to shed light on the factors contributing to the students' poor performance in the subject. This was considered particularly

useful because of the multiplicity of dimensions of modern life such as information technology, digitization and globalization which now impact on students' communicative styles and behavior both in the academic and professional spheres.

Data was gathered through ten focus group interviews with the 2024 first year students studying for a degree in Chemical Engineering, Electrical Engineering, Mechanical Engineering Extraction Metallurgy and Engineering Metallurgy at one campus of the comprehensive university where the research was carried out. According to Paton (1987: 23), "A focus group interview is an interview with a small group of people on a specific topic. Groups are typically six to eight people who participate in the interview for half an hour to two hours." In this case the interviews lasted an average of thirty-five minutes.

The participants in a focus group interview are typically a relatively homogenous group of people who are asked to reflect on questions asked by the interviewer." The purpose of the group is to produce qualitative data to "…provide insights into the attitudes, perceptions, and opinions of participants" (Krueger 1994:19). The hallmark of a focus group is the explicit use of the group interaction to produce data and insights that would be less accessible without the interaction found in a group" (Morgan 1988: 12). In this study, the groups each consisted of ten students. The students were selected on the basis that they were in first year and studying Communication Skills as part of a degree in Engineering curriculum.

The interview questions which the students were asked focused on their perceptions of the Communication Skills module with respect to the following areas: The extent to which they thought they were coping with the content demands of the module; their evaluation of the methods of instruction in the module and the support systems thereof; the extent to which they thought that what they learnt in the module prepared them for the world of work; the extent to which they thought what they learnt in the module enabled them to be better citizens of South Africa and the world and whether they would recommend the module to someone enrolling at the University for the first time.

A deductive approach to qualitative content analysis was used to analyse the results of the interviews. According to Mayring (2000), in qualitative research, deductive content analysis works with prior formulated theoretically derived aspects of analysis, bringing them in connection with the text. This implies that the researcher condenses the raw data into categories or themes based on his or her inference and interpretation. In this case, the results of the focus group interviews with the students were categorized into themes on the basis of their perceptions of Communication Skills which emerged from their ideas, comments and opinions as expressed in the interviews.

IV. ANALYSIS

The results of this study indicate several trends in the factors perceived by students as beneficial regarding their experiences in the module in question. The overall research questions have been used to organize the presentation of the data. Quotes provided in this section are from interviews with the participants.

Student perceptions

Mixed views were expressed in terms of students' perceptions of the degree to which they thought they were coping with the demands of the Communication Skills course. Those students who said they thought they were coping with the demands of the course used their grades in recently written tests as a measure. One participant from this category of students said, "I'd say I'm coping. I've done well in all my tests so far." Such students could have been successfully using the surface, deep or strategic approaches to learning. There would thus be a need to establish which of these three strategies the students were using to determine both the efficacy and sustainability of the method. About half of the participants said they were not coping with the demands of the module, and they used performance in assessments as an indicator. One of them said, "I'm really struggling with the course. I have so far scored very low marks in both the written and oral tests." On further probing, these students gave poor school background and language of instruction as the major drawbacks. As one participant from the Electrical Engineering group said, "As you know, some of us did our high school in the rural areas. English was not that important. Even Literature and History weretaught in our mother tongue. Now when we come here its English, English, English….that makes it difficult to cope."

Students who fall into this category are likely to continue performing poorly in the course. This can be explained in terms of the lack of articulation between what and how they learnt in high school on one hand, and what and how they are expected to learn at university. Such students do not, however, bring completely blank minds to the learning situation at university. It would therefore be necessary to establish how best that which they already know, irrespective of how little it may be, can be used as a resource for the new material which they have to learn.

Perceptions of the effectiveness of the methods of instruction in the module

Most of the participants in the focus group interviews were of the view that the methods of instruction used

in the module were beneficial and instrumental in helping them to pass the course. The analysis of the interview transcripts reflected that the participants identified the following factors as beneficial in their groupwork: clarity of objectives, teamwork, motivation of group members, time management, accountability, and instructor feedback. indicated similar results. Most of the participants indicated that building familiarity among group members, instructor's help with group formation, clear feedback and guidelines regarding the group project was beneficial.

All participants perceived building familiarity among group members as beneficial. Getting to know one another to build professional relationships is known as "building familiarity."

One participant, Amy, for instance, highlighted the value of developing relationships by saying, "It's difficult to understand where people are coming from, their reactions, and what they really mean when you can't see each other's faces." Amy offered the following advice regarding fostering relationships: I believe that a good group cannot exist without enjoyment. Therefore, before attempting to navigate all the confused communications, it could be best for people to meet out of class g and try to strengthen their relationship.

Thabo, another student, added that because "the group pretty much knew each other," there wasn't any disagreement in his group. He knew two of the five people in his group from a prior lesson. "I got a chance to talk to them and hear stories about them, just little things, about family and what they did in their spare time," he said, describing how he started to become closer to his group members. I became closer to everyone else as a result. In order to develop relationships, he recommended that students spend some time discussing "not justteamwork, [or] about projects, but we talked about things outside of school" in order to get to know the personalities of the group members.

