I. INTERNATIONAL

VARNA

SCIENTIFIC RESEARCH AND INNOVATION CONGRESS

07-08 May 2026

Varna-Bulgaria

Editors:

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Prof. Dr. Tuğrul TALASLIOĞLU

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CONGRESS ID

CONGRESS TITLE

1. INTERNATIONAL VARNA SCIENTIFIC RESEARCH AND INNOVATION CONGRESS

DATE AND PLACE

07-08 MAY 2026, Varna-BULGARİA

ONLINE PRESENTATIONS

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Algeria, Armenia, Australia, Bulgaria, Georgia, India, Indonesia, Macedonia, Morocco, Nigeria, Pakistan, Romania, Tunisia

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08.05.2026 / Session-1 Hall-1			
	ANKARA LOCAL TIME		MEETING ID: 870 0911 7134
	10 00 : 12 00		PASSCODE: 810084

HEAD OF SESSION: Prof. Dr. Ümit ARPACIOĞLU

TOPIC TITLE	AUTHORS	AFFILIATION
The Use Of Wood In Construction Systems: From Traditional To Modern Technology	Gülşah ÇELİK TEK Assoc. Prof. Dr. Sibel DEMİRARSLAN	Kocaeli University
Integration Of Life Cycle Assessment (LCA) And Artificial Intelligence (AI) In The Construction Industry	Dr. Neriman Gül ÇELEBİ Prof. Dr. Ümit ARPACIOĞLU	Mimar Sinan Fine Arts University
Spatial Configuration And Contınuıty In Traditional Houses: The Case Of Safranbolu Mahir Ağa Mansion	Y. Mimar Büşra ARSLAN	Karabük Üniversity
Evaluation Of Post-Restoration Spatial And Functional Changes In Traditional Houses Of Safranbolu	Y. Mimar Büşra ARSLAN	Karabük Üniversity
The Impact Of Projections On Street Silhouette Along A Touristic Urban Axis: The Case Of Hacı Munirbey Street (Tokat)	Y. Mimar Büşra ARSLAN Y. Mimar Tuğberk Yağız ALTUNSOY	Karabük Üniversity
Separation And Recovery Of Metal Particles From Electropolishing Waste Solutions	Dr. Emine Özlem DENGİZ	Samsun University
Smart Factories And Materials Engineering: A Reinforcement Learning Approach	Moses Adeolu AGOI Oluwanifemi Opeyemi AGOI Oluwatoyosi Philip OLALEKAN Success Eniola OGBOYE	Lagos State University of Education, Obafemi Awolowo University, Nigeria
The Torsion Phenomenon In Steel Structural Systems: A Holistic Approach From Initiating Causes To Their Consequences	Prof. Dr. Tugrul TALASLIOGLU	Osmaniye Korkut Ata University

08.05.2026 / Session-1 Hall-2			
	ANKARA LOCAL TIME		MEETING ID: 870 0911 7134
	10 00 : 12 00		PASSCODE: 810084

HEAD OF SESSION: Prof. Dr. Ahmet Niyazi ÖZKER

TOPIC TITLE	AUTHORS	AFFILIATION
Mapping Intercultural Dialogue in International Student Mobility: A Bibliometric Analysis of Erasmus and Cross-Cultural Exchange Research	Sudenur DOĞAN Prof. Dr. Zeynep Birsu ÇİNÇİN	Çanakkale Onsekiz Mart University, University of Insurance and Finance (VUZF University), ADAM European nstitute for Lifelong Learning
Intercultural Dialogue And Social Dynamics In International Student Mobility: A Sociological Bibliometric Analysis Of Cross-Cultural Exchange Research	Cansu ÇAKAN Prof. Dr. Zeynep Birsu ÇİNÇİN Bosko NELKOSKI	Aydın Adnan Menderes University, ADAM European Institute for Lifelong Learning
Recalibration Of Tight Monetary Policy And Strengthening Of Fx Balance In Türkiye's Fight Against Inflation	Prof. Dr. Ahmet Niyazi ÖZKER	Bandirma Onyedi Eylul University
Hastanelerde Yapay Zekâ Uygulamaları ve Hizmet Kalitesi: Sağlık Yönetimi Perspektifinden Kavramsal Bir Değerlendirme	Assoc Prof. Dr. Hüseyin ALKIŞ Assist. Prof. Dr. Abdulkadir ERTAŞ	Tokat Gaziosmanpaşa University, Bilecik Şeyh Edebali University
Sectoral Asymmetries In Price Pass-Through: PPI-CPI Gap And Profit Margin Dynamics In The Turkish Economy	Lect. Dr. Gökhan SALMAN	Ondokuz Mayıs Üniversity
Integration Of Digital Tools Into Financial Control, Management And Decision-Making Systems In SMEs	Bosko NELKOSKİ	University of Insurance and Finance (VUZF University), Bulgaria ADAM European Institute for Lifelong Learning, Macedonia

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	ANKARA LOCAL TIME		MEETING ID: 870 0911 7134
	10 30 : 12 30		PASSCODE: 810084

HEAD OF SESSION: Major Gheorghe GIURGIU

TOPIC TITLE	AUTHORS	AFFILIATION
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Therapeutic Potential Of Lemon Water And Garlic (*Allium Sativum*) In The Treatment Of Intestinal Parasitic Worms	Tasawar IQBAL	University of Agriculture
The Gut-Brain-Skin Axis In Acne: Impact Of Polenoderm	Major Gheorghe GIURGIU Prof. Dr. Manole COJOCARU	Deniplant-Aide Sante Medical Center Titu Maiorescu University, Romania
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HEAD OF SESSION: Assoc. Prof. D.Sc. Ivaylo STAYKOV

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HEAD OF SESSION: Assist. Prof. Stanislava STATEVA

TOPIC TITLE	AUTHORS	AFFILIATION
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Reducing Environmental Impacts through Sustainable Nitrogen Practices	ELABBARI Chaimaa Pr. Labjar NAJOUA Pr. EL Hajjaji SOUAD	Mohammed V University, Morocco

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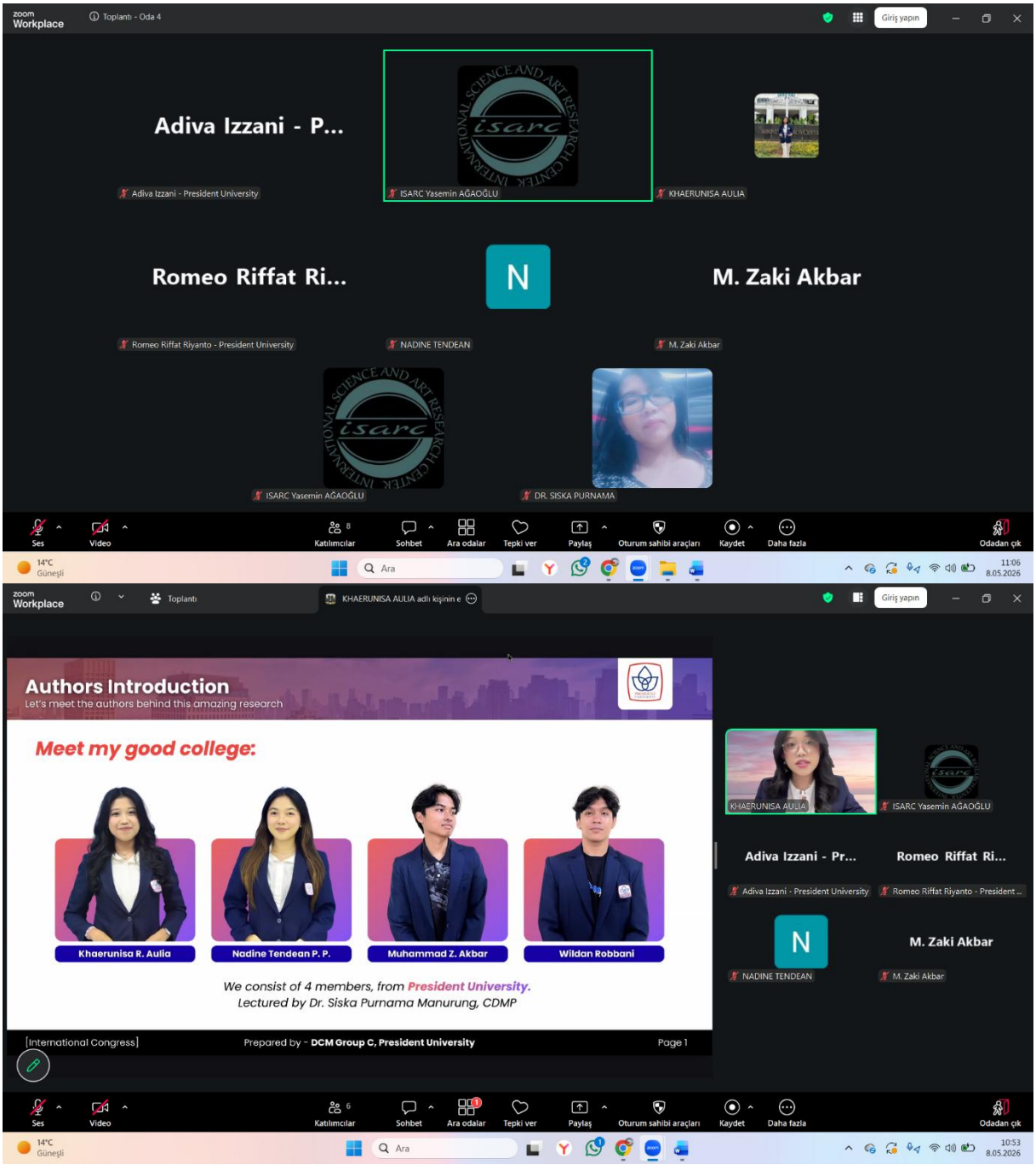

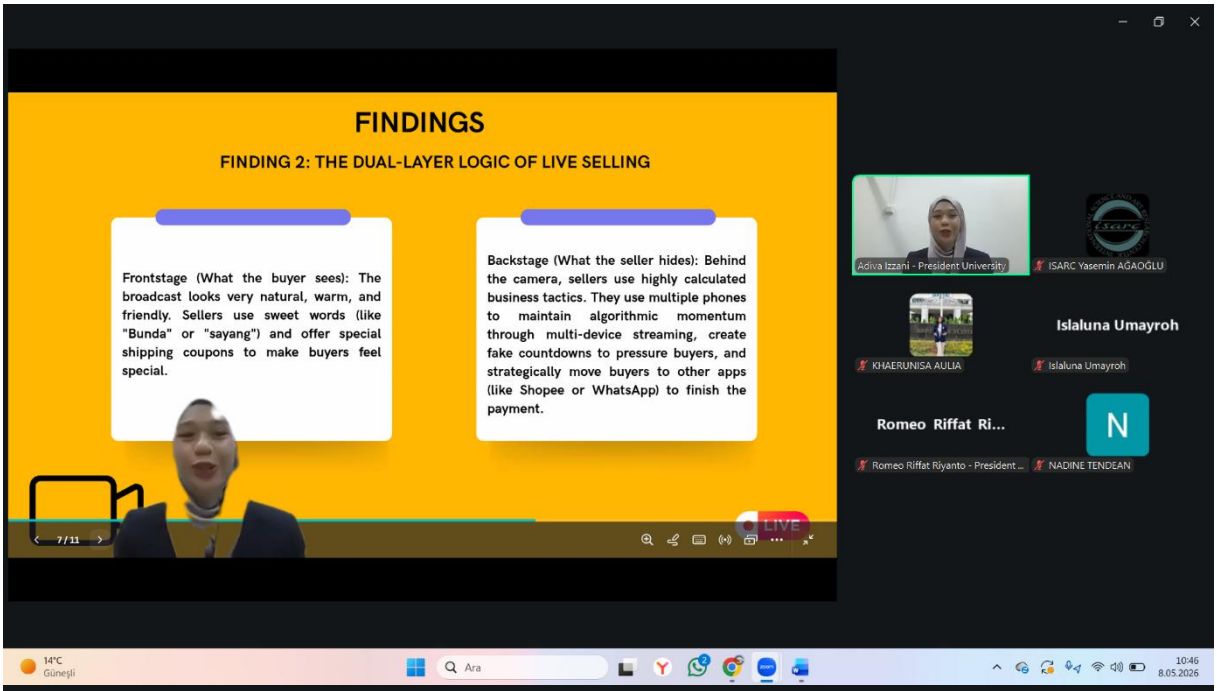
FINDINGS
FINDING 2: THE DUAL-LAYER LOGIC OF LIVE SELLING
Frontstage (What the buyer sees): The broadcast looks very natural, warm, and friendly. Sellers use sweet words (like "Bunda" or "sayang") and offer special shipping coupons to make buyers feel special.
Backstage (What the seller hides): Behind the camera, sellers use highly calculated business tactics. They use multiple phones to maintain algorithmic momentum through multi-device streaming, create fake countdowns to pressure buyers, and strategically move buyers to other apps (like Shopee or WhatsApp) to finish the payment.
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LIVE
Adiva Izzani - President University
ISARC Yasemin AĞAOĞLU
KHAERUNISA AULIA
Islaluna Umayroh
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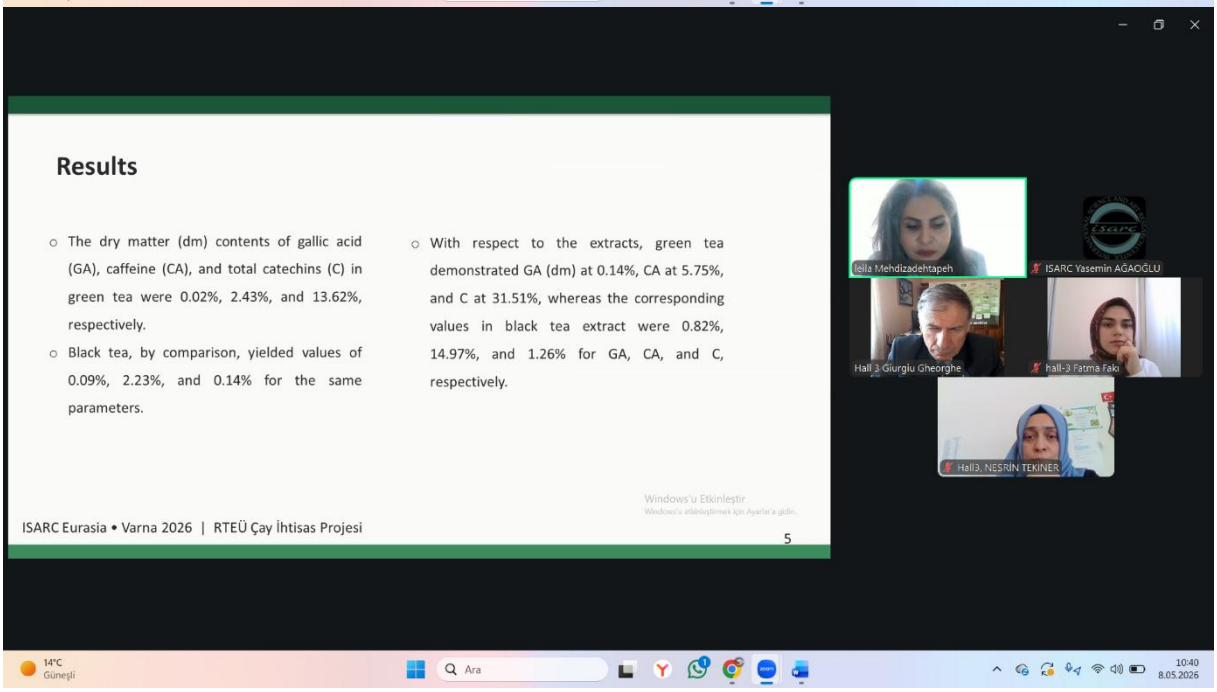
Romeo Riffat Riyanto - President ...
NADINE TENDEAN