Additionally, the participants thought it was helpful to have help in establishing groups. Because students did not have the opportunity to establish a solid rapport following a single in-person meeting, it was challenging to find a group in this online learning environment. Commonalities, group size, interest, varying skill levels, and appropriate responsibilities are all elements that influence the development of groups. One of the participants, Limaya, emphasized the value of the group members' shared interests, subject areas, and subject knowledge. “At least we shared some subject area knowledge to work with,” she said. Thabi also expressed her negative experience and pointed out how the instructor's facilitation of the group process would have been helpful given the group members ‘different interests and backgrounds. She suggested that the instructor should help students to find an “appropriate” group formation. "It was challenging because everyone had such diverse backgrounds and interests," she said.

Furthermore, I was truly marginalized. So, a lot of them were very similar to each other. But I was just way out there. So, that's a big challenge I think that the professor needs to facilitate that.

Most of participants perceived the instructor's prompt and clear feedback and guidelines as beneficial. Niko expressed his positive experience about this type of feedback. His team asked for feedback to make sure they were going in the right direction. His instructor gave them imperative feedback such as “You need to change this,” “Maybe you need to look into this more,” and “You're going in the right direction.”

Perceptions of the extent to which Communication Skills helps students to cope with other courses

About a third of the students who took part in the study expressed appreciation over the contribution the Communications Skills course made to their performance in the other modules they were doing. The students pointed out that the skills that they had gained from the module had helped them improve, for example, in terms of comprehension of concepts, reading and writing skills as well as critical thinking. This, the students said, had also contributed to an improvement in their performance in those modules where they could apply the skills learnt from Communication Skills. For these students therefore, there might be a transition from negative to positive attitudes towards Communication Skills as a result of the utility value that they might begin to place on the module. This is in keeping with the instrumental value of attitudes as suggested by Fontana (1995). Good performance by such students in the module could therefore be explained in terms of their adoption of a strategy that helps them to place value on the concepts which they learn in the module in the knowledge that they will need to apply these concepts and skills in other modules.

Close to half of the students who took part in the focus group interviews were of the view that Communication Skills does not help them to cope with the other modules which they were doing. This view was mainly based on the differences between Communications Skills and the other modules. The students pointed out that while Communication Skills was a theory-based subject, the other modules which they were enrolled for were quantitative in nature.

One of the students said, “I don’t think Communication Skills has helped me to cope with other modules which I am studying. For example, in Mathematics 1 and Physics 1, all that we do are

calculations which have nothing to do with theory and lengthy explanations.

Poor performance in Communication Skills by students who hold such a view can also be explained in terms of the instrumental value of attitudes (Fontana 1995). When students do not think that the skills which they gain from Communication Skills, which for them is non-core, can be applied to any of their other modules, chances are that they will not place much instrumental value on Communication Skills. Even in terms of approaches to learning they are unlikely to adopt approaches which guarantee success in assessments.

Perceptions of the extent to which Communication Skills contributes to character building

The skepticism over the use-value of Communication Skills notwithstanding, overall, there was agreement amongst most of the students that the topics learnt in the module contribute to character building. This was said to be in ways that were beneficial to students both in their lives at university and after graduation. The students identified a number of topics which they said helped to improve their inter-personal skills. One of the participants said,

I think I am a better person now and I will be in future because of what I learnt in this module. The topic on stereotypes made me aware of the dangers of generalized judgments of individuals who belong to a particular social group. I also think when I start working, I will be able to handle conflict with colleagues in a more professional manner than someone who has not done Communication Skills at varsity. Now I can also speak to a big audience in English. In the past I would have been only comfortable to do so in my venac.

This realization of the applicability of skills learnt in the Communication Skills to other areas of life was a good indicator of how some of the students might perceive the Communication Skills module done in the second semester. It might also therefore be a good predictor of good performance in the module.

V. CONCLUSION

The results of the study show that there were many points of convergence in terms of the students' perceptions of the Communication Skills module; there were also some points of divergence. Most students shared the same views on the satisfaction with the efficacy of the instruction methods; the use of skills gained from Communication Skills as enablers of performance in other modules and the possibility of using skills learnt in the module to character building and preparation of students for future professional roles. The students' performance could be explained in terms of their perceptions of the Communication Skills module. These in turn have an influence on the learning strategies which they employ in the face of any psycho-social and institutional impediments to success.

The researchers recommend the use of teaching and learning strategies which are culturally based and provide personalized assistance to students needing help with their oral and written communication skills. The researchers also recommend the aligning of the goals of the Communication Skills module to the need to produce transformative experiences for students. This can be achieved through the inclusion of exercises which make students cognizant of mental and behavioral dynamics of which they were previously unaware and to challenge their assumptions about communication and themselves. This would, in the view of the researchers, make it possible to use the Communication Skills module as a vehicle for students' cognitive, emotional and social development as opposed to the current over-emphasis on assessments as a measure of communicative competence.