Results
The dry matter (dm) contents of gallic acid (GA), caffeine (CA), and total catechins (C) in green tea were 0.02%, 2.43%, and 13.62%, respectively.
Black tea, by comparison, yielded values of 0.09%, 2.23%, and 0.14% for the same parameters.
With respect to the extracts, green tea demonstrated GA (dm) at 0.14%, CA at 5.75%, and C at 31.51%, whereas the corresponding values in black tea extract were 0.82%, 14.97%, and 1.26% for GA, CA, and C, respectively.
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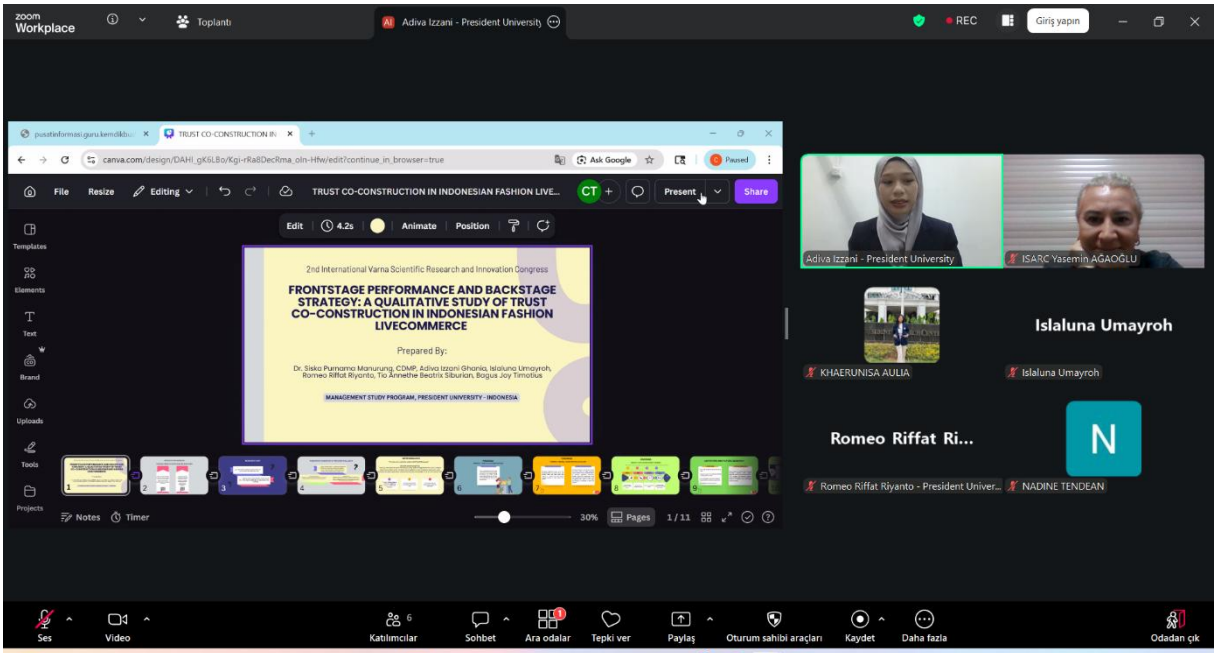
ISARC Yasemin AĞAOĞLU
Hall 3 Giurgiu Gheorghe
hall-3 Fatma Faki
Hall3, NESRİN TEKİNER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Adiva Izzani - President University
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Giriş yapın
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Present
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2nd International Varna Scientific Research and Innovation Congress
FRONTSTAGE PERFORMANCE AND BACKSTAGE STRATEGY: A QUALITATIVE STUDY OF TRUST CO-CONSTRUCTION IN INDONESIAN FASHION LIVECOMMERCE
Prepared By:
MANAGEMENT STUDY PROGRAM, PRESIDENT UNIVERSITY - INDONESIA
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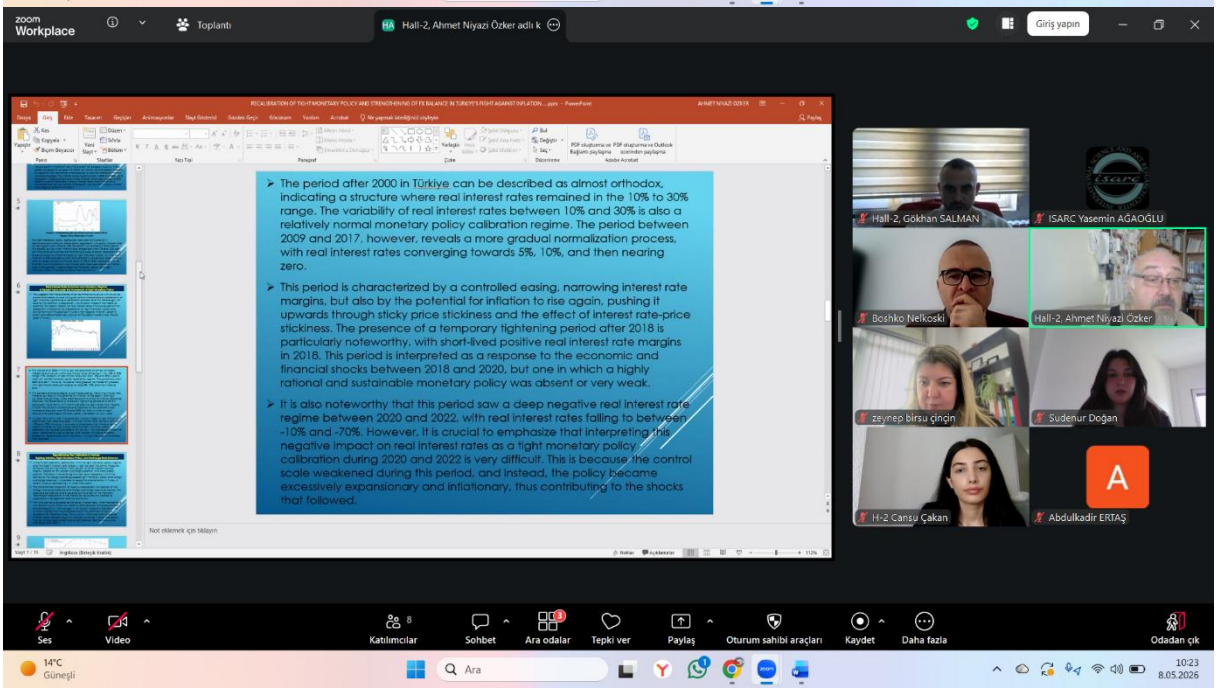
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Hall-2, Ahmet Niyazi Özker adlı k
Giriş yapın
The period after 2000 in Türkiye can be described as almost orthodox, indicating a structure where real interest rates remained in the 10% to 30% range. The variability of real interest rates between 10% and 30% is also a relatively normal monetary policy calibration regime. The period between 2009 and 2017, however, reveals a more gradual normalization process, with real interest rates converging towards 5%, 10%, and then nearing zero.
This period is characterized by a controlled easing, narrowing interest rate margins, but also by the potential for inflation to rise again, pushing it upwards through sticky price stickiness and the effect of interest rate-price stickiness. The presence of a temporary tightening period after 2018 is particularly noteworthy, with short-lived positive real interest rate margins in 2018. This period is interpreted as a response to the economic and financial shocks between 2018 and 2020, but one in which a highly rational and sustainable monetary policy was absent or very weak.
It is also noteworthy that this period saw a deep negative real interest rate regime between 2020 and 2022, with real interest rates falling to between -10% and -70%. However, it is crucial to emphasize that interpreting this negative impact on real interest rates as a tight monetary policy calibration during 2020 and 2022 is very difficult. This is because the control scale weakened during this period, and instead, the policy became excessively expansionary and inflationary, thus contributing to the shocks that followed.
Hall-2, Gökhan SALMAN
ISARC Yasemin AĞAOĞLU
Boshko Nelkoski
Hall-2, Ahmet Niyazi Özker
zeynep birsu çinçin
Sudenur Doğan
H-2 Cansu Çakan
Abdulkadir ERTAŞ
Ses
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Katılımcılar
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Paylaş
Oturum sahibi araçları
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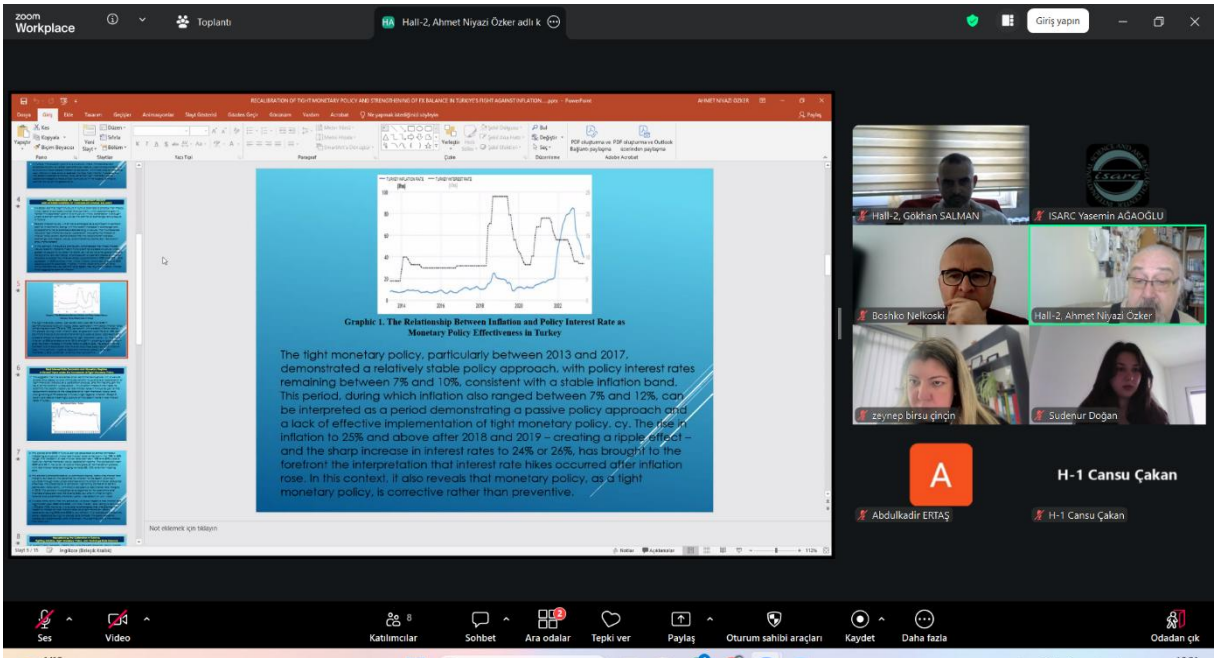
Daha fazla
Odadan çık


Graphic 1. The Relationship Between Inflation and Policy Interest Rate as Monetary Policy Effectiveness in Turkey
The tight monetary policy, particularly between 2013 and 2017, demonstrated a relatively stable policy approach, with policy interest rates remaining between 7% and 10%, consistent with a stable inflation band. This period, during which inflation also ranged between 7% and 12%, can be interpreted as a period demonstrating a passive policy approach and a lack of effective implementation of tight monetary policy. cy. The rise in inflation to 25% and above after 2018 and 2019 – creating a ripple effect – and the sharp increase in interest rates to 24% or 26%, has brought to the forefront the interpretation that interest rate hikes occurred after inflation rose. In this context, it also reveals that monetary policy, as a tight monetary policy, is corrective rather than preventive.
Hall-2, Gökhan SALMAN
ISARC Yasemin AĞAOĞLU
Boshko Nelkoski
Hall-2, Ahmet Niyazi Özker
zeynep birsu çinçin
Sudenur Doğan
Abdulkadir ERTAŞ
H-1 Cansu Çakan
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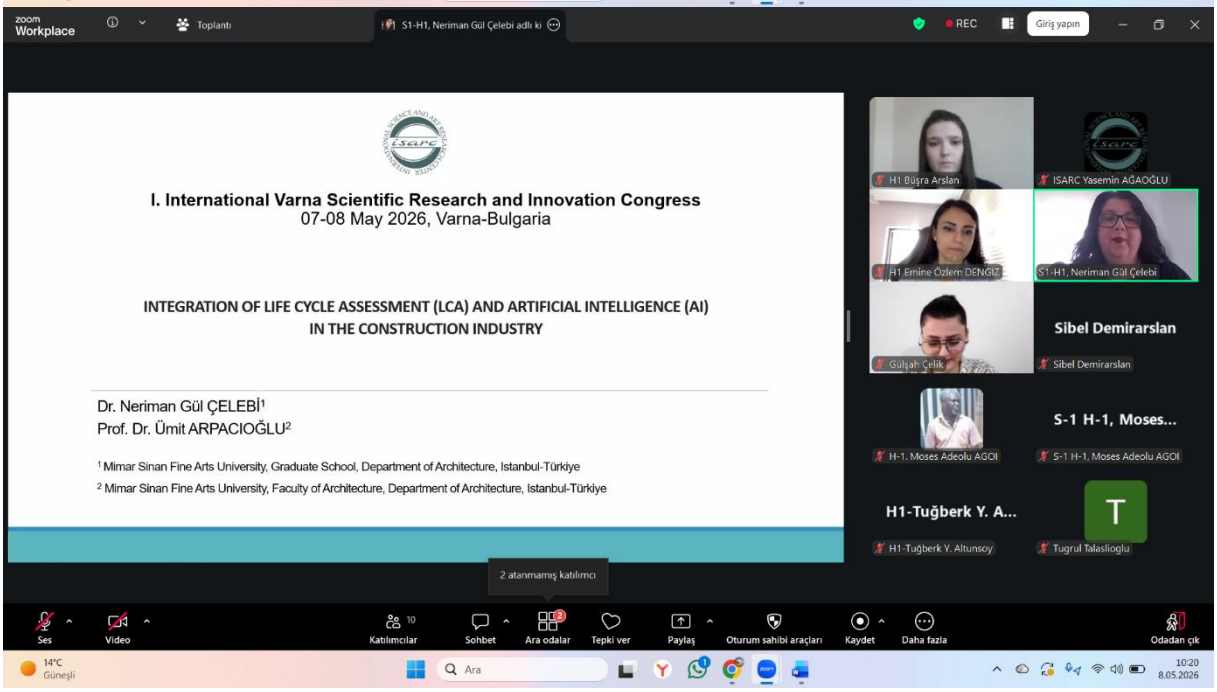
I. International Varna Scientific Research and Innovation Congress
07-08 May 2026, Varna-Bulgaria
INTEGRATION OF LIFE CYCLE ASSESSMENT (LCA) AND ARTIFICIAL INTELLIGENCE (AI) IN THE CONSTRUCTION INDUSTRY
Dr. Neriman Gül ÇELEBİ[1]
Prof. Dr. Ümit ARPACIOĞLU[2]
[1] Mimar Sinan Fine Arts University, Graduate School, Department of Architecture, Istanbul-Türkiye
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H1 Büşra Arslan
ISARC Yasemin AĞAOĞLU
H1 Emine Özlem DENGİZ
S1-H1, Neriman Gül Çelebi
Gülşah Çelik
Sibel Demirarslan
H-1, Moses Adeolu AGOI
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H1-Tuğberk Y. A...
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Daha fazla
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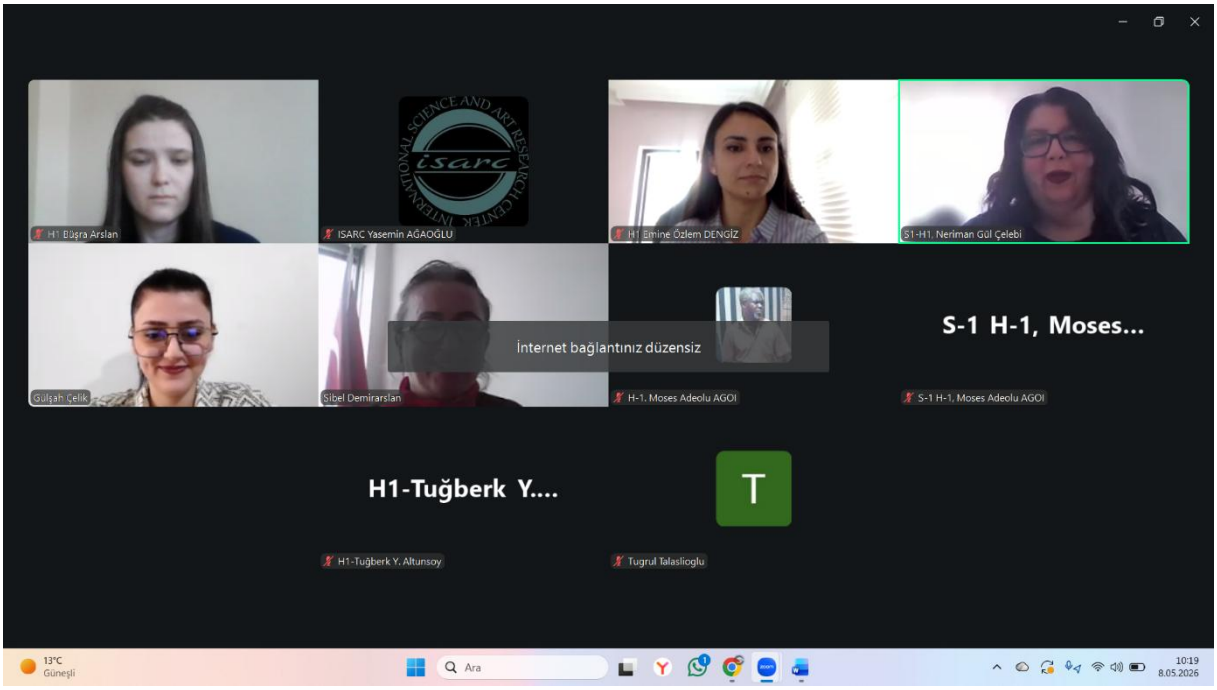
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ISARC Yasemin AĞAOĞLU
H1 Emine Özlem DENGİZ
S1-H1, Neriman Gül Çelebi
Gülşah Çelik
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INTERNATIONAL SCIENCE AND ART RESEARCH CENTER

REF: Kongre Katılımcı Bilgisi **19.05.2026**

İLGİLİ MAKAMA

1. ULUSLARARASI VARNA BİLİMSEL ARAŞTIRMALAR VE İNOVASYON KONGRESİ 07-08 MAYIS 2026 tarihleri arasında **VARNA/BULGARİSTAN** 'da online olarak **13** farklı ülkeden (**Türkiye: 11 bildiri** ve diğer **Ülkeler: 22 bildiri ; Toplam:33 bildiri**) akademisyen/araştırmacıların katılımı ile gerçekleşmiştir. Kongre, 16 Ocak 2020 Akademik Teşvik Ödeneği Yönetmeliğine getirilen '' Tebliğlerin sunulduğu yurt içinde veya yurtdışındaki etkinliğin uluslararası olarak nitelendirilebilmesi için Türkiye dışından en az 5 ülkeden farklı tebliğ sunan konuşmacının katılım sağlaması ve tebliğlerin yarıdan fazlasının Türkiye dışından katılımcılar tarafından sunulması esastır. '' değişikliğine uygun düzenlenmiştir. Bilgilerinize arz edilir.

Saygılarımla

Sefa Salih BİLDİRİCİ
HEAD OF İSARC

NOTIFICATIONS

GELENEKSEL TEKNOLOJİDEN GÜNÜMÜZ TEKNOLOJİSİNE YAPIM SİSTEMLERİNDE AHŞAP KULLANIMI*

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ÖZET

Ahşap, insanlık tarihinin başlangıcından günümüz teknolojisine kadar olan süreçte barınma, korunma, enerji kaynağı, teknoloji, sanat, mimari gibi birbirine bağımlı ve bağımsız birçok alanda çeşitli işlevlerde kullanılmıştır. Ahşap malzemenin çadır gibi basit sistemlerle başlayan yapı süreci, sivil mimarlık ürünleri olan geleneksel yapılarla devam etmiştir. Geleneksel yapılar döneminin teknolojik, lojistik ve ustalık bilgisi çerçevesinde imal edilmiş kültürel yapılar olma özelliği taşımaktadır. Geleneksel yapı sistemleri, süreç içerisinde ergonomi, konfor, yapı kurgusu ve kat sınırlılıkları sebebiyle gelişen teknoloji ve mimarlık anlayışına yetersiz kalmıştır. Ahşabın yerine yapı sektöründe geniş açıklık ve yüksek yapılara uygun betonarme ve çelik malzeme kullanımı yaygınlaşmıştır. Ancak bu yapı teknolojilerinin oluşturduğu çevre kirliliği ve karbon ayak izinin yol açtığı küresel sorunlar sebebiyle inşaat sektöründe sürdürülebilir, çevre dostu sistemler önem kazanmıştır. Bu bağlamda sürdürülebilir malzeme olan ahşabın yetersizlikleri belirlenerek, yüksek mukavemet, yangın ve su dayanımına sahip yüksek performanslı ürünler olan endüstriyel ahşap malzemeler ve yeni ahşap yapım sistemleri geliştirilmiştir. Endüstriyel ahşap sistemler ile geniş açıklıklara sahip, çok katlı ahşap ve hibrit yapılar inşa edilebilmektedir. Bu çalışmada geleneksel yapılardan günümüz teknolojisine kadar olan süreçte ahşap malzemenin ve ahşap yapım sistemlerinin kullanımı ve gelişimi incelenmiştir. Araştırma doğrultusunda günümüz teknolojisinde küresel mimaride kendi yapı kategorisinde en yüksek ahşap yapılar olan Mjøstårnet, Brock Commons Tallwood House ve Stadthaus'un yapım sistemleri, imalat ve montaj yöntemleri incelenerek değerlendirilmiştir. Çalışmaya konu olan ahşap malzeme, ahşap yapım sistemleri ve örneklemlerin sürdürülebilir mimari ve ahşap yapı sistem teknolojisine katkı sağlaması amaçlanmıştır.

Anahtar kelimeler: Ahşap, sürdürülebilirlik, endüstriyel ahşap, ahşap yapım sistemleri, ahşap detayları

**"Bu çalışma, İç Mimar Gülşah Çelik Tek tarafından Kocaeli Üniversitesi Sosyal Bilimler Enstitüsü İç Mimarlık Ana Sanat Dalı'nda Doç. Dr. Sibel Demirarslan danışmanlığında gerçekleştirilen (sürdürülen) yüksek lisans tezinden üretilmiştir."

THE USE OF WOOD IN CONSTRUCTION SYSTEMS: FROM TRADITIONAL TO MODERN TECHNOLOGY

ABSTRACT

Wood has been used, throughout the process from the beginning of human history to the present day, in many dependent and independent areas in various functions such as shelter, protection, energy source, technology, art, and architecture. The construction process of wood material, which began with simple systems such as tents, has continued with traditional structures that are products of civil architecture. Traditional buildings are characterized as cultural structures constructed within the framework of the technological, logistical, and craftsmanship knowledge of their time. Traditional building systems have fallen short of meeting the demands of evolving technology and architectural concepts due to limitations in ergonomics, comfort, structural design, and floor-to-floor heights. In the construction industry, the use of reinforced concrete and steel, suitable for wide spans and high-rise structures, has become widespread as an alternative to wood. However, due to the environmental pollution and carbon footprint caused by these building technologies, sustainable and environmentally friendly systems have gained importance in the construction sector. In this context, the shortcomings of wood, a sustainable material, have been identified, and industrial wood materials and new wood construction systems have been developed as high-performance products with high strength, fire and water resistance. Industrial timber systems make it possible to construct multi-story timber and hybrid structures with wide spans. This study examines the use and development of wood materials and woodworking systems from traditional structures to modern technology. In line with the research, the construction systems, manufacturing and assembly methods of Mjøstårnet, Brock Commons Tallwood House and Stadthaus, which are the tallest timber structures in their category in global architecture with today's technology, were examined and evaluated. The aim of this study, which focuses on wood materials, wood construction systems, and examples, is to contribute to sustainable architecture and wood construction system technology.

Keywords: Wood, sustainability, industrial wood, wood construction systems, wood details

1.GİRİŞ

İnsanlık tarihinin başlangıcından günümüze kadar devam eden süreçte en temel yapı malzemelerinden biri olan ahşap, en yalın haliyle ‘‘ağacın odun kısımları’’(Hasol, 2016, s.10) olarak tanımlanabilmektedir. Doğadan elde edilebilmesi, ahşabın yapı tarihini köklü bir geçmişe dayandırmaktadır. Ahşabın yapı malzemesi olarak kullanılmaya başlaması beton ve

çeliğe oranla çok daha eskidir. ‘‘İlkçağ insanlarının ağaç kovuğunda barınması ile başlamış ve günümüze kadar süregelmiştir’’(Topçu ve Uygunoğlu, 2021, s.266).

Ahşap diğer yapı malzemeleri gibi karmaşık bağlantı elemanlarına ihtiyaç duymadan, fazla iş gücü gerektirmeden de işlenebilmektedir. Toplumların göçebe yaşam sürdüğü dönemlerde doğadan elde edilebilen malzemeler tercih edilerek bu süreçte ahşap; çadır, yığma sistemler gibi yapılarda minimum işlem ve ilkel metotlarla kullanılmıştır.

Göçebe yaşamın yerini yerleşik yaşama bırakmasıyla birlikte yapı tipleri de değişim göstermiştir. İlkel yapılar iklim koşulları, yaşam biçimi ve ihtiyaçlara yetersiz hale gelmiş; daha fonksiyonel ve dayanıklı yapılara ihtiyaç duyulmaya başlanmıştır. Buna bağlamda yapım sistemleri önemli bir değişime uğrayarak basit sistemler geliştirilerek kesme, oyma, geçme ve birleştirme teknikleriyle inşa edilen nitelikli yapı sayısı giderek artmıştır. Bu teknolojik gelişmeler, strüktürel anlayışın da gelişmesini sağlayarak geleneksel yapı sistemlerinin oluşumuna zemin hazırlamıştır.

Geleneksel ahşap yapım sistemleri, bulundukları coğrafyanın yerel ve kültürel izlerini taşıyarak, iklim ve ahşabın fiziki özelliklerine göre şekillenmiştir. Hımış, bağdadi ve iskelet karkas gibi teknikler ihtiyaç duyulan yapı tipine olanak sağlarken aynı zamanda deprem etkilerine karşı da dayanım sağlamıştır. Bilimin günümüz seviyesine ulaşmadığı dönemde ustalık bilgisi ile inşa edilen geleneksel yapılar, döneminin kültürel izlerini de yansıtmaktadır. ‘‘Yapı tekniklerinin ve sosyo-ekonomik koşulların değişmediği bütün sanayi öncesi ortamlarda geleneksel ev tipolojisi basmakalıptı. Bunun nedeni dış dünya ile ilişkilerin sınırlılığı ve görsel çeşitliliğin eksikliğidir’’(Kuban, 2023, s.3).

Yaşanan Sanayi Devrimi ve gelişen mühendislik çalışmaları ile birlikte çelik, betonarme ve fabrikasyon malzemeler yaygınlaşmış, ahşabın yapıda kullanımı büyük ölçüde azalmıştır. Toplumların hızlı tüketim anlayışı, değişen yaşam biçimleri ve yüksek yapılaşma tercih edilirliği seri üretime uygun malzemelerin yapılarda ön plana çıkmasına neden olmuştur. Ancak uzun bir dönem geri planda kalan ahşap, düşük karbon ayak izi ve sürdürülebilirlik kavramlarının önem kazanmasıyla birlikte yeniden gündeme gelmiştir. Ahşap yapı sistemleri, günümüzün modern mühendislik teknikleriyle geliştirilen CLT, Glulam ve LVL gibi endüstriyel ahşap ürünleri ile yeniden ivme kazanmıştır.

Bu bildiride, gelenekselden günümüze ahşap yapım sistemlerinin tarihsel süreçte geçirmiş olduğu değişim, dönüşüm ve teknolojik alanındaki gelişmelerinin bu sistemlerin uygulamasına olan etkileri incelenmiştir. Çalışmada günümüz teknolojisinde endüstriyel ahşap malzemeler ile inşa edilen, kendi yapım sistemi kategorisindeki en yüksek bina olma özelliğini taşıyan küresel yapılar vaka analizi ile değerlendirilmiştir. Bu araştırmanın ahşabın yapı malzemeleri

arasındaki yerine ve günümüzdeki kullanımına ilişkin literatüre yol gösterici olması hedeflenmektedir.

2.YÖNTEM

Bu çalışma geleneksel yapı teknolojilerinden günümüz gelişmiş teknolojisine kadar olan süreci kapsayan bir içeriğe sahiptir. Nitel araştırma yöntemi kullanılmıştır. Bu bağlamda literatür taraması ve vaka analizleri yapılmıştır. Çalışma kapsamında incelenmek üzere belirlenen örnekler literatürde, kendi kategorisinde dünyada en iyi olarak nitelendirilen binalardan tercih edilmiştir.

Ahşap malzemenin tanımı ve özelliklerinden başlayarak süreç aşamalarında yaşanan dönüşüm ve gelişmelerin anlaşılması ve bu alanda yapılacak araştırmalar için elde edilen veriler çalışmanın sınıflandırma sistemi içinde değerlendirilmiştir. Yapılan araştırma ve değerlendirmelerin literatüre katkı sağlaması amaçlanmıştır.

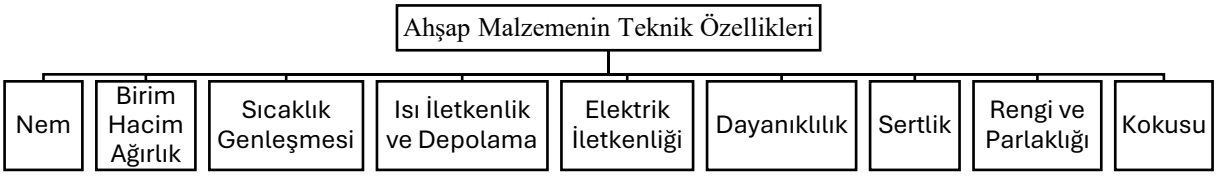
3. MALZEME OLARAK AHŞAP

Ahşap doğal yollarla elde edebildiğimiz karbon ayak izi düşük, insan yaşamına olumsuz etkisi az, sürdürülebilir bir yapı malzemesidir. Ahşabın özellikleri fiziksel ve mekanik olmak üzere incelenebilmektedir. İklim, yağış, nem, güneş gibi faktörler ahşabın fiziksel ve mekanik özelliklerine doğrudan etki etmektedir.

Ahşap, imal edildiği ağaç türüne göre çeşitli özelliklere sahip bir malzemedir. Yapısal ağaç türleri sert ve yumuşak olarak sınıflandırılabilmekte ve jullanım alanlarına göre farklı ağaç türleri tercih edilebilmektedir. Ladin, çam, göknar gibi yumuşak ağaçlar veya meşe, kayın, dişbudak gibi sert ağaç türleri yapıda kullanılabilmektedir. Çalışmanın bu bölümünde ahşabın mekanik ve fiziksel özelliklerini etkileyen unsurlar açıklanmıştır.

3.1. Ahşap malzemenin özellikleri

Ahşap biyolojik esaslı anizotrop bir malzeme olması nedeniyle çevre etkilerine karşı duyarlıdır, bu durum malzemenin boyut ve hacimde değişimlere sebep olabilmektedir. Ahşabın doğal yapısı, nem, rutubet gibi durumlardan daha hızlı etkilenmesi ve çevre koşullarının etkisinde olması onu çalışan bir malzeme haline getirmektedir. Bir ağaç kesildikten sonra zaman içerisindeki suyu ve nemi büyük ölçüde kaybeder; büzüşme yapabilir veya kanalları arasında boşluklar meydana gelebilir. Bir ağacın yoğunluk değerinin değişkeni olan nem; sertliği belirleyen ana etkendir. Rutubet ise ağacı mantar ve organizmaların yaşamına uygun hale getirip yapısal değişimlere neden olarak ahşabın mukavemetinde farklılık oluşturur.



Şekil 1: Ahşap malzemenin teknik özelliklerinin sınıflandırılması.

Topçu ve Uygunoğlu (2021, s.268-269) çalışmalarında ahşabın teknik özelliklerini nem, birim hacim ağırlık, sıcaklık genleşmesi, ısı iletkenlik ve depolama, elektrik iletkenliği, dayanıklılık, sertlik, rengi ve parlaklığı, kokusu ve mekanik özellikleri başlıkları altında incelemişlerdir. Ağaçlar yetiştiği bölgedeki güneşlenme miktarı, rüzgâr, yağış gibi büyüme koşullarına bağlı olarak dış özelliklerinde çeşitliliğe sahiptir. Renk, doku, parlaklık ve koku gibi fiziki özellikler, ağacın yetiştiği iklim koşulları hakkında yaklaşık bir fikir vererek uygun kurutma koşullarının belirlenmesinde rol oynamaktadır.

Ahşabın yoğunluğu yani birim hacim ağırlığı basit bir matematiksel mantıkla ağırlığın hacme oranı (kg/m³) olarak hesaplanmaktadır. Ağacın içerdiği nem birim hacmin değişmesindeki ana ögedir. Sıcaklık genleşmesi malzemenin etkisinde kaldığı ısıya bağlı olarak sıcaklık etkisiyle genleşip, soğukluk ile büzülmesi olayıdır. Bu özellik malzemenin kullanılacağı bölgenin sıcaklık koşullarına uygun olmalı; ağacın cinsi buna göre belirlenmelidir.

‘‘Ahşap malzemenin elektriksel özelliği düşük nem içerdikleri durumlarda iyi bir yalıtkan olmasıdır’’ (Toprakcı, 2025, s.9). Yalıtkanlık ağacın içerdiği nem miktarı ile ters orantılıdır. ‘‘Ahşap hücreli yapısı ve yapının esasını oluşturan maddenin selüloz olması nedeniyle, ısı bakımından iletkenliği çok düşüktür. Ahşabın lif yönünde termal iletkenliği, life dikey yöndeki iletkenliğin yaklaşık iki katıdır’’ (Topçu ve Uygunoğlu, 2021, s. 268).

Toprakcı, (2025, s.10) ahşabın mekanik özelliklerini ‘ahşap malzemenin biçimini değiştirmeye zorlayan dış kuvvetlere karşı koyma gücü’ olarak tanımlamış ve bunları direnç, elastiklik ve teknolojik özellikleri olarak kategorize etmiştir. Dirençle ilgili özellikleri ise, ‘eğilme direnci, çekme direnci ve basınç direnci’ olarak alt başlıklara ayırmıştır. Mekanik özellikler değerlendirilirken ağaçtan elde edilecek sonuçlar ağacın lif yönüne göre farklılık göstermektedir. Buna ek olarak dayanım, basınç ve tüm özellikler yine ağacın cinsine bağlı olarak farklılık göstermektedir.

Şekil 2: Ahşap malzemenin mekanik özelliklerinin sınıflandırılması.

Mukavemeti yüksek bir malzeme olan ahşabın esneme ve hareket dayanımı sebebiyle deprem etkisinde yapı hareketine adaptasyonu diğer malzemelere göre daha yüksektir. Ancak ahşap yüksek baskı ve kuvvet altında yarılma, kırılma veya bağlantı yerlerinden ayrılma yaparak yenilenmeyi gerektirebilmektedir. Ahşap yapıda taşıyıcı olarak kullanılabildiği gibi kapı, pencere, dış kaplama gibi farklı amaçlarla ince yapı ögesi olarak da kullanılabilir.

3.2. Ahşap malzemenin bakımı, korunması ve onarımı

Ahşap, rüzgâr, UV ışınları, iklim, nem, rutubet, bakteri, mantar, böcek gibi doğal unsurlardan olumsuz etkilenebilmektedir. Fazla nem ve su altında mantar, bakteri, böcek gibi organizmalar için uygun yaşam alanı haline gelebilir ve organizmalar sebebiyle çürüme veya mukavemet sorunları oluşabilmektedir.

Ahşabın kuru tutulması, yapıda nem, rutubet oluşumunu biyolojik organizmaların gelişimini engellemede en etkili önlemlerden biridir. ‘‘Cephe elemanlarının doğru tasarım, uygulama ve bakımla kuru tutulması, yapı içine su sızmasının ve su buharının içerde yoğuşmasının engellenmesi önlemlerdir. Islaklığı engelleyen doğru bir tasarım, tek başına çürümenin engellenmesi için yeterli değildir. Ahşabın direnç kazanması için ilaçlama yapılması gerekir’’ (Günay, 2001, aktaran KUDEB, 2009, s.137).

‘‘Ağaç malzemenin ve ahşap yapıların hizmet ömrünü artırmak için alınan her türlü önlem ‘odun koruma’ olarak adlandırılmaktadır. Emprenye ise yine ağaç malzemenin hizmet ömrünü artırmak amacı ile odunun yapısı içerisine koruyucu özellikteki kimyasal maddelerin çeşitli yollarla verilmesi anlamına gelmekte ve eksik bir ifade olmakla birlikte kimyasal koruma olarak da tanımlanabilmektedir’’ (Kartal, 2009, s.80).

Ahşap malzeme, yapıda dış etkenlere yoğun olarak maruz kalan konumlarda diğer kullanım alanlarına göre daha olumsuz etkilenmektedir. Bu bağlamda, yapıda en sık olumsuz etkilere maruz kalan ahşap elemanlar; çatı ahşap elemanları, baca ve havalandırma boşluklarındaki ahşap elemanlar, veranda, kapı ve cephe kaplamasında kullanılan ahşap elemanlar ile toprak-temel ile ilişkisi olan ahşap elemanlar olarak değerlendirilebilir. Bu sebeple bu bölgelerdeki

ahşap malzemelerin sık sık kontrolü yapılmalıdır. Bunlara ek olarak darbe, tamirat hataları, yük sınırının aşımı, yanma gibi yapay etkenlerde ahşabın bozulmasına sebep olabilmektedir.

Ahşap malzemede herhangi bir bozunma fark edildiğinde yapılara kendi yapım sisteminin gerektirdiği imalat detayları doğrultusunda bakım ve onarım yapılmalıdır. Eğer bu sistem bakım ve onarım için yetersiz ise var olan sistemle uyumlu bir teknik uygulanabilmektedir.

4.GELENEKSEL AHŞAP YAPILARIN TARİHSEL GELİŞİMİ VE YAPIM SİSTEMLERİ

Geleneksel ahşap yapılar, iklim koşulları, çevre etkisi, hammaddeyi doğadan hazır bulabilme, ulaşılabilirlik, inşa süresi ve sürdürülebilirlik çerçevesinde inşa edilmiş sistemler olarak incelenebilmektedir. Ustalık bilgi ve becerisi ile imal edilen bu yapılar yapım dönemlerine ve inşa edildikleri coğrafi bölgeye göre benzer özellikler taşımaktadır.

Geleneksel ahşap yapıların ilk örneklerini el işçiliği yüksek, yardımcı eleman sayısı minimum olarak değerlendirilebilecek yığma sistemler oluştururken; zaman içerisinde geliştirilen birleşim detayları, yük aktarım çözümleri ve yeni malzeme keşifleri ile ahşap sistemler de gelişim sağlamıştır. Süreç içerisinde iskelet karkas sistem geliştirilmiş, bağdadi, hımış ve dolma sistemler kullanılmaya başlanmıştır.

4.1. Ahşap yığma sistemler

Yığma ahşap yapım sistemleri, bağlantı elemanı kullanılmadan bindirme veya geçme tekniği ile ağaçların yatay olarak birbiri üzerine istiflenmesi ile imal edilmektedir. Ülkemizde yığma sistemlerde kullanılan ‘‘çantı tekniği halk arasında ‘çivisiz’ olarak geçmektedir. Bunun nedeni ağaç tomruklarının kabukları alındıktan sonra köşe noktalarda birbirlerine bindirilerek oturtulmasıdır’’(Furtuna ve Binan, 2021, s.13). Yığma ahşap yapıların dünyanın farklı yerlerinde imalat şekillerinde benzerliğe rastlansa da birleşim yöntemleri ağaç cinsine ve coğrafyaya göre farklılık gösterebilmektedir.

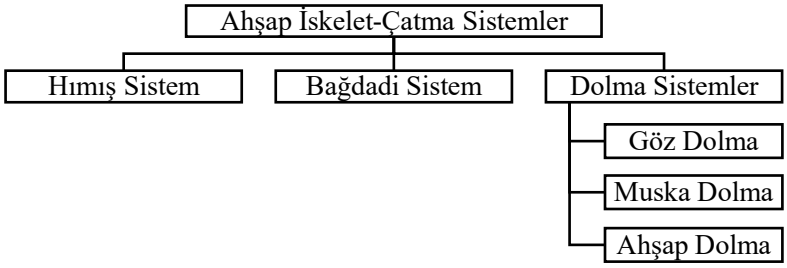
Yığma sistemler lojistik ağın gelişmediği dönem yapıları olduğu için bulunulan coğrafyadaki yerel malzemeler ile bağlantılı bir imalat yöntemine sahiptir. Kütük yığma, tahta yığma, kare kesitli yığma olarak farklı ağaç formları ile oluşturulabilmektedirler. Bu sistemlerde ahşabın zeminle ilişkisi nem, rutubet gibi durumlara yol açabileceğinden taş temeller üzerine oturtularak imal edilmişlerdir.

Yığma yapım sistemi sökülebilirlik ve taşınabilirlik açısından sınırsız hareket özgürlüğüne sahiptir. Yapı duvarlarının taşıyıcı olması sebebiyle pencere ve kapılar için sık ve geniş açıklıklar bırakmak olumsuz etki oluşturacağından kısıtlı bir yapı kurgusu vardır. Geleneksel ahşap yığma sistemler açıklık ve yükseklik sınırları olması sebebiyle mimari tasarımda işlev ve ergonomik açıdan yetersiz kalmaktadır.

4.2. Ahşap iskelet-çatma sistemler

Yığma sistemin sınırlılıkları, uzun geçişlerin yapılamaması, ergonomi ve konfor açısından yetersiz olması gibi sebeplerle süreç içerisinde iskelet karkas sistemi kullanılmaya başlanarak çok katlı, daha geniş alanlara sahip yapılar tercih edilmeye başlanmıştır. ‘‘Türkiye'de ahşap iskeletli yapım tekniği, 17. yüzyıldan itibaren uygulanmış ve 20. yüzyılın ilk çeyreğine kadar yaygınlığını sürdürmüştür’’ (Aydın, 2024, s.366). Bol yağışlı, ormanlık alanları geniş yerleşim bölgelerinde sıklıkla tercih edilmiştir.