From a teaching perspective there is also the need to be cognizant of the view that in a university context, the idea of communication skills should not be allowed to carry the notion of something basic for the less able, but something that all students should be deliberately exposed to. This can be achieved through not only teaching the requisite linguistic skills but also enabling students to acquire knowledge of how and why we communicate and about the application of that knowledge in different personal, social cultural and professional contexts. Lastly, we recommend that communication educators should be mindful of the critical role they play in the future lives of their students. They therefore ought to ensure that all their students graduate with the communication competencies necessary to succeed personally and professionally well after graduation.

Additionally, the paper makes the case that in the classroom setting, it is necessary to collaborate with students to help them develop a sense of familiarity and community. It takes time and effort to create a supportive learning community (Garrison & Vaughan, 2008). Without a supportive community of students, maintaining high student motivation and fostering joy in learning can be challenging. Integrating strategies for community building into the design of the course may assist with this effort (Song et al, 2004). Continued research related to community building strategies in a variety of contexts is also needed to enable the advancement of best practices in the dynamic context of the learning environment.

Furthermore, to improve group collaboration in Communication Skills courses, efficient instructional

design is required. The design ought to concentrate on the social, task, and technological aspects that affect the process of group development (Carabajal et al., 2003). This activity will also be facilitated by further investigating design paradigms that work well for online collaborative learning. Lastly, to better facilitate students' group projects, educators must modify their pedagogical approaches. It could be advantageous to develop teaching strategies to assist students with their group projects.

REFERENCES

[1] Almeida, E. P. 2004, A Discourse Analysis of Student Perceptions of their Communicative Competence. Communication Education, 53(4), 357-364.

[2] Breier, M. & le Roux, P. (2012). 'Black access to varsity: What's the full story?' in the Mail & Guardian, January 27to February 2. pp 34-35.

[3] Burroughs, N. F. 2008, Raising the Question #10 Non-Native Speakers of English: What More Can We Do? Communication Education; Vol. 57 Issue 2, p289-295

[4] Burton, G. &Dimbley, R. 1990, Teaching Communication, London: Routledge.

[5] Burt, M., H. Dulay & M. Finnochiaro (Eds.). 1977. Viewpoints on English as a second language. New York; Regents Publishing Company

[6] Brown, S. Armstrong, S. and Thompson, G. 1998, Motivating Students, London; Kogan Page

[7] Courtney, B., Merriam, S., & Reeves. 1998. The centrality of meaning-making in Transformative learning: How HIV-positive adults make sense of their lives. Adult Education Quarterly, 48, 65-84.

[8] Cranton, P. 1994. Understanding and promoting transformative learning: A guide for educators of adults. San Francisco, CA: Jossey-Bass.

[9] Eagly, A.H., & Chaiken, S. 1993. The Psychology of Attitudes, Harcourt Brace Jarvanovich, Fort Worth

[10] Entwistle N. J. 2000. Approaches to studying and levels of understanding: the influences of teaching and assessment. In J. C. Smart (Ed.), Higher Education: Handbook of Theory and Research (Vol. XV) (pp. 156-218). New York: Agathon Press.

[11] Entwistle, N.J., McCune, V. & Walker P. 2000. Conceptions, styles and approaches within higher education: analytical abstractions & everyday experiences in Sternberg, R.J & Zhang L-F, Perspectives on Cognitive Learning and Thinking Styles, Mahwah & Erlbaum, New York

[12] Entwistle, N.J., & Smith, C.A. 2002. Personal understanding and target understanding mapping influences on the outcomes of learning. British Journal of Educational Psychology. 72, (321-342)

[13] Fontana, D. 1995. Psychology for Teachers, London; Macmillan

[14] Freeman, J. 2010, Nzimande: Don't fail students just because our schools do' in The Saturday Star, 04 September 2010.

[15] Glimore, D., Christie, P. &Soudien, C. 2012. 'Lofty education ideals narrow a system driven by test results.' Mail & Guardian, 14 September

[16] Krueger, R.A. 2000 Focus Groups: A Practical Guide for Applied Research, New York, Sage

[17] Lindsey, P. & Norman, D.A. 1977. Human Information Processing: An introduction to Psychology, London; Butterworths

[18] Louw, M. & Du Plooy-Celliers, F. Let's talk about interpersonal communication, 2nd edition (2006), Cape Town; Hienneman

[19] Marton, F and Saljo, R. (1976) On qualitative differences in learning - 1: outcome and process, British Journal of Educational Psychology, 46, 4-11.

[20] McCroskey, J. C. (1984). The communication apprehension perspectice. In J. A Daly & J. C. McCroskey (Eds.). Avoiding communication: Shyness, reticence, and communication apprehension (pp. 13-38). Beverly Hills, CA: Sage.

[21] McCroskey, J. c., & McCroskey, L. L. (May, 1986). Self-report as an approach to measuring communication competence. Paper presented at the International Communication Association Conference, Chicago, IL.

[22] Mayring, P. 2000, Qualitative Content Analysis- Qualitative Forum: Qualitative Social Research, Vol. 1(2)

[23] Mezirow, J. 1991. Transformative dimensions of adult learning. San Francisco, CA: Jossey-Bass.

[24] Morgan, D.L. 1988, Focus groups as qualitative research in Qualitative Research Methods (16)

[25] Mortenson, S. T. 2007 Raising the Question #7 Should We Teach Personal Transformation as a Part of Interpersonal Communication? If so, How is it Done? Communication Education Vol. 56, No. 3, pp. 401_408

[26] Mthethwa, N. 2013, 'How could I have failed varsity?' in the Mail & Guardian, January 11-17 (pp22)

[27] Nongxa, L. (2010) 'Tertiary institutions ignore primary lessons at their peril' in the Sunday Times, 01 August 2010.

[28] Patton, M.Q. 1987, Qualitative Methods in Evaluation, Sage, New York

[29] Sewlall, H. (2010), Scrap fees for juniors, let students get loans in The Star, 30 March 2010.

[30] Stiwne, E.E. &Jungert T. (2010), Engineering students' experiences of transition from study to work 23 (5) (417-437)

[31] Taylor, E. W. 1998. The theory and practice of transformative learning: A critical review. (Information series 374). Columbus, OH: ERIC Clearinghouse on Adult, Career and Vocational Education, Center on Education and Training for Employment. (ERIC Document Reproduction Service No. ED423422).

[32] Travers, R.M.W 1982. Essentials of Learning, Macmillan Publishing Company Inc: New York

★★★

ARTIFICIAL INTELLIGENCE-ASSISTED SEMANTICS IN BIOMIMETIC DESIGN EDUCATION: ENHANCING GENERATIVE DESIGN CAPABILITIES

[1]WEI-CHEN, CHANG, [2]CHIN-HORNG CHAN

[1,2]Department of Industrial Design, Chang Gung University, Taoyuan, Taiwan
E-mail: [1]weichen@mail.cgu.edu.tw; [2]wkchiu@cgu.edu.tw

Abstract - This study aimed to develop a teaching method for a semantics course that guided biomimetic design using artificial intelligence (AI). By exploring linguistics through the lens of AI, the research integrated human language studies with machine learning, examining language forms, meanings, and environmental contexts. The analysis generated comprehensive outputs, such as images and symbols, via AI drawing software. The study found that ChatGPT can analyze word formation, grammar, semantics, and phonology in linguistics. As the field of biomimetic design continues to evolve, the integration of natural language processing (NLP) models has become increasingly crucial. This paper explores the generalization of NLP models to enhance the semantic understanding and generative design capabilities within the context of biomimetic design education. The study concludes the following: (1) Effective use of product semantics helped students explore the value of their biomimetic designs through word formation, grammar, and semantics, enhancing AI drawing and generative design capabilities. (2) The transformative power of symbols and their meanings can achieve the integration of "internal and external" biomimetic design. (3) Utilizing the dual knowledge of denotation and connotation to extract inspiration and organize language meanings and contexts guides design. Therefore, new knowledge construction methods will be effective for learning in the face of artificial intelligence, providing new perspectives and expressions for cross-field design and design education practice.

Keywords - Artificial Intelligence, Semantics, Biomimetic, Generative Design, Design Education, Design Capabilities

I. INTRODUCTION

In the rapidly evolving era of artificial intelligence (AI), the Taiwanese government's 2030 educational policy integrated the "Taiwan AI Action Plan", emphasizing "AI in education, and education in AI" since 2018. This initiative aimed to align Taiwan's education system with global trends, ushering in a new era of AI education and advanced personalized learning. Cultivating interdisciplinary AI talent in higher education is a critical and challenging task, requiring the integration of courses from various fields, such as information science, engineering, biomedical science, and economics (Southworth et al., 2023). This interdisciplinary approach equips students with diverse knowledge and skills, enhancing their ability to understand the interconnections between different domains.

According to Wang and Chuo (2021), integrating education 2030 with AI under the guidance of action plans can lay the foundation for higher education by providing a supportive AI education environment. This prepared students for autonomous learning, tailored through teacher guidance, and the development of digitalized teaching aids, fostering lifelong learners with interdisciplinary AI technology readiness.

Biomimetic design involves applying structures, functions, and systems from nature to technology and intelligent design (Aversa et al., 2016). This method combined interdisciplinary knowledge from biology, materials science, and engineering to create more efficient, aesthetically pleasing, and sustainable product designs. Biomimetic designers studied the characteristics of biological organisms, seeking innovative elements for product design. Examples included designing anti-slip surfaces inspired by shark skin and developing efficient turbines modeled after bird wings (Boaretto et al., 2021). Biomimetic design not only aligned products with natural principles but also enhanced performance, functionality, and sustainability (Hayes et al., 2020).