İskelet sistemde dikme ve kirişler, yapıya gelen yükleri temele aktaran düşey taşıyıcı sistem elemanları olarak işlev görmektedir. Ahşap iskelet sistemlerde su basman seviyesine kadar yükseltilen taş duvarlar üzerine ahşap sistem kurulmaktadır. Bu bağlamda düşey taşıyıcılar yükleri taş duvarlar üzerine aktarmaktadır.



Şekil 3: Geleneksel ahşap iskelet-çatma sistemlerin sınıflandırılması.

İskelet sistemlerde duvar karkası imal edilirken hımış, bağdadi ve dolma gibi farklı sistemler kullanılabilmektedir. Bu sistemler benzer prensiplerle imal edilmesine rağmen karkası oluşturan yatay, dikey ve ara taşıyıcıların bağlantı biçimleri farklılık göstermektedir. Bu bağlamda yalıtım amacıyla kullanılan dolgu malzemesini belirleyen etken farklı karkas formlarına sahip yapı elemanları arasındaki boşluklar olmaktadır.

İskelet karkas sistemi karma sistem olarakta kullanılabilmektedir. Zemin katı yığma veya kagir olan bir yapının birinci katında ahşap iskelet uygulaması yapılabilmektedir. Bu bağlamda ahşap iskelet sistemin geliştirilmesi, var olan tek katlı yapıların çok katlı yapıya çevrilmesinde alternatif olmuştur. Çalışmanın bu bölümünde iskelet karkas sistemine sahip farklı yapı tipolojiler incelenmiştir.

4.2.1. Hımış sistemler

Hımış sistemlerde duvarlar, zemin ve tavan arasına dikey taşıyıcılar, çapraz ve yatay destek elemanlarının yerleştirilmesi ile oluşturulmaktadır. İskelet karkasın dolgu malzemesi taş, tuğla, ahşap veya kerpiç gibi yerel ve yöresel malzemelerden oluşmaktadır.

Dolgu malzemesi ısı yalıtımı ve cephede estetik bir görünüm sağlar. Hımış yapıların alt katları ahşaba zarar verici zemin koşullarından korumak amacıyla çoğunlukla taştan yapılmaktadır. ‘‘Duvarlarda kullanılan çapraz elemanlar, yapının deprem performansını iyileştirmek ve duvar köşelerini desteklemek amaçlıdır’’ (Türer ve İzol, 2024, s.144).

Şekil 4: Hımış tekniği kullanılarak yapılmış bir duvar örneği. (Yazar arşivi, 2022)

Hımış, ahşap iskeletli sistemin temel tekniği olarak değerlendirilebilmektedir. Şekil 4’te dış cephesi görülen hımış yapının karkas dolgusu aynı zamanda cephe kaplaması işlevini yerine getirmektedir. İnşa edildikleri dönemde cepheler bu şekilde kullanılabildiği gibi ahşap kaplama, sıva gibi yöntemler uygulanan örnekleri de bulunmaktadır.

4.2.2. Bağdadi sistemler

Bağdadi sistemler, duvar karkasını oluşturan dikey, yatay ve ara dikmelere, ince ahşap çıtaların sıralı ve yatay biçimde uygulanması ile oluşturulmaktadır. Bu sebeple duvarlar imal edilirken bağdadi çıtaların çakılabilmesi için belirli aralıklarla zemin ve tavan arasına dikmeler eklenmektedir. ‘‘Çıtaların üzerine genellikle çamur harcı veya sıva uygulanır. Uygulanan dolguların dayanıma kısıtlı katkısı vardır. Her sırada tek çivi kullanıldığı ve çıtalar ince olduğu için duvarın düzlem içi yük taşıma kapasitesi sınırlıdır’’ (Türer ve İzol, 2024, s.144).

Şekil 5: Bağdadi duvar çıtalama örneği. (Öznur, 2011)

Şekil 5’te bir restorasyon uygulamasında sıvaları temizlenmiş duvarın bağdadi çıta düzeni görülmektedir. Duvarlarda dikmeler arası taş, kerpiç, tuğla gibi dolgu malzemeleri ile doldurulabildiği gibi boşta bırakılabilmektedir. Uygulanan bu yöntemde kullanılan dolgu,

yalıtım malzemesi işlevi görmektedir. Günümüz teknolojisinde bağdadi tekniği uygulanırken sıvanın daha iyi tutunabilmesi tel kafes de tercih edilebilmektedir.

4.2.3. Göz, muska ve ahşap dolma sistemler

Ahşap iskelet sisteminde dolma yapım sistemleri birbirleri ile benzer özellikler taşımaktadırlar. Yapılar tek bir dolma sistemi ile imal edileceği gibi farklı çeşitlerde dolma teknikleri de bir arada kullanılabilmektedir. Ahşap dolma sistemler ana ve ara taşıyıcı dikmeler arası tahtaların yatay olarak üst üste dizilmesi ile oluşmaktadır.

Şekil 6: Geleneksel göz dolma sistemi uygulaması örneği. (Algül, 2011)

Göz dolma tekniğinde, duvar karkası dikey, yatay ve ara taşıyıcı ahşap elemanlarla kare veya kareye yakın dörtgen formlu bölmeler elde edilir. ‘‘Gözler, düzgün dere taşlarıyla doldurulup kireç harçla sıvanır. İç kısımlarda bağdadi sıva veya ahşap kaplama yapılır. Pencere boyutları göz ölçütlerine göre belirlenirken, havalandırma gereken alanlarda bazı gözler boş bırakılır’’ (Şensoy, 2024, s.261).

Göz dolma sisteminde dörtgen formlar belirlenen ölçü referansı ile yapıldığı için kapı ve pencere açıklıkları da gözlerin ölçüsüne göre oluşturulmuştur. Bu durum mimari olarak tutarlı bir cephe kurgusu oluşturmaktadır.

Şekil 7: Geleneksel muska dolma sistemi uygulaması örneği. (Güler ve Bilge, 2011)

Muskalı dolma sistemi göz dolmadan farklı olarak ahşap geçme sistemi yerine metal bağlantı elemanlarının kullanımı ile imal edilmektedir. ‘‘Muskalı dolma tekniği, 15-25 cm aralıklarla yerleştirilen ahşap dikmeler arasına yaklaşık 60 derece açıyla konulan ahşap parçalarla üçgen boşluklar (muska) oluşturur. Metal bağlayıcılar kullanılarak detay işlemler hızlandırılır, ancak bu sistemde sökülüp takılma özelliği yoktur’’ (Şensoy, 2024, s.261).

Muskalı dolma sisteminde dolgu malzemesi göz dolmada olduğu gibi taş ve kireçtir. Gözlerdeki üçgen formdan dolayı taşlar küçük parçalar haline getirilerek boşlukların kireçle doldurulmasıyla imal edilebilmektedir. Geçmişten günümüze kadar ulaşan bu sistemler, aynı zamanda döneminin kültürel izlerini taşıyan geleneksel eserler olma özelliğini de taşımaktadır.

5.AHŞAP YAPILARDA KULLANILAN ENDÜSTRİYEL AHŞAP MALZEMELER VE YAPIM SİSTEMLERİ

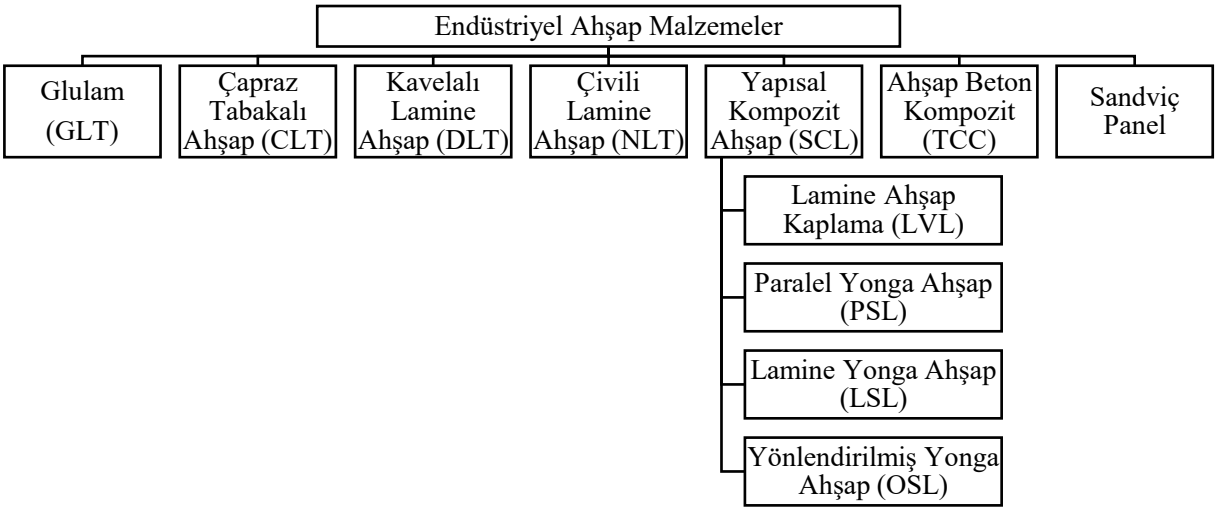
İlkel ve geleneksel yapılarda kullanılan ahşap malzeme, 20. Yüzyılda yapıda betonarme ve çelik malzemelerin yaygın kullanımı sebebiyle tercih edilirlik bağlamında büyük bir ivme kaybetmiştir. Betonarme ve çelik malzeme daha geniş açıklıklara sahip, çok katlı yapıların oluşumuna olanak sağlaması sonucunda ahşabın yerini almıştır. Ahşap malzemenin ivme kaybının sebepleri büyük yangınlar yaşanması, yapı tiplerinin değişimi ve ahşap malzemenin yapı teknolojisinin gerisinde kalması ile ilişkilendirilebilmektedir.

5.1. Endüstriyel ahşap malzemeler

Ahşabın biyolojik esaslı ve anizotropik olması malzeme mukavemetinde değişkenlikler oluşturmaktadır. Buna ek olarak budak, çatlak gibi form bozulmaları ahşapta direnç ve dayanım değerlerinde değişkenlik oluşturmaktadır. Çevresel faktörler ve canlı organizmalar ahşap üzerinde büyük bir etkiye sahiptir. Tüm bu durumlar ahşapta kusur ve zayıflıklar oluşturmakta ve ahşap malzemenin kullanım alanlarını sınırlandırmaktadır.

20. yüzyılda betonarme ve çelik malzeme ile üretilen sistemlerin çevrede oluşturduğu CO^2, hava kirliliği, inşa sürecinin çevreye olumsuz etkileri gibi nedenlerle sürdürülebilirlik kapsamında ahşabın yapıda tercih edilirliğini yeniden artırmıştır. Endüstriyel ahşap malzemeler teknoloji ve mühendislik çalışmalarının ürünü olan kereste, yonga ve levha formundaki ahşap malzemelerin kimyasal veya fiziki yöntemlerle bir araya getirilmesi ile üretilen yapı elemanlarıdır. Mukavemeti yüksek endüstriyel ahşap malzemelerin geliştirilmesi ve kullanılması ile birlikte ahşap malzemenin yetersizlik durumu ortadan kalkmıştır.

‘‘Mühendislik ürünü ahşap malzemelerin geliştirilmesi, ahşabı yalnızca estetik bir unsur olmaktan çıkararak yüksek yapı potansiyeline sahip bütüncül bir sistem çözümüne dönüştürmüştür’’ (Akşar ve Öztürk, 2025, s.106). Endüstriyel ahşap malzemelerde yaşanan gelişimler ahşap yapıları geleneksel yapım tekniklerinin etkisinden çıkararak çok katlı, geniş açıklıklı ve modern mimari izleri taşıyan yapıların imal edilmesini sağlamıştır.



Şekil 8: Endüstriyel ahşap malzeme çeşitlerinin sınıflandırılması.

5.1.1. Glulam (GLT)

‘‘Endüstriyel ahşap ürünlerin en eskisi olan tutkallı tabakalı ahşap (Glulam), ahşap tabakaların lif yönüne paralel uç uca – yan yana eklenmesi ve üst üste yapıştırılmasıyla elde edilen, iki veya daha fazla tabakadan oluşan yapısal üründür’’ (Avlar, 2021, s.43). Laminasyon işlemi ile oluşturulan bu malzeme farklı boyut ve formlarda imal edilebilmektedir. Masif ahşaba göre daha dayanıklı olan ve daha az çalışma payına sahip olan bu malzeme; kolon, kiriş, kemer gibi yapısal elemanlarda kullanılmaktadır.

5.1.2. Çapraz tabakalı ahşap (CLT)

‘‘Çapraz lamine ahşap, yüksek performanslı kerestenin lif yönleri dik şekilde katmanlı olarak yapıştırılmasıyla üretilen ahşap malzeme türüdür. CLT malzeme üç, beş veya yedi katman olarak üretilebilmektedir. CLT malzeme döşeme, kiriş, kolon, çatı, duvar gibi ana yapı elemanlarında kullanılmaktadır’’ (Coşkun ve Yardımlı, 2021, s.22). Panel formunda üretilen ve yüksek dayanımlı olan bu malzeme geniş açıklıklarda kullanılabildiği için prefabrikasyon veya hibrit yapılarda tercih edilebilmektedir. Çok katlı yapılarda inşaat süresi, iş gücü ve enerji verimliliği gibi konularda avantaj sağlamaktadır.

5.1.3. Kavelalı lamine ahşap (DLT)

Yapısal kerestelerin sert ağaç kavelalar ile birleştirilmesi ile elde edilen bir malzemedir. Kavelalı lamine ahşap malzeme, tamamı ahşaptan oluştuğu için geri dönüşümünü ve işlenmesi diğer malzemelere göre daha kolaydır. Bu malzeme yapısal döşeme ve duvar bloklarında tercih edilmektedir.

5.1.4. Çivili lamine ahşap (NLT)

Yapısal kerestelerin belirli aralık düzeni kullanılarak çivilerle birbirine bağlanması ile oluşturulmaktadır. Kavelalı lamine ahşap ile benzer imalat prensibine sahiptir ve aynı şekilde yapısal döşeme ve duvar bloklarında tercih edilmektedir.

5.1.5. Yapısal kompozit ahşap (SCL)

Ahşap esaslı kompozit malzemeler ahşabın işlenme biçimi, kalitesi ve yapıştırma şekline göre farklılıklar göstermektedir. Yapısal kompozit ahşap (SCL) ‘‘APA (The Engineered Wood Association) ‘ya göre lamine kaplama ahşap (LVL), paralel yonga ahşap (PSL), lamine yonga ahşap (LSL) ve yönlendirilmiş yonga ahşap (OSL) ürünleri kapsayan, tabakaların kurulması ve derecelendirilmesi ile oluşan endüstriyel ahşap ürünleri ailesini kapsamak için kullanılan bir terimdir’’ (Caştur, 2021, s.70).

Yapısal ahşap kompozitlerde kullanılan ağaç ve yapıştırıcı kimyasalların kalitesi; su direnci, mukavemet, boyutsal stabilite, işlenebilirlik gibi özellikleri doğrudan etkilemektedir. SCL malzemeler yapıda kolon, kiriş gibi ana taşıyıcı eleman olarak kullanılabileceği gibi döşemeler, duvar kaplamaları, dekorasyon gibi amaçlarla da tercih edilebilmektedir.

5.1.5.1. Lamine ahşap kaplama (LVL)

LVL, ‘‘TS EN 14374 standardına göre tomruklardan soyma yöntemi ile elde edilen yaklaşık 3mm kalınlığında ahşap papellerin katlar halinde laminasyonu ile üretilmiş’’(Ulusal Ahşap Birliği, 2022) yapısal malzeme olarak tanımlanabilir. LVL’de ahşap katmanlar poliüretan reçine ve çeşitli kimyasal malzemeler ile birleştirilmektedir. Yapısal ahşap olan bu malzeme çerçeve sistem, kolon ve kirişlerde tercih edilmektedir.

5.1.5.2. Paralel yonga ahşap (PSL)

Paralel yonga ahşap (PSL), yüzeyi düzgün, farklı kalınlıklarda imal edilebilen, yüksek mukavemetli bir endüstriyel malzemedir. ‘‘Dar şeritler halinde kesilen ve tane yönü esas olarak elemanın uzunluğuna paralel olacak şekilde, basınç altında birbirine tutkalla yapıştırılan kaplama şeritlerinden üretilen yüksek mukavemetli yapısal kompozit ahşap (SCL) ürünüdür’’ (Caştur, 2021, s.83). Yonga levha üretiminde birçok ağaç türü ve formu kullanılabildiği için üretim kolaylığına sahiptir. Bu bağlamda üretiminin daha kolay olması, yonga levhanın kullanım alanlarını ve üretim miktarını olumlu yönde etkilemekte olup; ihtiyaç halinde su ve yangına dayanıklı hale getirilebilmektedir.

5.1.5.3. Lamine yonga ahşap (LSL)

Ahşabın ince ve uzun parçalar haline getirilip tutkal ve kimyasallarla uygun koşullar altında preslenmesi ile imal edilmektedir. OSB ile en temel farkı içerdiği ahşap parçalarının boyutlarıdır. ‘‘LSL, taşıyıcı direklerden mimari/yapısal uygulamalara kadar çok çeşitli

kullanım yerinde değerlendirilmektedir. Kapılar, pencereler vb. yüksek kaliteli kereste gerektiren doğramalarda ve ayrıca kamyon kasaları gibi çeşitli alanlarda kullanımı mümkündür'' (Demir vd., 2024, s.13).

5.1.5.4. Yönlendirilmiş yonga ahşap (OSL)

''OSB, ahşap parçaların boyuna yönde rendelenmesi sonucu çıkan yongaların, belirli yönlerde bir araya getirilip, tutkal ve vaks gibi kimyasallarla sıcaklık ve basınç etkisiyle birleştirilmesi sonucu oluşan malzemedir. OSB levhalar OSB-1, OSB-2, OSB-3 ve OSB-4 şeklinde kullanım alanlarına göre 4 farklı çeşitte üretilmektedir'' (Yonga Levha Sanayicileri Derneği, t.y.).

Bu ayrım OSB'nin nem, rutubet dayanıklılığına bağlı kullanım alanı ve mukavemet farkları gözetilerek yapılmıştır. OSB çatı kaplamaları, dekorasyon, döşeme veya duvar kaplamalarında sıklıkla tercih edilmektedir.

5.1.6. Ahşap beton kompozit (TCC)

''Ahşap beton kompozit (TCC), ahşap ve beton bileşenler arasında yapısal bir bağlantı kurarak performans ve malzeme gereksinimlerini en uygun hale getirmeye odaklanan bir teknoloji ürünüdür. İki malzeme arasında kompozit etki yaratarak yapısal verimlilik elde edilmektedir'' (Şentürk, 2019, s.36).

Beton malzemenin altında kullanılan ahşap malzeme projeye göre DLT, NLT, LVL ve GLT olabilir. TCC'nin tamamı fabrikasyon hazırlanabilir veya ahşap kısım montajlandıktan sonra beton yerinde de dökülebilmektedir.

5.1.7. Sandviç panel

Sandviç paneller iki ahşap plaka arasına basınç ile yalıtım işlevi göre dolgu malzemesi preslenmesiyle oluşturulan malzemelerdir. ''Dış yüzey genellikle yüksek sertlik, mukavemet ve süneklik özelliklerine sahip malzemelerden üretilirken, içyapısı düşük mukavemete ve yüksek enerji emme kapasitesine sahiptir'' (Karakaya ve Ekşi, 2022, s.843).