While AI's capabilities in computation and data analysis far surpass human abilities, human unique problem-solving approaches, creativity, and adaptability remain indispensable (Borger et al., 2023). AI plays a pivotal role in biomimetic design by rapidly analyzing vast amounts of biological data to identify key structural features and functional patterns (Badini et al., 2023). This capability aided designers in gaining deeper insights into natural systems, providing valuable information for product design. Additionally, AI algorithms can iteratively optimize design schemes, enhancing design efficiency and performance, and significantly shortening the product development cycle (Wang et al., 2022). Moreover, AI-driven virtual simulations enabled designers to quickly test and evaluate various biomimetic design schemes, identifying and solving problems before actual manufacturing begins. These applications of AI collectively advanced the field of biomimetic design, making the process more efficient, insightful, and effective (Dhamdar et al., 2024).

This study aimed to integrate the theories of linguistics with project-based learning (PBL) to guide designers (students) through semantic prompts in biomimetic design, leveraging intelligent design assistance to solve design problems. This approach sought to harmonize AI applications with future educational paradigms. In addition, this study explored the application of AI in the industry, particularly in education, by examining the role of product semantics in curriculum design. It aimed to understand how linguistics can be applied to generative design in AI, with a focus on prompt engineering. The objectives of this research were as follows:

1. To explore how linguistic tools such as semantics, pragmatics, syntax, and semantics can aid students in biomimetic design, enhancing AI's generative design capabilities and the application of prompt-based dual knowledge.

2. To understand how the extension and connotation of product semantics can inspire, organize linguistic meanings, and guide contextual learning in biomimetic design, serving as a pedagogical method for AI educational activities.

II. LITERATURE REVIEW

Personalization is a key feature of generative AI systems, which is equally applicable in education (Binhammad et al., 2024). Generative AI can offer personalized teaching plans and tutoring materials based on students' learning situations and needs, helping them master knowledge and skills better (Liu et al., 2023). It can also automatically grade assignments and exams, quickly and accurately providing evaluations and feedback, thus improving teaching efficiency and quality (Awidi, 2024). For example, Speechify, a text-to-speech generative AI tool, enables students with visual impairments or reading disabilities to learn more easily. (Liu et al., 2023; Bozkurt et al., 2023).

With the emergence of image-generating AI, artists and designers face job risks, especially those providing original drawings and designs for the gaming industry (Bordàs, 2023). Image-generating AI can produce lifelike images or create pictures in different styles based on instructions, generating in seconds and vastly exceeding the productivity of designers (Hanafy, 2023). In addition to Midjourney and Stable Diffusion, Photoshop software has also integrated generative AI features; by selecting a specific area and inputting instructions, the tool can quickly fill, replace, or expand elements within the image. (Bordàs, 2023; Linkinen, 2024)

The applications of AI in industries and the significance of prompt engineering in product design are becoming increasingly evident. Through effective prompt engineering strategies and biologically inspired design, designers and engineers can create more innovative and practical products, enhancing efficiency and competitiveness across various industries. In future research, we should continue to explore and optimize these design methods to meet the increasingly complex engineering and design challenges. Establishing strong interdisciplinary partnerships can foster the exchange of knowledge and the development of innovative teaching methodologies that harness the power of NLP-driven generative design.

III. METHODS

3.1 File Format

This study was carried out through a university course on product semantics, utilizing linguistics analysis and case analysis methods to guide designers (students) in exploring and understanding the crucial role of prompts in a product semantics course. It incorporated AI-assisted semantics, pragmatics, syntax, and language structure into biomimetic design to assist and enhance designers' (students') biomimetic design output (Figure 1). Deconstruction prompt: These prompts open up the design context, helping to understand how the context is constructed and understanding the coder’s thoughts and methods. For example:

- What kind of composition does this picture prompt you to make about your... (lines, colors, materials, structures...)?
- In the context your design, what actions will you take regarding your... (lines, colors, materials, structures...)?
- Do these things you mentioned contribute to any special feelings in your life?

3.2 Case Analysis

This method often involves in-depth study of specific cases to understand the underlying factors, connections, and impacts. In a product semantics course, case analysis can be used to explore the role of prompts in different products and reveal their significance.The applications of NLP models in biomimetic design education can also enhance teaching and learning experiences. Students can benefit from intelligent language-based interfaces, personalized feedback, and adaptive learning systems that cater to individual needs and learning styles.

3.3 Reconstruction of AI biomimetic design

Based on the concepts established by the above methods, this study further proposes the reconstruction of AI biomimetic design: Selecting research subjects from nature, then establishing various physical or virtual models based on these subjects, using various technical means (including materials, processes, computers, etc.) to conduct research, and making quantitative mathematical foundations. Through

qualitative and quantitative analysis of biological organisms and models, transforming the forms and structures of organisms into abstract functions that can be utilized in technical fields, considering using different materials and processes to create new forms and structures.

- Starting from function, studying the structural forms of organisms—creating biological models: Identifying the biological principles of the research subjects, forming a perceptual understanding of the organism through perception. Starting from function, studying the structural forms of organisms, based on perceptual understanding, removing irrelevant factors, simplifying, and proposing a biological model. Conduct qualitative analysis against the biological prototype and simulate biological structural principles with the model. The purpose was to study the structural principles of the organism itself.
- Starting from structural forms, achieving abstract functions—creating technical models: According to the analysis of organisms, making quantitative mathematical foundations, using various technical means (including materials, processes, etc.) to create technical models that can be experimented on in products. Grasping the scale of quantity, abstracting functional principles from concrete forms and structures. The purpose was to study and develop the technical model itself.
- Feasibility Analysis and Research: After establishing the models, further feasibility analysis and research are carried out, focusing on issues such as ergonomics, semantics, materials, and processing techniques in this process.

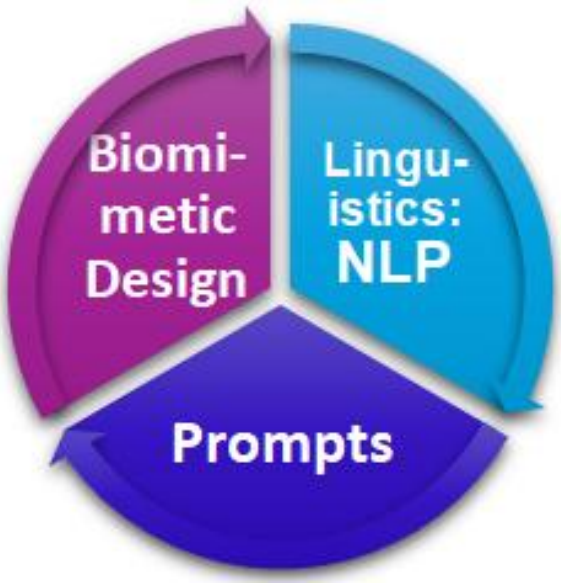


Table 1: AI-assisted biomimetic design model w/NLP

IV. RESULTS

4.1 Reconstruction of AI biomimetic design:

T This study was conducted through a university course on product semantics, guiding students to use AI assisted semantics, pragmatics, syntax, and semiotics to incorporate biomimetic design. The students fully participated in the course and produced related product outcomes upon completion. This study used one of these products, as an example (Figure 2). This hermit crab-inspired garbage cleaning robot features, perfectly mimicking a hermit crab. Its rounded, hemispherical shell, slightly extended at the rear, is made from high-strength plastic or metal alloy. The robot has six or eight mechanical legs with multiple joints, made from carbon fiber or special polymers, the leg ends are designed like crab claws or suction cups. The front grabbing device, resembling crab pincers, is equipped with sensors for accurately identifying and picking up garbage of various sizes and shapes. The inner sides of the pincers are lined with rubber to prevent slippage. The robot's front and sides have small sensor windows with optical cameras and infrared sensors for environmental sensing and garbage identification. An LED display on the top or side shows status information such as battery level and garbage storage. The internal garbage storage compartment is large, easy to clean. (By Leonardo AI)



Table 2: Ant Palace biomimetic design

The results of the questionnaire survey: After fully participating in the course with or without AI-assisted biomimetic design, the industrial design students completed a relevant course questionnaire. The aim was to explore and understand the differences in learning outcomes between students who used AI-assisted biomimetic design and those who did not. A t-test was conducted to analyze the differences between these two groups based on responses to various survey items. The following are the results of the questionnaire survey (Table 1):

- Teaching materials: The with AI group rated the effectiveness of the teaching materials significantly higher (M = 4.67) compared to the without AI group (M = 4.00), with a p-value less than 0.05. This suggested that the inclusion of

AI-assisted biomimetic design in the curriculum notably improved participants' perceptions of how well the teaching materials supported their design practice and learning.