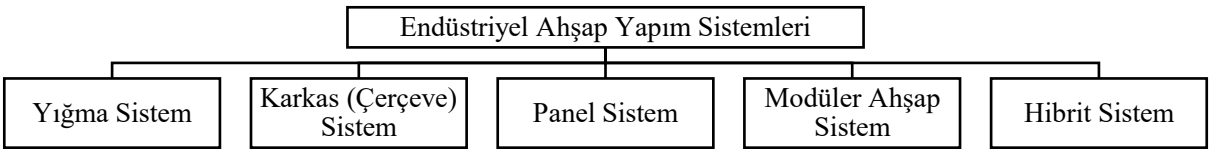
''Ahşap sandviç paneller, inşaat uygulamaları için hafif, yalıtım sağlayan alternatifler sağlama amacıyla 20. yüzyılın ortalarında geliştirilmiştir.' (Demir vd., 2024, s.14). Dış katmanlarında OSB, kontrplak gibi panel ürünler kullanılmaktadır. Dolgu kısmı ise XPS, cam yünü, taş yünü, poliüretan olarak imal edilebilmektedir. Prefabrik yapı imalatında, hızlı montajı, işlenebilirliği, yüksek dayanımı ve düşük maliyeti nedeniyle tercih sebebi olmaktadır. Prefabrik yapı haricinde iç duvarlarda, çatı ve duvar yapımında, stant tasarımlarında kullanılabilmektedir.

5.2. Endüstriyel yapım sistemleri

Endüstriyel yapım sistemler malzemelerde yaşanan inovatif değişiklikler sayesinde geleneksel yapılarda olduğu gibi tek veya az katlı yapı sınırlamasına sahip değildir. Gelişmiş malzeme

teknolojisi ile geniş açıklıklı çok katlı yapıların imal edilebildiği, biçim ve formlarda standart dışı yapılara olanak sunan bir sistem anlayışı sunmaktadır.

‘‘Ahşabın modern devrinin bir önemli bileşeni de birleşimlerdir. Ahşap yapı sistemlerinde birleşimler tutkal, çelik, ahşap gibi elemanlar ile oluşturulabilir. Birleşim türü seçiminde yükleme durumu, yapı ömrü gibi çeşitli tasarım kriterleri etkin rol oynamaktadır’’ (Çelik ve Şakar, 2022, s.302).



Şekil 9: Endüstriyel ahşap yapım sistem çeşitlerinin sınıflandırılması.

Günümüzde ahşap çerçeve, panel, modüler ve hibrit sistemler sıklıkla tercih edilmektedir. Bu sistemler sürdürülebilirlik, kolay işlenebilirlik ve hızlı imalat gibi konularda betonarme ve çelik malzemeye göre daha avantajlıdır. Çalışmanın bu bölümünde endüstriyel yapım sistemleri incelenmiştir.

5.2.1. Ahşap yığma sistem

Yapım tekniği olarak geleneksel ahşap yığma sistemle arasında benzerlikler bulunmaktadır. Yığma ahşap yapı sisteminde kolon ve kiriş sistemi olmadığından duvarlar hem mekân bölücü hem de taşıyıcı işlevinde görev yapmaktadır. Kütükler üst üste yığma metodu ile birleştirilmeden önce kütükler arasına kauçuk ve keçeler kullanılabilir. Bu yöntem aynı zamanda yalıtıma da katkı sağlamaktadır. Yapı şekli ve projesine göre çok çeşitli köşe birleşme ve sabitleme uygulamaları bulunmaktadır.

Şekil 10: Endüstriyel ahşap yığma sistem uygulaması örneği. (Johns, 2023)

Proje tasarımı yapılırken tüm detaylar belirlenerek süreç aşamaları planlı bir şekilde ilerlemektedir. Temel hazırlandıktan sonra yatay taşıyıcı elemanlar yerleştirilerek yapı inşasına başlanır. Pencere ve kapı boşlukları proje tasarım aşamasında belirlenerek, duvar imalatları

açıklıklara uygun şekilde yapılmaktadır. Kapı ve pencere boşlukları için bırakılan boşluklar dikey elemanlarla çerçevelenmektedir.

Bu sistemde keresteler GLT tercih edilebilmekte ve ön işlemlere tabi tutularak kullanılabilmektedir. Bu işlemler sırasında malzemelerin boyları ve formları biçimlendirilerek uygulamada geçmeler kullanılacak ise gerekli kesme, biçme işlemleri yapılmaktadır.

5.2.2. Ahşap karkas (çerçeve) sistem

Karkas sistemler günümüzde az katlı ahşap yapılarda sık tercih edilen ön üretime uygun ve işçiliği kolay bir sistemdir. ‘‘Karkas (çerçeve) sistemler, bir boyutu diğerine göre uzun olan kolon ve kiriş gibi çizgisel elemanlar ile oluşturulan taşıyıcı sistemlerdir. Endüstriyel ahşap malzemenin kullanıldığı ahşap karkas sistem ile inşa edilen yapılarda kolon ve kiriş elamanlarında çoğunlukla tutkallı tabakalı ahşap malzeme kullanılır’’ (Yürekli ve Karaman, 2023, s.764). Kullanılan endüstriyel malzemeler ile daha geniş açıklıkların geçilebildiği ve daha esnek planlar oluşturulabilen yapılar imal edilebilmektedir.

Şekil 11: Endüstriyel karkas (çerçeve) sistem uygulaması örneği. (Solutions, t.y.)

Yapı elemanları fabrikada üretilen bu sistemler zemin tesviyesi yapılmış beton üzerine inşa edilmektedir. Karkas sistemlerde taşıyıcı sistem elemanlarında kereste kullanımına ek olarak mukavemet özellikleri yüksek ve ekonomik ön üretimli elemanlar kullanılmaktadır. ‘‘Karkas sistem elemanlarının birbirlerine ve temele bağlantılarında özel bağlantı elemanları kullanılmakla birlikte sadece çivi ve geçme teknikleri ile yapılan üretimler de mevcuttur’’ (Örs ve Togay, 2003, s.576).

Karkas sistemler, kolon-kiriş sistemi ile inşa edildiğinden dolayı mekânsal esneklik ve alanın çok yönlü kullanımına olanak sağlayabilmektedir. Dolgu malzemesi olarak hedeflenen yalıtım değerine uygun, XPS, cam yünü, taş yünü gibi çok çeşitli malzemeler kullanılabilmektedir. İç kaplamasında alçıpan, bağdadi, lambri gibi duvar kaplamaları uygulanabilmektedir. Dış cephesinde ise ahşaba monte edilebilen dış etkilere dayanıklı lambri, boardex, yalı baskı gibi dış cephe malzemeleri tercih edilebilmektedir.

5.2.3. Panel sistem

Ahşap panel sistemler prefabrikasyon tekniği ile imal edilen yapılardır. Proje imalat detayları belirlendikten sonra yapının duvar, döşeme ve çatı gibi ana karkas elemanları üretim tesisinde projeye uygun olarak imal edilmektedir.

Şekil 12: CLT panel sistem montaj örneği. (Gibson, 2017)

Yüksek mukavemetli, özel boyutlarda imalatı mümkün olan CLT, SIP, sandviç panel gibi endüstriyel ahşap plakalar ile oluşturulan duvar, döşeme ve çatı elemanlarının mühendislik uygulamasıdır. Geniş açıklıklar tek bir parçayla geçilebildiği için imalatı yapılacak malzeme projeye için gereken niteliklerde üretilebilmekte ve montajı yapılmaktadır. Bu sistemlerde iş yükü büyük ölçüde iş makinaları ile sağlandığı için inşaat süresi diğer yapı sistemlerine göre kısadır.

5.2.4. Ahşap modüler sistem

Prefabrikasyon sistemler gibi yapının bir bütün veya parçalar halinde ön üretimli olarak üretim tesislerinde imal edilerek şantiye alanına taşınan sistemlerdir. ‘‘Modüler yapı, birkaç modülün istenen şekle getirilmesiyle oluşturulan bir inşaat sistemi olarak tanımlanabilir; modül ise boyutsal olarak birleştirilmiş bir uzamsal birimi (segment) temsil eder’’(Hořínková, 2021, s.2) Ahşap modüler sistemler, üretim tesisinden şantiyeye lojistik ağlar ile ulaştırıldığı için nakliye koşullarının gerektirdiği sınırlılıklar ekseninde oluşan, kısıtlı bir tasarım kurgusuna sahiptir. Ancak üretim tesislerinde imal edildiği için inşaat süresi, iş gücü, yapı performansı, çevre etkisi, atık miktarı gibi konularda yerinde imal edilen betonarme ve çelik yapı sistemlerine göre avantaj sağlamaktadır.

Şekil 13: Modüler ahşap sistem. (Husverket, t.y.)

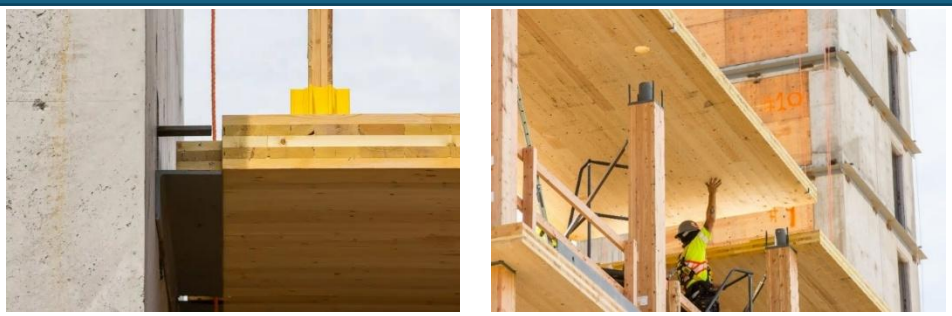
Ahşap modüler sistemler işlev, ihtiyaçlar, lojistik sınırlar, tesis kapasitesi gibi etkenler dikkate alınarak üretim, montaj ve lojistik süreç aşamalarının tamamı bütüncül bir yaklaşımla planlanmaktadır. Ahşap modüler sistemlerde, yapı modülleri hacimsel olarak üretim tesisinde tamamlanabilmekte veya duvar, zemin, çatı ve iç duvarlar üretim tesisinde imal edilip yerinde montajı yapılabilmektedir. Bu bağlamda tasarım aşamasında karar verilen faklı üretim yaklaşımları verimi artırabilmektedir.

Modüler sistemler tek bir modülden oluşabileceği gibi birkaç modülün birleştirilmesi ile az veya çok katlı yapılar inşa edilmesini de sağlamaktadır. Yapım sistemleri arasında ön üretimi en yüksek olan bu sistemler şantiye ve üretim sürecinde sağladığı avantajlar ile tercih edilir bir sistemdir.

5.2.5. Hibrit sistem

Hibrit sistemler yapısal çözümler ve yapı teknolojisinde alternatifler üretmek amacı ile ahşabın farklı sistem ve farklı malzemelerde birlikte kullanımının sonucu olarak ortaya çıkmıştır. ‘‘Hibrit bir yapı sistemi; estetik, ısıl, sürdürülebilirlik, kaynak erişimi, yapısal ağırlık, yapım süresi konularında verimli bir çözüm sunma potansiyeline sahiptir’’ (Bakış, 2022, s.15).

‘‘Hibrit yapım sistemlerinde amaç kullanılan malzemelerin olumlu yönlerinden maksimum faydayı sağlamaktır. Böylece daha ince kesitlerle daha fazla açıklık geçilerek mekânsal esneklik de sağlanmış olur’’ (Yürekli ve Karaman, 2023, s.764). Ahşabın işlenebilirliği kolay, sürdürülebilir olmasına karşın hafif olması çok katlı yapılarda dezavantaj sağlayabilmektedir. Çok katlı ahşap yapıların taşıyıcı strüktüründe ülke yönetmeliklerine de bağlı olarak belli bir kata kadar sadece ahşap kullanılabilmektedir. ‘‘Kat yüksekliği arttıkça taşıyıcılığın yanında betonarme ve çelik malzemenin kullanılması, ahşap strüktür ile inşa edilmiş bir yapının yangın performansını artırmak için alınmış bir önlemdir’’ (Kalkışım ve Vural, 2024, s.220).



Şekil 14: Betonarme-ahşap hibrit sistem uygulaması örneği. (Law, 2016)

‘‘Hibrit ahşap yapının avantajları; rijitliğin ve yük taşıma kapasitesinin artması, ses yalıtımının iyileşmesi, titreşimlere duyarlılığın azalmasıdır. Beton bir elemana kıyasla avantajları; ölü yükün azalması, sürdürülebilir kaynaklı malzeme kullanımı ile CO^2 emisyonunun azalması, prefabrikasyon ile birlikte zaman ve kaynak yönetiminin iyileşmesi, beton için gerekli kalıp işçiliğinin azalmasıdır’’ (Bakış, 2022, s.17).

Bu bağlamda yapıda hibrit sistem seçilmesinin bir veya birden fazla nedeni olabilmektedir. Üretim hızı, dayanım, yapısal ağırlık gibi konular sistem seçiminde belirleyici unsur olabilmektedir. Hibrit bir yapıda ana yapı malzemesinin seçimi, proje tipi ve yapım yöntemine göre yapılmaktadır. Bu bağlamda seçilen malzemeler birbirini tamamlayacak şekilde kullanılmaktadır.

6. ENDÜSTRİYEL SİSTEM AHŞAP YAPI ÖRNEKLEMİ

Çalışmanın bu bölümünde farklı sistem ve malzemeleri içeren kendi yapım sistemi kategorisinde dünyada en yüksek olma özelliği taşıyan 3 farklı ahşap yapının, yapısal özellikleri ve kurguları incelenmiştir. Dünyanın farklı bölgelerinden seçilen ve kendi yapım sistemi kategorilerinde yapılmış en yüksek yapılar, vaka analizi yöntemiyle değerlendirilmiştir.

6.1. Mjøstårnet

Mjøstårnet, Norveç’in Brumunddal kentinde binaya adını veren Mjøsa gölünün kıyısında yer almaktadır. Sürdürülebilir inşaatı, ahşabın mimarideki sınırlarına yeni bir bakış açısı kazandıran 2019 yılında inşa edilen bu yapı, 18 katlı karma kullanımlı bir ahşap binadır. Şekil 15’te incelenebilen Mjøstårnet ‘‘CTBUH tarafından dünyanın tamamen ahşap, en yüksek binası olarak onaylanmıştır. Mjøstårnet; ofisler, 72 otel odası, balkonlu 33 daire, zemin katta bir restoran, konferans salonları ve çatı terasından oluşmaktadır’’ (Liven ve Abrahamsen, 2023, s.4209).

Şekil 15: Mjøstårnet binası yan görünüş. (Foto, 2019)

‘‘Binanın taban alanı yaklaşık 17 x 37 m²'dir. Zemin kattaki betonarme döşeme, altındaki ana kayaya kadar çakılmış kazıklar tarafından desteklenmektedir’’ (Abrahamsen, 2017, s.5). ‘‘2-11. katlarda ahşap döşeme kasetleri, 12-18. katlarda ise 300 mm kalınlığında beton plakalar kullanılmıştır’’ (Liven ve Abrahamsen, 2023, s.4210). Beton malzeme, ahşabın yüksek katlarda rüzgâra dayanımında oluşabilecek sorunları önlemek amacıyla uygulanmış ve oluşması muhtemel sarsıntı faktörünü önlemesi amaçlanmıştır.

Projede kullanım alanına göre farklı endüstriyel ahşap malzemeler tercih edilmiştir. ‘‘Glulam, projede birincil yük taşıma sistemindeki kirişler, kolonlar ve çatılar için, CLT panelleri asansör boşlukları, merdivenler ve balkon zemin elemanı olarak kullanılmıştır. Yapısal kereste ve CLT için kullanılan ağaç türü Norveç ladinidir. Pergoladaki açıkta kalan kereste, bakır emdirilmiş İskoç çamından yapılmıştır’’ (Abrahamsen, 2017, s.6).

‘‘Mjøstårnet için hazırlanan yangın stratejisi raporunda, ana taşıyıcı sistemin 120 dakika yangına dayanması gerektiği belirtilmektedir. Döşemeler gibi ikincil taşıyıcı sistemlerin ise 90 dakika dayanması gerekmektedir. Ayrıca yapının tamamen yanmaya dayanması ve çöküşünün önlenmesi şartı bulunmaktadır’’ (Liven ve Abrahamsen, 2023, s.4212) . Yapı bu raporda belirtilen koşulları sağlayacak şekilde imal edilmiş olup malzemeler montajdan önce yangın dayanım testlerine tabi tutulmuştur.

Mjøstårnet endüstriyel ahşap malzeme ve mühendislik çalışmalarının bütüncül yaklaşımı ile ahşabın çok katlı yapılarda da kullanılabileceğinin bir örneğidir. Günümüzde kullanımı devam eden bu yapı sürdürülebilirlik, inşaat hızı gibi konularda birçok yapıya öncülük etmiştir.

6.2. Brock Commons Tallwood House

Brock Commons Tallwood House Kanada British Columbia Üniversitesi’nin Point Gray kampüsünde bulunan 18 katlı ve 54 metre yüksekliğinde 404 öğrenciye barınma imkânı sunan bir öğrenci yurdudur. Bu projede tasarım, imalat, montaj ve nakliye gibi konular bütüncül bir yaklaşımla planlanmıştır.

Şekil 16: Brock Commons Tallwood House binası perspektif görünüş (Elkan, 2019).

Şekil 16'da incelenebilen ‘‘Tallwood House hibrit masif ahşap yapı olarak Kasım 2015'ten Mayıs 2017'ye kadar 18 aylık bir süreçte inşa edilmiştir. Şantiyedeki inşaat genel hatlarıyla merdivenler ve asansör çekirdekleri de dâhil olmak üzere betonarme yapı, masif ahşap yapı ve bina dış cephesi, iç mekânlar ve bina sistemleri olarak üç aşamaya ayrılmıştır’’ (Kasbar vd., 2021, s.957).

‘‘Temel, zemin kat, merdiven ve asansör çekirdekleri yerinde dökme betondan yapılmıştır; 2-18. katlarda ise ahşap döşeme panelleri ve kolonlar kullanılmıştır. Masif ahşap bileşenler, GLT kolonlar ya da PSL kolonlar üzerinde noktasal olarak desteklenen 5 katmanlı, CLT panellerden oluşmaktadır’’ (Poirier vd., 2022, s.31).

Endüstriyel ahşap malzemelerin çeşitli türleri kullanılan inşaatta malzeme seçimi mukavemet özelliklerine göre yapılmıştır. ‘‘Her kat 722 m² alana sahip olup 29 adet CLT panel ve 78 adet kolon içermektedir. CLT, iki yönlü açıklık özelliği sayesinde kiriş ihtiyacını ortadan kaldırdığı için tercih edilmiştir. GLT kolonlarına bağlı çelik kirişler üzerindeki metal kaplama ise çatı yapısını oluşturur’’ (Kasbar vd., 2021, s.960).

Şekil 17: Brock Commons Tallwood House binası şantiye aşaması. (Naturally:wood t.y.)

Binanın inşaat hızını artırmak amacıyla prefabrik cephe sistemi tercih edilmiştir.(Şekil 17) ‘‘Kütleli ahşap yapı (CLT döşeme panelleri ve GLT ve PSL kolonlar) ve bina dış cephesi önceden imal edilmiştir. Bunların tamamı veya bir kısmı, şantiyede beton işleri devam ederken

üç aylık bir süre içinde ilgili imalatçıların tesislerinde üretilmiştir''(Staub-French vd., 2022, s.8).