- Course effectiveness and design outcomes: Participants in the with AI group also rated the overall teaching effectiveness and design outcomes as excellent (M = 4.73) compared to those in the without AI group (M = 4.00), with a p-value less than 0.05. This implied that the AI-enhanced approach was perceived to significantly enhance the quality of both teaching and design results.
- Instructor's background knowledge: The with AI group felt that the instructor provided more comprehensive background knowledge and content (M = 4.64) than the without AI group (M = 4.10), with a p-value less than 0.05. This indicated that the AI-assisted course may have contributed to a more effective transfer of relevant knowledge and content by the instructor.
- The statistically significant differences observed across these items suggest that incorporating AI-assisted biomimetic design into the course led to higher evaluations of course effectiveness and support. Participants in the with AI group perceived the teaching materials, overall course effectiveness, and the instructor's provision of background knowledge as notably superior compared to those in the without AI group. These findings highlighted the potential benefits of integrating AI technologies into educational settings, particularly in enhancing the quality and effectiveness of design education.
- Course engagement and satisfaction Instructor's teaching methods: The AI-assisted group rated the instructor's teaching methods significantly higher (mean = 4.60) than the traditional group (mean = 4.00), with a p-value less than 0.05. This significant difference suggested that the AI-enhanced course methods were perceived as more engaging and effective in stimulating students' interest and promoting critical thinking. The use of AI likely contributed to a more dynamic and interactive learning environment, which positively influenced students' perceptions of the instructor's teaching approach.
- Course enjoyment: Students in the AI-assisted group reported greater enjoyment of the course (mean = 4.36) compared to the traditional group (mean = 4.18), with a p-value less than 0.05. This finding indicated that the AI-assisted course was perceived as more enjoyable. The incorporation of AI likely added elements of novelty and interactivity that enhanced students' overall satisfaction and engagement with the course material.
- Course value and recommendation: The AI-assisted group rated the course as significantly more valuable and expressed a higher likelihood of recommending it to others (mean = 4.66) compared to the traditional group (mean = 4.07), with a p-value less than 0.05. This substantial difference highlighted that the AI-assisted course was perceived as having greater overall value. Students were more inclined to endorse the course, reflecting a higher level of satisfaction and perceived benefit from the AI-enhanced learning experience.

4.2 Strategies for Model Generalization

- Transfer Learning：Leveraging the knowledge and capabilities of pre-trained NLP models through transfer learning can accelerate the development of domain-specific language understanding for biomimetic design applications.
- Multimodal Integration：Combining natural language processing with other modalities, such as visual and spatial reasoning, can create a more holistic and contextual understanding of biological systems and their design implications.
- Contextual Adaptation：Adapting NLP models to the specific terminology, semantics, and design-related concepts within the biomimetic domain can enhance their accuracy and relevance in supporting the design process.

V. DISCUSSION

IncorporatingNLP-driven tools and methodologies into the biomimetic design curriculum, providing students with hands-on experience in leveraging language-based insights to inform their design process. Therefore, continuously evaluating and refining the integration of NLP models in biomimetic design education, based on student feedback, learning outcomes, and advancements in the underlying technologies.

- Natural Language Processing：Advanced NLP techniques, such as language models, named entity recognition, and semantic parsing, can enhance the extraction and interpretation of relevant biological concepts and relationships from textual sources.
- Multimodal Learning：Integrating NLP with computer vision, knowledge graphs, and other modalities can create a more comprehensive understanding of biological systems, enabling students to make informed design decisions.
- Knowledge Representation：Developing robust knowledge representations, such as ontologies and graph-based models, can capture the complex relationships and contextual factors inherent in biological systems, facilitating their translation into biomimetic design solutions.
- Machine Learning：Applying advanced machine learning techniques, including deep learning and reinforcement learning, can enable the continuous

refinement and adaptation of NLP models to the evolving needs of biomimetic design education.

VI. CONCLUSION

The generalization of natural language processing models presents a significant opportunity to enhance the field of biomimetic design education. By integrating advanced NLP capabilities, students can gain deeper insights into the semantic relationships and contextual factors that underlie biological systems, ultimately translating these insights into more innovative and impactful design solutions.

As the field continues to evolve, the integration of NLP models with other emerging technologies, such as computer vision, knowledge representation, and machine learning, will further expand the possibilities for biomimetic design education. By fostering interdisciplinary collaboration and continuously refining the pedagogical applications of these tools, educators can empower the next generation of biomimetic designers to push the boundaries of what is possible.

REFERENCES

[1] Aversa, R., Petrescu, R. V., Petrescu, F. I., & Apicella, A. (2016). Biomimetic and evolutionary design driven innovation in sustainable products development. *American Journal of Engineering and Applied Sciences*, 9(4).

[2] Awidi, I. T. (2024). Comparing expert tutor evaluation of reflective essays with marking by generative artificial intelligence (AI) tool. *Computers and Education: Artificial Intelligence*, 6, 100226.

[3] Badini, S., Regondi, S., & Pugliese, R. (2023). *Unleashing the power of artificial intelligence in materials design. Materials*, 16(17), 5927.

[4] Binhammad, M. H. Y., Othman, A., Abuljadayel, L., Al Mheiri, H., Alkaabi, M., & Almarri, M. (2024). Investigating How Generative AI Can Create Personalized Learning Materials Tailored to Individual Student Needs. *Creative Education*, 15(7), 1499-1523.

[5] Bordàs Vives, A. (2023). *Artificial Intelligence and the Creative Industries*.

[6] Borger, J. G., Ng, A. P., Anderton, H., Ashdown, G. W., Auld, M., Blewitt, M. E., ... & Naik, S. H. (2023). Artificial intelligence takes center stage: exploring the capabilities and implications of ChatGPT and other AI‐assisted technologies in scientific research and education. *Immunology and cell biology*, 101(10), 923-935.