Tallwood House'da yangın dayanımı ve korunma stratejilerine önem verilmiştir. ''Otomatik sprinkler, yangın söndürme sistemi, kuru sprinkler ve binaların birbirine yakın olduğu bölgelerde zemin kat perde duvarında su perdesi sistemi yer almaktadır. Tüm yapı elemanları ve iç bölmeler için en az 2 saatlik yangın dayanımı sağlamaktadır'' (Poirier vd., 2022, s.32).

Tercih edilen hibrit yapı sistemi betonarme ve çelik yapılara önemli bir alternatif oluşturmaktadır. Ahşap sektörünün yeniden ivme kazanmasına katkıda bulunan bu yapı, kendinden sonra inşa edilecek yapılara sistem çözümleri olarak örnek oluşturmaktadır.

6.3. Stadthaus

Stadthaus Londra'da 2009 yılında 9 katlı konut binası olarak inşa edilmiştir. ''Çapraz lamine ahşap panellerden inşa edilerek tek katlı beton bir temel üzerine oturtulmuştur. Daireler "petek" şeklinde düzenlenmiş ve merkezi ahşap asansör ve merdiven çekirdeklerinin etrafına yerleştirilmiştir'' (Northrup, 2009-2010, s.198).

''Birinci kattan itibaren tamamen çapraz lamine ahşaptan inşa edilen Stadthaus, dünyanın en yüksek ahşap konut yapısıdır. Dokuz katlı bina, taşıyıcı duvarları, döşemeleri ve çekirdeklerini tamamen ahşaptan inşa eden bu yükseklikteki ilk yapıdır''(Waugh vd., 2010, s.1). Sistem bütünüyle ahşap malzemeden oluştuğu için çevre etkisi hibrit ve karma sistemlere göre daha düşük düzeydedir.

''Temeller, benzer büyüklükteki betonarme çerçeveli bir binanın ağırlığını taşıyacak şekilde boyutlandırılmış, yerinde dökme takviyeli beton kazıklardan oluşmaktadır'' (Waugh vd., 2010, s.2). ''Zemin kat duvarlarının yapımında CLT paneller yerine betonarme kullanılmıştır. Tasarımcılar ve mühendisler, ahşabın en büyük zayıflıklarından birinin neme karşı hassasiyeti olduğunu düşünerek ahşabı zeminden mümkün olduğunca uzak tutmaları gerektiğine karar vermişlerdir'' (Northrup, 2009-2010, s.198).

Stadthaus'un imalat sürecinde tercih edilen CLT panellerden oluşan sistem, montaj ve işçilikte verim sağlayarak inşaat süresini kısaltmıştır. ''Paneller, kullanılacakları sıraya göre imal edilerek şantiyeye teslim edilip, hasar riskini önlemek için vinçlerle yerlerine yerleştirilmiştir. Binada, her katın bir önceki katın üzerine inşa edildiği "platform" inşaat yöntemi kullanılarak iskele kullanılmamıştır''(Northrup, 2009-2010, s.199).

Stadthaus da diğer ahşap yapılar gibi belirli bir yangın dayanımına göre tasarlanmıştır. Stadthaus'un yangın kriterleri ''Konut birimleri için, daireler içindeki bölmelerin yarım saatlik, daireler arasında bir saatlik ve daireler ile ana dikey sirkülasyon arasında iki saatlik bütünlüğe sahip olması gerekmektedir''(Waugh vd., 2010, s.4) şeklinde olup bu şartları sağlamaktadır.

Şekil 18: Stadthaus binası perspektif görünüş. (Pryce, 2010).

Şekil 18'de incelenebilen CLT ahşap paneller ile imal edilen bu konut inşaat süresi, çevre etkisi, montaj kolaylığı gibi konularda Stadthaus'tan sonra yapılacak yapılar için radikal bir bakış açısı sağlamıştır. Özellikle yüksek katlı konut mimarisinde sık tercih edilen beton malzemeye önemli bir alternatif olabileceğini bu yapı ile değerlendirebilmekteyiz.

7.SONUÇ

İnsanlık tarihi ile başlayan yapı kavramında ahşap, doğal ve sürdürülebilir bir malzeme olması sebebiyle tüm dönemlerde yapılarda farklı biçim, form ve işlevle tercih edilmiştir. Lojistik ağların yetersiz ve yerel malzemenin önemli olduğu dönemlerde yapılarda en sık tercih edilen malzemelerden biri olmuştur. Ustalık bilgisine dayalı geleneksel yapım yöntemleriyle yığma ve iskelet sistemde birçok yapı inşa edilmiştir. Ancak yangınlar, depremler, çok katlı yapılaşmaya geçiş gibi ahşabın yetersiz kaldığı durumlar oluşmaya başladığında yapı sektöründe ahşaba alternatif malzemeler geliştirilmiştir.

Beton ve çeliğin yaygınlaşması ile birlikte ahşap ivme kaybederek yapılarda taşıyıcı sistem yerine yardımcı unsur veya ince yapı elemanı olarak kullanılmaya başlanmıştır. Uzun bir dönem bu şekilde devam eden süreçte beton ve çelik sistemlerin imalat aşamasında oluşturduğu çevre kirliliği, hammaddenin elde edilmesi için harcanan enerji, fazla miktarda atık oluşması önemli bir çevre kirliliği oluşturmuştur.

Ahşap malzemenin işlemsiz kullanımında yapı ihtiyaçları karşılanamadığı için endüstriyel ahşap ürünler geliştirilmiştir. Geliştirilen malzemeler ile verimlilik ve dayanıklılık artırılmış; ahşap boyutunda yaşanan yetersizlik aşılmıştır. Beton ve çeliğe kıyasla mühendislik ürünü ahşap yapıların kaynak tüketimleri, çevre etkileri ve karbon ayak izi çok daha düşüktür. Aynı zamanda ahşap yapılar önemli miktarda CO^2 tutulması sağlayarak çevreye olumlu bir katkı sağlamaktadır.

Endüstriyel ahşap ürünler keresteye göre daha geniş açıklıklar sağlayabilen, yangına daha dayanıklı, estetik, yüksek mukavemetli malzemelerdir. Aynı zamanda bu malzemeler yapıda yeniden kullanılabilme, sökülebilme, geri dönüşüm ve değiştirilebilme esnekliğine sahiptir.

Ahşap küresel mimaride desteklenen ve kullanımının yaygınlaşması amaçlanan bir yapı malzemesidir. Bu bağlamda günümüz teknolojisinde ahşap yapım sistemleri de geliştirilerek modern inşaat teknolojilerine yeterli hale gelmesi sağlanmıştır. Günümüzde modüler, panel ve hibrit sistemler kullanılarak, betonarme ve çelik sistemle imal edilen binalara benzer veya üstün özellikler taşıyan az veya çok katlı yapılar imal edilebilmektedir.

Ahşabın dönüşümü ve gelişimi, yapı sektörü için olumlu bir gelişme olmuştur. Ahşap yapım sistemleri iş gücü gereksinimi, sürdürülebilirlik, işlenebilirlik, yeniden kullanılabilme, doğa dostu olması avantajları ile gelecekte daha fazla tercih edilebilecektir. Ayrıca ahşap malzeme geçmişten günümüze ulaşan en eski yapısal ögelerden biri olduğu için geniş bir kullanım alanına sahip olmuş ve çok sayıda yapı meydana getirilmiştir.

Yapılan bu çalışmanın değişen ve gelişen küresel teknolojide ahşap malzemenin kullanım şekilleri ve sistemleri incelenerek gelecekte yapılacak çalışmalarda literatüre katkı sağlaması hedeflenmiştir. Bu bağlamda ahşap malzeme ve yapı sistemlerinin anlaşılmasına, uygulanmasına ve sağladığı avantajlar açıklanarak; ahşap malzemenin yapı sektörü için önemi vurgulanmıştır.

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INTEGRATION OF LIFE CYCLE ASSESSMENT (LCA) AND ARTIFICIAL INTELLIGENCE (AI) IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry has a significant impact on the environment due to its energy and resource consumption and emission production, and it plays a key role in solving environmental problems. Life Cycle Assessment (LCA) is a fundamental method for quantitative sustainability assessment and an environmental management tool. LCA is a systematic approach that analyzes and evaluates resource consumption and environmental impacts throughout the entire life cycle of products, as well as processes and services. Rapid advancements in data generation, storage, and analysis are increasing interest in leveraging the power of large datasets and employing artificial intelligence or machine learning techniques to enhance LCA. This study investigates artificial intelligence applications supporting LCA processes. Trends, methods, advantages and disadvantages, and gaps in literature are investigated. A systematic approach has been developed to examine applications related to the integration of LCA and artificial intelligence. A comprehensive review of current applications of machine learning in the various LCA phases and their associated advantages and challenges is necessary. Furthermore, identifying future research directions to improve the integration of machine learning and LCA is also required. In this context, this systematic approach aims to shed light on the areas that future research in this field should focus on.

Keywords: Artificial intelligence, machine learning, life cycle assessment, construction industry.

1. INTRODUCTION

The world today faces major environmental problems such as global warming, ozone depletion, and waste accumulation (Cabeza et al., 2014). The architecture, engineering, and construction industries are responsible for a significant portion of global greenhouse gas emissions and energy consumption. The building industry plays a crucial role in constructing a sustainable and carbon-neutral built environment. Life cycle assessment (LCA), the fundamental method of quantitative sustainability assessment, is the most powerful environmental management tool. Life cycle assessment is an environmental management tool that analyzes and evaluates, in an

integrated and systematic way, the environmental impacts of a product or system throughout its life cycle (Khasreen et al., 2009; Cabeza et al., 2014). Developed over the years, particularly in the 1970s and 80s, the LCA concept focuses on quantifying the energy and materials used throughout their life cycle, as well as the emissions released into the environment (Sharma et al., 2011).

Computational methods, including artificial intelligence (AI) and machine learning (ML), are increasingly being used to overcome data integration challenges in the construction industry, particularly such as matching construction data with environmental datasets. Machine learning is a subfield of artificial intelligence and is the study of computer algorithms that improve automatically through experience (Romeiko et al., 2024). In the construction industry, artificial intelligence and machine learning are being used to predict environmental impacts, optimize resource use, and address data gaps frequently encountered in LCA studies. By benefiting enhanced techniques, machine learning can analyze large datasets, improving the accuracy of predictions related to carbon emissions, energy consumption, and materials sustainability (Jalota & Ayazi, 2025). In their study, Jalota & Ayazi (2025) stated that regression-based machine learning models such as random forest (RF), extreme gradient boosting (XGBoost), and artificial neural networks (ANN) are currently the most widely applied techniques in modeling sustainability indicators, environmental performance, and carbon emissions due to their high accuracy and versatility.

To generate quantitative data on life cycle environmental impact, important software such as One Click LCA, Open LCA, and Athena IA, particularly GaBi and SimaPro, are available. GaBi and SimaPro, which are at the center of academic studies, provide powerful and comprehensive LCA analyses. In this respect, the integration of artificial intelligence into LCA should offer an approach that provides more effective benefits than simply generating quantitative data, such as supporting process optimization and decision-making systems. This study systematically reviews advantages, limitations, gaps, and future directions of LCA and AI integration. In this context, the study is aimed to shed light on future areas of research.

2. MATERIAL AND METHODS

This study primarily develops a framework or approach for systematically analyzing and evaluating studies related to life cycle assessment (LCA) and artificial intelligence (AI) integration (Figure 1). The evaluation framework consists of three main stages. Stage 1 involves a literature review and problem definition. Stage 2 involves defining the evaluation criteria. The evaluation criteria consist of LCA Framework, AI Tool, and Integration mechanism parameters. Stage 3 consists of identifying gaps in the literature and defining areas for future research. In

this study, studies on LCA & AI integration applications are analyzed in accordance with the developed systematic approach (evaluation criteria). The findings are explained comprehensively.

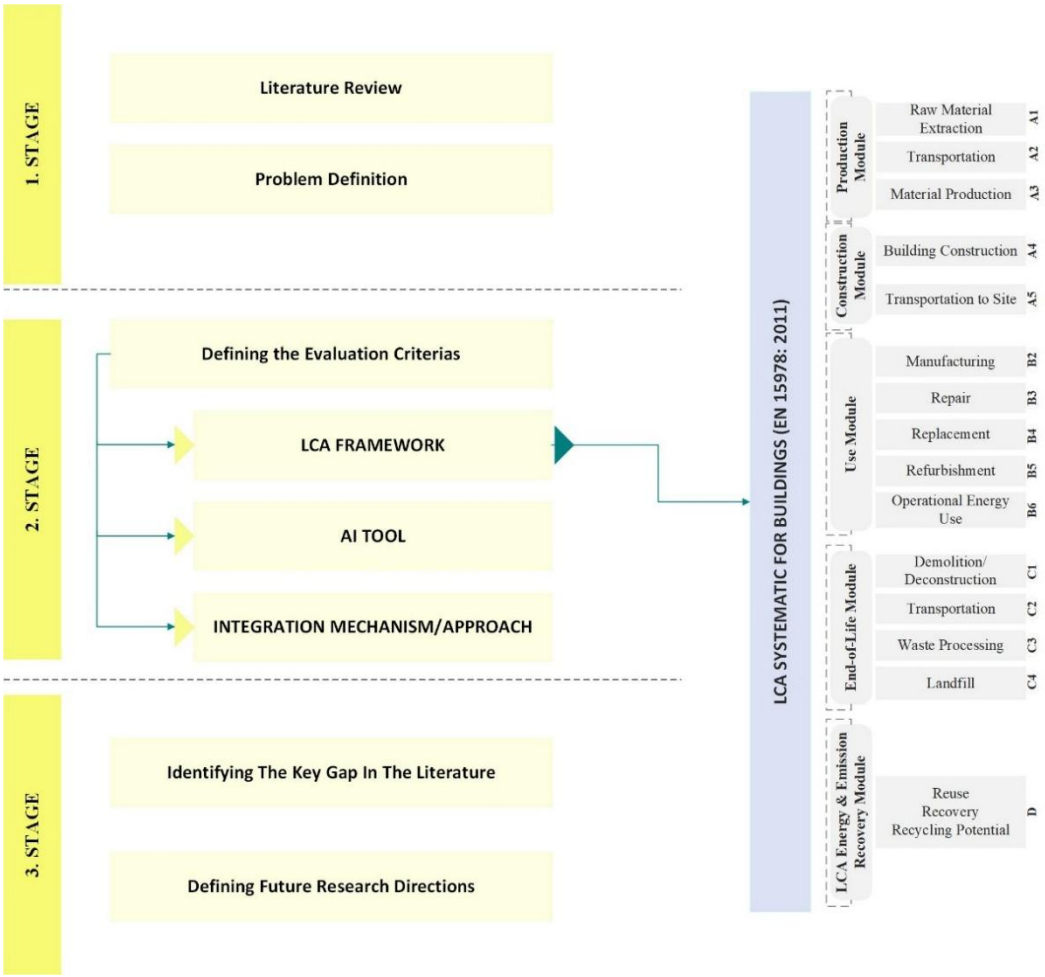

Figure 1. Developed Analysis Methodology (Created by the authors)

The LCA system boundaries and framework are defined in the EN 15978:2011 standard. The lifecycle framework consists of production module, construction module, use module, end-of-life module, and recovery module (benefits beyond the system boundary), and their sub-parameters. Lifecycle modules include operational and embodied environmental loads. The energy consumed and emissions produced for heating, cooling, ventilation, air conditioning, and equipment represent operational loads (Lechner, 2015). Embodied loads occur for all other sub-modules and applications. The environmental impact of a building or building component throughout its lifecycle can differ in terms of operational and embodied loads (energy and carbon emissions). While operational energy is a significant factor for the building envelope, structural systems do not directly affect a building's operational energy. In this respect, defining the LCA framework is of great importance.

AI (artificial intelligence) refers to the artificial intelligence methods or applications used. The LCA and AI integration mechanism refers to the lifecycle and artificial intelligence integration approach, method, or scope. Defining the integration approach is crucial for identifying trends in current research and gaps in the field.

3. RESULTS AND DISCUSSION

In this section, the studies by Gachkar et al. (2025), de Paula Salgado et al. (2025) and Azari et al. (2016) are systematically analyzed and evaluated in accordance with the developed framework. Data related to the studies analyzed under the main criteria of LCA Framework, AI Tool and Integration Mechanism are shown in Table 1.

Table 1. Analysis of Studies on LCA & AI Integration

References	LCA FRAMEWORK	AI TOOL	INTEGRATION MECHANISM
(Gachkar et al., 2025)	Production Stage	Fuzzy String Matching and Random Forest (Phyton)	The methodology for integrating and matching building and environmental databases combines fuzzy logic and RF algorithms in a complementary framework.
(de Paula Salgado et al., 2025)	Production and Construction Stage	PCA (Principal component analysis), Machine Learning Model, Multi-Objective Optimization (Pareto)	Integration of LCA-derived sustainability constraints into ML-assisted material design optimization framework.
(Azari et al., 2016)	Whole-building life cycle environmental assessment	Multi-objective optimization algorithms, Pareto-based optimization, simulation-assisted optimization	Integration of building energy simulation and LCA into an optimization framework to identify envelope configurations with improved life-cycle environmental performance.

In their study, Gachkar et al. (2025) developed a methodology that automates data integration using fuzzy string matching and Random Forest (RF) based supervised learning. The aim of this study is to integrate and match construction and environment database elements by combining fuzzy string matching with supervised learning techniques, and to explore the potential of supervised learning, particularly Random Forest algorithms. While fuzzy matching detects matches based on textual similarity, supervised learning facilitates matches even when textual similarities are low, providing a more comprehensive matching process. Python was used in the study due to its versatility, extensive library ecosystem, and strong support for

machine learning and text processing. The study indicated that when medology was applied to the Andalusian Construction Cost Database (BCCA) and ecoinvent databases, high accuracy was achieved and manual intervention time was reduced by 90%.

In their study, Paula Salgado et al. (2025) aimed to optimize the design of impact-resistant mineral-bonded fiber-reinforced composites using a sustainability-focused, machine learning-based modeling approach. They proposed a three-stage integrated framework combining an experimental testing database, sustainability assessment (LCA), and machine learning modeling. GaBi software and databases were used for life cycle inventory modeling and impact assessment. The proposed machine learning model demonstrated high accuracy in predicting global warming potential (GWP) and energy dispersion.

In their study, Azari et al. (2016) use a multi-objective optimization algorithm to investigate the optimal building facade design in relation to energy use and the environmental impact of the life cycle in a low-rise office building located in Seattle, Washington. The eQuest 3.65 simulation tool was used to analyze operational energy consumption; the Life Cycle Assessment (LCA) methodology and Athena IE were used to analyze environmental impacts. A hybrid artificial neural network (ANN) and genetic algorithm (GA) approach was used as the optimization technique. LCA results for 91 design combinations were taken to the optimization phase to determine the optimum values for the design inputs. An evolutionary optimization algorithm was used to train the defined artificial neural networks and to fine-tune and optimize their weights and deviations. The performance of the developed artificial neural network model was further checked by comparing the predicted values of each response variable with real experimental data.

In the study by Gachkar et al. (2025), a matching of a construction database with an environmental database was performed. While this aspect is valuable, a significant limitation of the study is its focus solely on the material production potential in the LCA systematic. Furthermore, powerful LCA software exists for an integrated environmental impact assessment. The study by de Paula Salgado et al. (2025) is quite valuable in that it uses machine learning to generate quantitative LCA data via software and integrate mechanical effects with an optimal decision-making mechanism. However, the study's focus on the production and construction phase is a significant limitation. The mechanism developed in Azari et al. (2016) for selecting facade configurations with optimal environmental performance through machine learning is quite valuable. However, the study's focus on a specific region and the limited number of design alternatives are significant limitations. As the study also mentions, there are many other design and location-related factors that can affect the environmental impact of building facades.

In conclusion, the studies conducted offer significant contributions. However, beyond generating quantitative data for lifecycle environmental sustainability, there is a need for adaptive integrated models, methods, or decision support systems that prioritize process optimization, support decision-making systems, and address all modules of the LCA methodology in an integrated and explicit manner. One of the most significant gaps in the literature regarding LCA and AI integration can be considered as a process optimization and integrated evaluation approach.

4. CONCLUSION AND SUGGESTIONS

This study presents a unique approach to the integration of artificial intelligence (AI) techniques into life cycle assessment (LCA) applications, particularly in the construction sector. Despite increasing interest, the integration of LCA and AI remains an underdeveloped and developing field. Therefore, systematically analyzing existing studies and identifying gaps in this area is crucial.

Existing studies generally focus on AI-assisted environmental impact prediction. This study systematically evaluates AI and life cycle analysis (LCA) integration mechanisms, the LCA framework, AI tools, and integration approaches from a specific perspective. AI should be considered not as a replacement for LCA's computing engine, but rather as an integration layer that enables LCA data to be used for decision support, data matching, process automation, and optimization in the construction industry.

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GELENEKSEL KONUTLARDA MEKÂNSAL KURGU VE SÜREKLİLİK: SAFRANBOLU MAHİR AĞA KONAĞI ÖRNEĞİ

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ÖZET

Safranbolu, geleneksel Türk konut mimarisinin özgün niteliklerini bütüncül bir yerleşim dokusu içinde günümüze taşıyan ve bu özelliğiyle mimarlık tarihi ile koruma çalışmaları açısından ayrıcalıklı bir konuma sahip olan önemli bir yerleşimdir. Kentte yer alan konutlar, yalnızca fiziksel varlıklarıyla değil; plan kurguları, yapım sistemleri ve mekânsal organizasyonları ile geleneksel yaşam biçimini yansıtan çok katmanlı bir miras sunmaktadır. Bu bağlamda Safranbolu evleri, geleneksel konut tipolojisinin anlaşılması açısından referans niteliğinde örnekler oluşturmaktadır. Bu çalışma kapsamında, Safranbolu'da yer alan Mahir Ağa Konağı, plan kurgusu ve mekânsal organizasyonu üzerinden incelenmiştir. Çalışmanın amacı, yapının mimari özelliklerini ortaya koymak ve geleneksel konut tipolojisine ait mekânsal ilkelerin yapı üzerindeki yansımalarını değerlendirmektir. Araştırma sürecinde, yapıya ait rölöve çizimleri ve plan şemaları incelenmiş; yerinde yapılan gözlemler ile mevcut mekânsal kurgu analiz edilmiştir. Bu doğrultuda, mekânlar arası ilişkiler, sofa mekânının organizasyondaki rolü ve katlar arası işlevsel dağılım ele alınmıştır. Ayrıca dolaşım sistemi ve düşey sirkülasyon kurgusu, mekânsal süreklilik bağlamında değerlendirilmiştir. Elde edilen bulgular, Mahir Ağa Konağı'nın sofa merkezli plan düzenini koruduğunu ve Safranbolu konutlarına özgü mekânsal organizasyon ilkelerini yansıttığını göstermektedir. Mekânsal elemanların varlığını sürdürmesi ve plan şemasının okunabilirliğini koruması, yapının özgün karakterinin günümüzde de izlenebildiğini ortaya koymaktadır. Bu yönüyle çalışma, tekil bir yapı üzerinden gerçekleştirilen mekânsal çözümleme ile geleneksel konut tipolojisinin anlaşılmasına katkı sunmayı ve yapının mimari özelliklerini belgelemeyi amaçlamaktadır.

Anahtar kelimeler: Safranbolu, geleneksel Türk konutu, mekânsal kurgu, mekânsal süreklilik, mimari analiz

SPATIAL CONFIGURATION AND CONTINUITY IN TRADITIONAL HOUSES: THE CASE OF SAFRANBOLU MAHIR AĞA MANSION

ABSTRACT

Safranbolu is a significant settlement that preserves the distinctive characteristics of traditional Turkish residential architecture within an integrated urban fabric, and thus holds a privileged position in the fields of architectural history and conservation studies. The houses in the city

represent a multilayered heritage, reflecting traditional ways of life not only through their physical presence but also through their spatial organization, construction techniques, and plan configurations. In this context, Safranbolu houses serve as reference examples for understanding traditional housing typology. Within the scope of this study, Mahir Ağa Mansion in Safranbolu is examined through its plan configuration and spatial organization. The aim of the study is to reveal the architectural characteristics of the building and to evaluate how the spatial principles of traditional housing typology are reflected in its structure. During the research process, measured drawings and plan schemes of the building were analyzed, and the existing spatial configuration was examined through on-site observations. Accordingly, spatial relationships, the role of the sofa space in the overall organization, and the functional distribution between floors were evaluated. In addition, the circulation system and vertical circulation were analyzed in terms of spatial continuity. The findings indicate that Mahir Ağa Mansion preserves a sofa-centered plan scheme and reflects the spatial organization principles characteristic of Safranbolu houses. The continuity of spatial elements and the readability of the plan layout demonstrate that the original architectural character of the building can still be observed today. In this respect, the study aims to contribute to the understanding of traditional housing typology through a spatial analysis of a single building and to document its architectural features.

Keywords: Safranbolu, traditional Turkish house, spatial configuration, spatial continuity, architectural analysis

1. GİRİŞ

Safranbolu, geleneksel Türk konut mimarisinin özgün niteliklerini büyük ölçüde koruyarak günümüze ulaştırmış yerleşimlerden biri olup, mimarlık tarihi ve koruma çalışmaları açısından önemli bir referans alanı oluşturmaktadır. Kentte yer alan konutlar, yalnızca fiziksel varlıklarıyla değil; mekânsal organizasyonları, yapım sistemleri ve toplumsal yaşam biçimini yansıtan kurgularıyla çok katmanlı bir kültürel miras niteliği taşımaktadır (Günay, 1998). Bu bağlamda Safranbolu evleri, geleneksel Türk konutunun tipolojik, mekânsal ve yapısal özelliklerini bütüncül biçimde ortaya koyan özgün örnekler olarak değerlendirilmektedir.

Geleneksel Türk konutunda plan organizasyonunun temelini oluşturan sofa mekânı, mekânsal ilişkileri düzenleyen ana unsur olarak öne çıkmaktadır. Eldem'in tanımladığı sofasız, dış sofalı, iç sofalı ve orta sofalı plan tipleri, bu organizasyonun çözümlenmesinde önemli bir kuramsal çerçeve sunmaktadır (Eldem, 1968). Safranbolu evlerinde sofa, yalnızca bir dolaşım alanı değil;

aynı zamanda gündelik yaşamın biçimlendiği, sosyal ilişkilerin kurulduğu ve mekânsal hiyerarşinin tanımlandığı merkezî bir mekân niteliğindedir (Günay, 1998).

Safranbolu konutları, topoğrafya ile kurdukları uyumlu ilişki, katlar arası işlevsel dağılım ve kullanıcı ihtiyaçlarına göre şekillenen esnek plan kurguları ile dikkat çekmektedir. Zemin katların daha çok servis mekânlarına ayrılması, üst katların ise yaşama alanı olarak düzenlenmesi ve sofa etrafında gelişen mekânsal organizasyon, bu konutların karakteristik özellikleri arasında yer almaktadır.

Geleneksel Safranbolu konutlarının korunarak gelecek kuşaklara aktarılmasında yürütülen belgeleme çalışmaları, yapıların özgün özelliklerinin ortaya konulması ve doğru biçimde anlaşılması açısından önemli bir rol üstlenmektedir. Özellikle tekil konutlar üzerinden yürütülen koruma projeleri, hem yapı ölçeğinde hem de kentsel ölçekte mimari sürekliliğin izlenmesine olanak sağlamaktadır. Bu kapsamda Safranbolu'daki konaklara yönelik hazırlanan çalışmalar, yapıların plan organizasyonu, yapım sistemi ve malzeme özelliklerinin detaylı biçimde ortaya konulmasına katkı sunmaktadır (Bağ, 2020). Bununla birlikte, geleneksel konutların günümüzdeki kullanımı da önemli bir dönüşüm sürecine işaret etmektedir. Safranbolu'da birçok konut, özgün işlevini yitirerek konaklama, otel ve kafe gibi farklı kullanım biçimlerine uyarlanmıştır. Bu kapsamda, yapıların mevcut durumlarının belgelenmesi ve müdahalelerin değerlendirilmesi, koruma pratiği açısından önemli bir gereklilik olarak öne arz etmektedir.

Ayrıca plan organizasyonu ile yapım sistemi arasında doğrudan bir ilişki bulunmaktadır. Ahşap karkas sistemin sunduğu modüler yapı ve taşıyıcı sistem içerisindeki dolgu elemanlarının esnekliği, mekânsal düzenin zaman içerisinde değişebilmesine ve genişleyebilmesine olanak tanımaktadır (Aksoy, 2003; Aksoy ve Ahunbay, 2005).

Ahşap karkas yapı sistemine sahip geleneksel konutlarda plan düzeninin yalnızca mekânsal organizasyonu değil, aynı zamanda yapının davranış biçimini de etkilediği bilinmektedir. Özellikle plan düzleminde düzenli ve süreklilik gösteren kurguların, dış etkiler karşısında daha dengeli bir performans ortaya koyduğu belirtilmektedir. Buna göre, duvar sürekliliğinin korunması, açıklık oranlarının dengeli dağılımı ve mekânsal bütünlüğün sağlanması, yapının genel dayanımını destekleyen unsurlar arasında değerlendirilmektedir.

Bu çalışma kapsamında incelenen Mahir Ağa Konağı, plan organizasyonu, mekânsal kurgusu ve mekânsal elemanları üzerinden ele alınmaktadır. Yapının yerinde gerçekleştirilen rölöve çalışmaları ile elde edilen veriler ve mevcut durumu birlikte değerlendirilerek, geleneksel Safranbolu konutlarının mekânsal sürekliliği ve organizasyon ilkelerinin ortaya konulması

amaçlanmaktadır. Bu doğrultuda çalışma, söz konusu yapının mimari özelliklerini özgün verilerle belgeleyerek literatüre katkı sağlamayı hedeflemektedir.

2. YÖNTEM

Bu çalışma, Safranbolu'da yer alan Mahir Ağa Konağı'nın mekânsal organizasyonu, plan şeması ve mekânsal özelliklerini incelemeyi amaçlayan nitel bir araştırma olarak kurgulanmıştır. Araştırma sürecinde ilk aşamada, geleneksel Türk konutu ve Safranbolu evlerine ilişkin literatür değerlendirilmiş; bu doğrultuda sofa mekânı, plan tipolojisi ve mekânsal kurguya ilişkin kuramsal bir çerçeve oluşturulmuştur. Çalışmanın temel verilerini, yapıya ilişkin yerinde gerçekleştirilen rölöve çalışmalarıyla elde edilen çizimler, plan şemaları ve saha gözlemleri oluşturmaktadır. Rölöve verileri üzerinden mekânların konumları, boyutları, birbirleriyle kurdukları ilişkiler ve dolaşım düzeni analiz edilmiştir. Bu kapsamda özellikle sofa mekânının plan içindeki yeri, mekânsal dağılımdaki işlevi ve katlar arası bağlantıları ayrıntılı biçimde değerlendirilmiştir. Saha incelemeleri sırasında yapının mevcut mekânsal düzeni doğrudan gözlemlenmiş; mekânsal elemanların kullanım biçimleri ve işlevsel ilişkileri yerinde incelenmiştir. İç mekân düzeni, dolaşım kurgusu ve mekânlar arası bağlantılar, yapının güncel durumu üzerinden okunarak yorumlanmıştır. Elde edilen tüm veriler, mekânsal analiz ve yorumlama yaklaşımı çerçevesinde değerlendirilmiş; yapı, plan kurgusu, mekânsal ilişkiler ve organizasyon ilkeleri bakımından bütüncül bir şekilde ele alınmıştır. Bu süreç sonucunda Mahir Ağa Konağı'nın mekânsal karakteri ortaya konulmuş ve yapının geleneksel konut tipolojisi ile kurduğu ilişki değerlendirilmiştir. Ayrıca, analizler mekânsal sürekliliğin izlenmesine olanak tanıyan bir yaklaşım doğrultusunda ele alınmıştır.

3. BULGULAR

3.1 Yapının Tarihsel Gelişimi ve Dönüşüm Süreci

Yapının tarihsel gelişimine ilişkin veriler, yapı işletmesi tarafından sağlanan yazılı ve dijital bilgiler doğrultusunda derlenmiştir. Çalışma kapsamında incelenen yapı, geçmişte "Arap Hacılar Evi" olarak anılmakta olup, günümüzde "Mahir Ağa Konağı" adıyla turizm amaçlı konaklama işleviyle kullanılmaktadır (Şekil 1).

Şekil 1. Mahir Ağa Konağı (Yazar arşivi)

Safranbolu, tarih boyunca Çin'den Avrupa'ya uzanan İpek Yolu güzergâhı üzerinde yer alması nedeniyle önemli bir ticaret ve konaklama merkezi olarak gelişmiştir. Kentte yer alan Cinci Han, Pamukçu Han ve Tuzcu Han gibi büyük ölçekli yapılar, uzun süre kervanların konaklama ihtiyacını karşılamıştır. Ancak zaman içerisinde, özellikle büyük yangınlar sonrasında bu yapıların özgün işlevlerini kaybetmesi ve depo gibi farklı amaçlarla kullanılmaya başlanması, kentteki konaklama sisteminde bir dönüşümü beraberinde getirmiştir. Bu süreçte, büyük hanların yerini daha küçük ölçekli ve dağınık konumlanan yolcu hanlarının aldığı anlaşılmaktadır. Geleneksel Safranbolu konut mimarisine benzer özellikler taşıyan bu yapılar, plan kurgusu ve kullanım biçimi açısından konutlardan ayrılmaktadır. Özellikle zemin katlarda "hayat" mekânı yerine ahır ve nalbant gibi işlevlere yer verilmesi, bu yapıların doğrudan yolculara ve ticari faaliyetlere hizmet ettiğini göstermektedir.

Bu bağlamda incelenen yapı, Han Arkası olarak bilinen bölgede konumlanmakta olup, geçmişte yolcu hanı olarak kullanılmış önemli örneklerden biridir. Zemin üzerine iki katlı olarak inşa edilen yapı; simetrik pencere düzeni ve belirgin köşe çıkması gibi mimari özellikleriyle dikkat çekmektedir. Giriş katında yer alan ahır mekânı ve buna eşlik eden üretim alanları, yapının ticaretle ilişkili kullanımını açıkça ortaya koymaktadır. Yapı, UNESCO Dünya Miras Listesi'nde yer alan Safranbolu'nun korunmuş tarihî dokusu içerisinde bulunmakta olup, bu kapsamda çeşitli koruma ve onarım müdahalelerine konu olmuştur. Geçmiş yıllarda gerçekleştirilen çalışmalarda, yapının özgün konaklama işlevi ve mimari karakteri korunarak onarım yapılarak, ahşap karkas sistem güçlendirilmiştir. Bu müdahaleler, yapının hem fiziksel sürekliliğinin sağlanmasına hem de geleneksel mimari özelliklerinin korunmasına katkıda bulunmuştur.

Yapı, tarihsel süreç içerisinde işlevsel bir dönüşüm geçirerek günümüzde turizm amaçlı konaklama işlevi ile kullanılmaktadır. Bu dönüşüm, yapının korunmasına katkı sağlamakla birlikte, iç mekân organizasyonu ve kullanım biçiminde çeşitli değişikliklere yol açmıştır. Bu yönüyle yapı, geleneksel konaklama yapılarının evrimi ile yeniden kullanım süreçlerinin birlikte okunabildiği önemli bir örnek niteliği taşımaktadır.

Yapı, Karabük ili Safranbolu ilçesinde, Eski Çarşı bölgesinde konumlanmakta olup Musalla Mahallesi sınırları içerisinde yer almaktadır. Konak, kentin tarihsel ticaret merkezi ile geleneksel konut dokusunun kesişim noktasında bulunması bakımından önemli bir konumsal özellik göstermektedir (Şekil 2).

Şekil 2. Mahir Ağa Konağı'nın Safranbolu kent dokusu içerisindeki konumu (Safranbolu imar planından düzenlenmiştir)

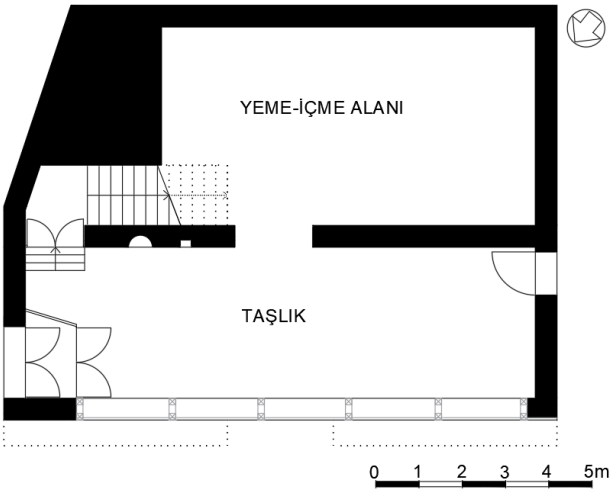
Konumu itibarıyla yapı, Safranbolu'nun önemli odak noktalarından olan ve tarihsel süreçte önemini korumaya devam eden Cinci Han ve Hıdırlık Tepesi ile yakın bir mekânsal ilişki içerisindedir. Bu durum, yapının tarihsel ticaret ağı ile doğrudan bağlantılı bir konumda yer aldığını göstermektedir. Ayrıca çevresindeki sivil mimari örneklerle birlikte değerlendirildiğinde, yapının bulunduğu alanın tarihsel ve sosyo-kültürel açıdan yoğun bir yerleşim dokusuna sahip olduğu anlaşılmaktadır.

Topografyaya uyumlu biçimde eğimli arazi üzerinde konumlanan yapı, Safranbolu konut dokusunun temel ilkelerinden biri olan yapıların birbirinin görüş ve ışığını engellemeyecek şekilde yerleşmesi prensibini yansıtmaktadır. Bu bağlamda konak, hem kentsel doku

içerisindeki konumu hem de çevresi ile kurduğu mekânsal ilişkiler açısından Safranbolu'nun geleneksel yerleşim karakterini temsil eden önemli bir örnek niteliği taşımaktadır.