[7] Boaretto, J., Fotouhi, M., Tende, E., Aver, G. F., Marcon, V. R. R., Cordeiro, G. L., ... &Vannucchi de Camargo, F. (2021). Biomimetics and composite materials toward efficient mobility: A Review. *Journal of Composites Science*, 5(1), 22.

[8] Bozkurt, A., Junhong, X., Lambert, S., Pazurek, A., Crompton, H., Koseoglu, S., ... & Romero-Hall, E. (2023). Speculative futures on ChatGPT and generative artificial intelligence (AI): A collective reflection from the educational landscape. *Asian Journal of Distance Education*, 18(1), 53-130.

[9] Dhamdar, T. S., Sandhya, K. V., & Basavaraj, B. V. (2024). Advancing Innovation through Biomimicry and AI: Inspiration to Implementation. *BIONATURE*, 44(1), 16-27.

[10] Hanafy, N. O. (2023). Artificial intelligence's effects on design process creativity:" A study on used AI Text-to-Image in architecture". *Journal of Building Engineering*, 80, 107999.

[11] Hayes, S., Desha, C., & Baumeister, D. (2020). Learning from nature–Biomimicry innovation to support infrastructure sustainability and resilience. *Technological Forecasting and Social Change*, 161, 120287.

[12] Linkinen, T. (2024). Generative Artificial Intelligences: *Challenges And Benefits For Game Development*.

[13] Liu, M., Ren, Y., Nyagoga, L. M., Stonier, F., Wu, Z., & Yu, L. (2023). Future of education in the era of generative artificial intelligence: Consensus among Chinese scholars on applications of ChatGPT in schools. *Future in Educational Research*, 1(1), 72-101.

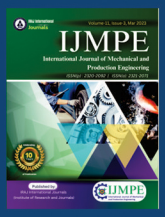
[14] Southworth, J., Migliaccio, K., Glover, J., Reed, D., McCarty, C., Brendemuhl, J., & Thomas, A. (2023). Developing a model for AI Across the curriculum: Transforming the higher education landscape via innovation in AI literacy. *Computers and Education: Artificial Intelligence*, 4, 100127.

[15] Wang, C.-H., & Chuo, K.-W. (2021). AI cross-domain, intelligent sustainability: The critical turning point of artificial intelligence (AI) and future education. *Taiwan Education*, (727), 13-21.

[16] Wang, Z., Zheng, P., Li, X., & Chen, C. H. (2022). Implications of data-driven product design: From information age towards intelligence age. *Advanced Engineering Informatics*, 54, 101793.

★★★

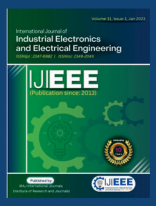
IRAJ INTERNATIONAL JOURNALS



International Journal of Mechanical and Production Engineering (IJMPE)

ISSN(P):2320-2092
ISSN(e):2321-2071

www.ijmpe.iraj.in



International Journal of Industrial Electronics and Electrical Engineering(IJIEEE).

ISSN(P):2347-6982
ISSN(e):2349-204X

www.ijieee.iraj.in



International Journal of Electrical, Electronics and Data Communication

ISSN(P):2320-2084
ISSN(e):2321–2950

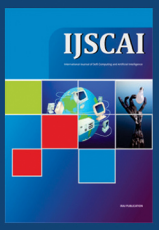
www.ijeedc.iraj.in



International Journal of Advances in Mechanical and Civil Engineering(IJAMCE)

ISSN(P):2394-2827

www.ijamce.iraj.in



International Journal of Soft Computing And Artificial Intelligence (IJSCAI)

ISSN(P):2321–404X
ISSN(e):2321–4384

www.ijscai.iraj.in



International Journal of Management and Applied Science (IJMAS)

ISSN(P):2394-7926

www.ijmas.iraj.in



International Journal of Advances in Computer Science and Cloud Computing (IJACSCC)

ISSN(P):2321–4058
ISSN(e):2321–4392

www.ijacscc.iraj.in



International Journal of Advance in Electronics and Computer Science (IJAECS)

ISSN(P):2393-2835

www.ijaecs.iraj.in



International Journal of Advances in Science, Engineering and Technology(IJASEAT)

ISSN(P):2321-8991
ISSN(e):2321–9009

www.ijaseat.iraj.in



International Journal of Mechanical and Production Engineering (IJMPE)

ISSN(e):2320-2106
ISSN(P):2320-2106

www.ijacen.iraj.in



Scan for Upcoming International Conferences

Or visit www.iraj.in/international-conferences.php

IRAJ Journals Listed in University Library

MIT, University of California Berkeley, Stanford, Cambridge, Oxford, Harvard

Visit for Upcoming International Conferences - www.iserd.co

Promotional Partners:

Conference Alert www.conferencealert.com

ALLCONFERENCEALERT www.allconferencealert.com

conferencealerts.in

WRL WORLD RESEARCH LIBRARY

This book will be available online at world Research Library www.worldresearchlibrary.org

ISBN
978-93-90150-29-8