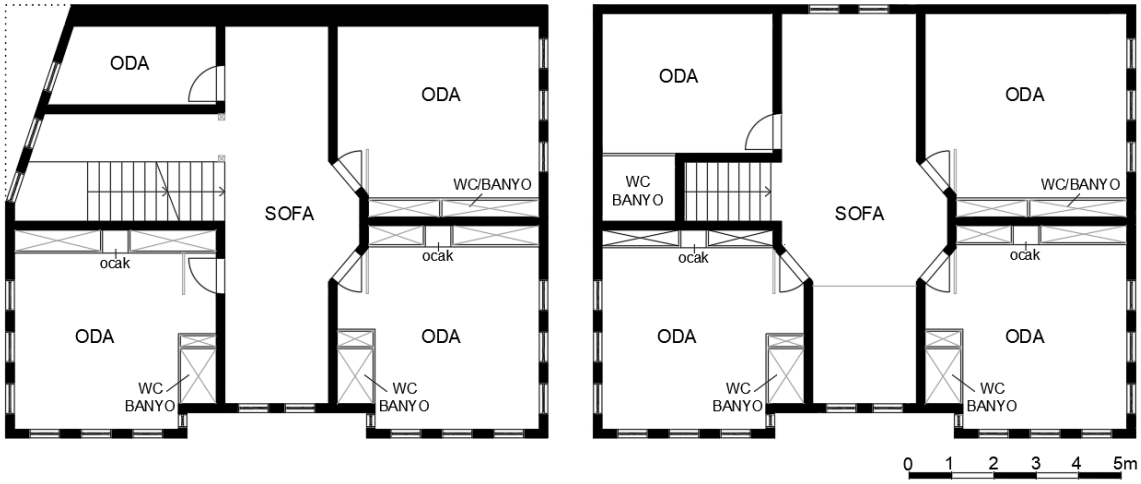
3.2. Plan Kurgusu ve Mekânsal Organizasyon

İncelenen yapı, geleneksel Safranbolu konut mimarisinin karakteristik özelliklerinden biri olan iç sofalı plan tipine sahiptir ve bu plan şemasını büyük ölçüde koruyarak günümüze ulaşmıştır. Yapı, zemin kat üzerine iki kat olmak üzere toplam üç katlı bir düzen göstermektedir. Konağın zemin katı, günümüzde yeme içme mekânı olarak işlev gösteren geniş bir taşlık mekânı ile yeme-içme mekânı olarak işlevin devam ettirildiği ve geçmişte ahır olarak kullanılan geniş bir alandan oluşmaktadır. Zemin kattaki mekanlar arası bağlantılar açık biçimde izlenebilmektedir (Şekil 3).



Şekil 3. Mahir Ağa Konağı zemin kat planı

Birinci ve ikinci katlarda ise sofa ve oda mekanları bulunmaktadır. Islak hacimler odaların içindeki yüklük kısımlarında çözülmüş olup üst katlarda sofa ile bu mekâna açılan odalardan oluşan bir düzen görülmektedir. Üst kat planlarının birbirine benzer bir şema göstermesi ise mekânsal organizasyonun tekrar eden bir kurgu ile oluşturulduğunu ortaya koymaktadır (Şekil 4).



Birinci kat planı İkinci kat planı

Şekil 4. Mahir Ağa Konağı üst kat planları

Plan organizasyonunda iç sofa, katların merkezinde konumlanarak tüm mekânsal dağılımı belirleyen ana unsur niteliğindedir. Odalar doğrudan sofaya açılmakta olup, sofa hem dolaşım hem de ortak kullanım alanı olarak işlev görmektedir. Mekânsal hiyerarşi açık ve okunabilir bir biçimde kurulmuştur. Sofadan odalara giriş ise daha da tanımlı hale getirilmiş olup, odaların girişi pahlı bir şekilde oluşturulmuştur (Şekil 5).

Şekil 5. Mahir Ağa Konağı birinci kat sofa görünümleri (Yazar arşivi)

Yapının geçmişte konaklama işlevine sahip olması, plan kurgusunda tipik Safranbolu konutlarına kıyasla daha fazla sayıda odanın yer almasına neden olmuştur. Ayrıca birinci ve

ikinci kat planlarının büyük ölçüde benzer olması, yapının kullanıcılar için standartlaştırılmış mekânsal bir düzen sunduğunu ve bu yönüyle konut tipolojisinden ayrıştığını göstermektedir.

3.3 Dolaşım Sistemi ve Düşey Sirkülasyon

Yapıda düşey sirkülasyon, merkezî mekân olan sofa ile doğrudan ilişkili bir biçimde kurgulanmıştır. Zemin kattan birinci kata ulaşım, taşlık mekânından başlayan ve dört basamaklı taş bir merdiven kolu ile sahanlığa ulaşılan, ardından tek kollu ahşap merdiven ile devam eden L biçimli bir düzen ile sağlanmaktadır. Birinci kattan ikinci kata geçiş ise tek kollu bir merdiven aracılığıyla gerçekleşmektedir. Birinci kattaki iç sofadan uzanan kısa bir geçiş üzerinden bir basamağın yükseltilmesiyle merdivene ulaşılmaktadır (Şekil 6).

Zemin kat taş basamakları

Ahşap zemin kat merdiveni

Birinci kat merdivenler arası geçiş

Birinci katta yükseltilmiş basamak

Birinci kat merdiveni alttan bakış

Birinci kat merdiveni üstten bakış

Şekil 6. Mahir Ağa Konağı merdiven görünümleri (Yazar arşivi)

3.4. Yapım Sistemi ve Strüktürel Özellikler

Yapının taşıyıcı sistemi, geleneksel Safranbolu konutlarında yaygın olarak kullanılan ahşap karkas (hımış) sistem ile oluşturulmuştur. Zemin katta taş duvarların tercih edilmesi, yapının topoğrafya ile uyumunu ve taşıyıcılık kapasitesini artırırken; üst katlarda kullanılan ahşap karkas sistem, yapıya esnek bir strüktürel kurgu kazandırmaktadır. Ahşap karkas sistemin modüler yapısı, mekânların zaman içerisinde yeniden düzenlenmesine olanak tanımış ve günümüzdeki kullanım değişikliklerinin yapıya uyumlu biçimde uygulanabilmesini mümkün

kılmıştır. Zemin katta yer alan taşlık ve ahır mekânları, işlevsel dönüşüme rağmen özgün yapım sisteminin okunabilirliğini korumaktadır (Şekil 7).

Şekil 7. Mahir Ağa Konağı'nın günümüzde kullanılan taşlık ve ahır mekanları (Yazar arşivi)

3.5. İç Mekân Elemanları ve Mekânsal Donatı

İç mekân elemanları incelendiğinde, yapının geleneksel mimari karakterini büyük ölçüde koruduğu görülmektedir. Odalarda yer alan yüklükler, orijinal işlevini bozmamıştır. Yüklükler, günümüzde kısmen banyo (gusülhane) işlevi ile kullanılmaktadır. Bu uygulama Safranbolu konaklarında sıklıkla karşımıza çıkmakta ve geleneksel mekânsal elemanların kullanım ihtiyaçlarına uyum sağlayarak varlığını sürdürdüğünü göstermektedir (Şekil 8).

Şekil 8. Mahir Ağa Konağı farklı odalardan yüklük örnekleri (Yazar arşivi)

Ocak nişlerinin korunmuş olması, mekânın özgün işlevine dair izlerin devam ettiğini ortaya koymaktadır. Ocaklar, geçmişteki işlevlerine bağlı olarak odaların merkezi bir noktasında bulunmaktadır. Günümüzde orijinal işlevinden ziyade odaların yeni işlevine bağlı ikincil

elemanı olarak varlığını sürdüren ocaklar, iki farklı odadaki örnekleri ile birlikte, Şekil 9'da verilmiştir.

Şekil 9. Mahir Ağa Konağı farklı odalardan ocak örnekleri (Yazar arşivi)

Sedirlerin özellikle pencere altlarında özgün yükseklikleri ile korunmuş olması, insan ölçeği ile mekân arasındaki ilişkinin günümüzde de okunabilmesini sağlamaktadır. Bununla birlikte geleneksel konutlarda karşımıza çıkan ve odaların girişindeki mahremiyeti sağlamak amacıyla kullanılan ahşap paravan elemanlarının korunmuş olması, geleneksel kullanım alışkanlıklarının sürdürüldüğünü göstermektedir (Şekil 10).

Şekil 10. Mahir Ağa Konağı'nda sedir ve ahşap paravan örnekleri (Yazar arşivi)

İç sofada yer alan sekilik ve niş elemanları, mekânın özgün kullanım biçimini yansıtan önemli detaylar olarak dikkat çekmektedir. Sekilik mekânı geleneksel işlevini sürdürmekte olup, Mehir Ağa Konağı'nda oturma alanı olarak karşımıza çıkmaktadır. Nişler ise dekoratif amaçla kullanılmaktadır (Şekil 11).

Şekil 11. Mahir Ağa Konağı'nın ikinci katında sekilik ve niş elemanları (Yazar arşivi)

Sofa ve odaların üst kotlarında yer alan ve geleneksel olarak "sergen" olarak adlandırılan ahşap raf sistemlerinin korunmuş olması, iç mekânın özgün karakterini destekleyen önemli unsurlar arasında yer almaktadır. Ayrıca ahşap tavan işçiliklerinin günümüzde hâlâ okunabilir durumda olması, yapının estetik ve yapısal özelliklerinin birlikte değerlendirilebilmesine olanak tanımaktadır. Mahir Ağa Konağı'nda kapı ve pencere üstlerinden mekân boyunca devam ettirilen raflar (sergen) ile birlikte baş odaya ait ahşap tavan süslemesi örneği Şekil 12'de görülmektedir.

Şekil 12. Mahir Ağa Konağı iç mekânında eden raflar ve tavan süslemesi (Yazar arşivi)

3.6. Cephe Özellikleri ve Açıklık Sistemi

Yapının cephe düzeni, Safranbolu konut mimarisinin karakteristik özelliklerini yansıtmaktadır. Ön cephede (kuzey) iki köşede yer alan ve mekân büyüklüğünde tasarlanan çıkmalar, üst katlardaki mekânsal genişlemenin dışarıya yansımasını sağlamaktadır. Bununla birlikte yapının doğu cephesinde yer alan gönye çıkma, Safranbolu konutlarında yaygın olarak kullanılan bir çözüm olup, üst kat plan organizasyonunun cephe üzerinden okunabilmesine olanak

tanımaktadır. Zemin katın topoğrafyaya uyumlu biçimde kurgulanmış olması da cephe oluşumunu doğrudan etkileyen önemli bir faktördür (Şekil 13).

Şekil 13. Mahir Ağa Konağı'nın çıkma görünümleri (Yazar arşivi)

Pencere sisteminde ise alt kısmı sabit, üst kısmı açılır kanatlı geleneksel düzenin korunduğu görülmektedir. Böylece, hem cephe karakterinin sürekliliğini hem de iç mekân aydınlatmasının özgün niteliği korunmaktadır. Mahir Ağa Konağı'na ait pencerelerin iç mekân görünümü ve cephedeki pencere düzeni Şekil 14'te sunulmuştur.

Şekil 14. Mahir Ağa Konağı pencerelerinin cepheden ve iç mekândan görünümü (Yazar arşivi)

Yapının zemin katında yer alan gliste elemanlarının, ilk inşa edildiği dönemde doğal havalandırma ve aydınlatmayı sağlamak gibi farklı amaçlarla açık biçimde kurgulandığı anlaşılmaktadır. Bu elemanlar, taşlık mekânının hava sirkülasyonu ve gün ışığı ile ilişkisini düzenleyen önemli bileşenler olarak işlev görmektedir. Ancak zaman içerisinde değişen kullanım ihtiyaçları doğrultusunda bu açıklıkların cam yüzeyler ile kapatıldığı görülmektedir. Buna rağmen, söz konusu müdahalenin özgün açıklık düzenini tamamen ortadan kaldırmadığı

ve gliste sisteminin ilk kurgusunun hâlâ okunabildiği anlaşılmaktadır. Safranbolu'da çok sayıda glisteli yapı örneği bulunmasına karşın, Mahir Ağa Konağı'nın bu sistemi büyük ölçüde koruyarak günümüze ulaştırması, yapıyı bu açıdan nitelikli ve temsil gücü yüksek bir örnek haline getirmektedir. Yapım sisteminin verdiği avantajlar ile yükseltilmiş taş duvarın üzerine inşa edilen gliste sistemi, günümüzde çeşitli dekoratif objeler için de görsel bir saklama alanı meydana getirmiş olup, Mahir Ağa Konağı'nın gliste görünümleri ve detayları Şekil 15'te verilmiştir.

Şekil 15. Mahir Ağa Konağı'na ait glistelerin görünümü ve detayları (Yazar arşivi)

4. SONUÇ

Bu çalışma kapsamında incelenen Mahir Ağa Konağı'nın, geleneksel Safranbolu konutlarına özgü mekânsal organizasyon özelliklerini büyük ölçüde koruyarak günümüze ulaştığı görülmüştür. Yapının plan şemasının sofa merkezli bir kurguya sahip olduğu ve mekânsal dağılımın bu merkez etrafında biçimlendiği tespit edilmiştir. Sofa mekânının hem dolaşım hem de ortak kullanım açısından belirleyici bir rol üstlenmesi, geleneksel konut tipolojisinin temel mekânsal ilkelerinin yapı üzerinde açık biçimde okunabildiğini göstermektedir.

Katlar arası işlevsel dağılım Safranbolu konutlarının karakteristik mekânsal organizasyon yapısı ile uyum göstermekte olup, zemin katlar daha çok servis mekânlarına ayrılırken, üst katlar yaşama alanı olarak kurgulanmıştır. Ayrıca yapının topoğrafya ile kurduğu ilişki, plan organizasyonunu ve mekânsal kurguyu doğrudan etkilemiş; mekânların yerleşimi ve cephe oluşumu üzerinde belirleyici olmuştur. Yapının mevcut durumu incelendiğinde, mekânsal elemanların büyük ölçüde varlığını sürdürdüğü ve plan şemasının okunabilirliğini koruduğu anlaşılmaktadır. Özellikle sofa, oda ilişkileri ve mekânsal hiyerarşinin korunmuş olması, yapının geleneksel konut tipolojisi ile kurduğu ilişkinin devam ettiğini göstermektedir.

Sonuç olarak Mahir Ağa Konağı, geleneksel Safranbolu konutlarının mekânsal kurgu ve organizasyon ilkelerini günümüzde de sürdüren nitelikli bir örnektir. Yapının mekânsal

özelliklerinin okunabilirliğini koruması, geleneksel konut mimarisinde sürekliliğin yalnızca fiziksel varlıkla değil, aynı zamanda mekânsal düzenin devamlılığı ile ilişkili olduğunu ortaya koymaktadır. Bu yönüyle çalışma, tekil bir yapı üzerinden gerçekleştirilen mekânsal çözümleme ile geleneksel konut tipolojisinin anlaşılmasına katkı sunmaktadır.

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SAFRANBOLU GELENEKSEL KONUTLARINDA RESTORASYON SONRASI MEKÂNSAL VE İŞLEVSEL DEĞİŞİMLERİN DEĞERLENDİRİLMESİ

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ÖZET

Bu çalışma, Safranbolu'daki geleneksel konutlarda restorasyon süreci sonrasında ortaya çıkan mekânsal değişimleri incelemeyi amaçlamaktadır. Araştırma kapsamında seçilen örnek yapılar üzerinden, özgün ve restorasyon sonrası kat planları karşılaştırmalı olarak değerlendirilmiştir. İnceleme sürecinde özellikle zemin ve üst kat planları esas alınarak, mekânsal organizasyon, mekânlar arası ilişkiler ve işlev dağılımındaki değişimler detaylı biçimde analiz edilmiştir. Elde edilen bulgular, restorasyon uygulamalarının konutların mekânsal kurgusunda belirli ve tekrarlayan dönüşümlere yol açtığını göstermektedir. Zemin katlarda özgün durumda depo ve ahır gibi servis işlevlerine ayrılan mekânların, restorasyon sonrasında mutfak ve yaşam alanlarına dönüştürüldüğü belirlenmiştir. Bu dönüşüm, zemin katın yalnızca yardımcı işlevlere hizmet eden bir kat olmaktan çıkarak, konutun aktif kullanım alanlarından biri haline gelmesine neden olmaktadır. Üst katlarda ise sofa etrafında gelişen plan düzeninin büyük ölçüde korunduğu, ancak çağdaş yaşam ihtiyaçları doğrultusunda wc ve banyo gibi yeni mekânların eklendiği görülmektedir. Bununla birlikte, bazı yapılarda mekânsal düzenin büyük ölçüde korunarak sınırlı müdahalelerle güncel kullanıma uyarlandığı, bazı örneklerde ise daha belirgin düzenlemeler yapıldığı dikkat çekmektedir. Bu farklılık, restorasyon sürecinde tek tip bir yaklaşım yerine yapı özelinde kararların alındığını göstermektedir. Sonuç olarak, restorasyon uygulamalarının geleneksel konutların özgün mekânsal karakterini değiştirmeden, işlevsel gereksinimler doğrultusunda yeniden yorumladığı anlaşılmaktadır. Bu yaklaşım, koruma ve kullanım dengesi gözetilerek gerçekleştirilen müdahalelerin, geleneksel konutların sürekliliği ve yaşatılması açısından önemli bir rol üstlendiğini ortaya koymaktadır.

Anahtar kelimeler: Safranbolu geleneksel konutları, restorasyon, mekânsal organizasyon, mekânsal değişim, işlev değişimi

EVALUATION OF POST-RESTORATION SPATIAL AND FUNCTIONAL CHANGES IN TRADITIONAL HOUSES OF SAFRANBOLU

ABSTRACT

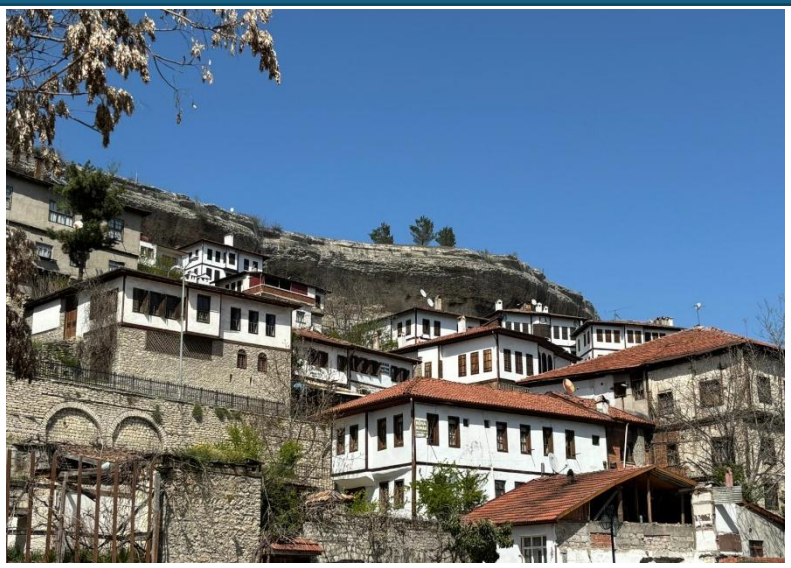
This study aims to examine the spatial changes that occur in traditional houses in Safranbolu following the restoration process. Within the scope of the research, selected sample buildings

were comparatively evaluated based on their original and post-restoration floor plans. The analysis focuses particularly on ground and upper floor layouts, investigating changes in spatial organization, spatial relationships, and functional distribution. The findings indicate that restoration interventions lead to recurring transformations in the spatial configuration of the houses. It is observed that spaces originally used for service functions such as storage and stables on the ground floors have been converted into kitchens and living-related areas after restoration. This transformation redefines the role of the ground floor, shifting it from a purely auxiliary level to an actively used part of the dwelling. On the upper floors, the plan organization structured around the sofa space has largely been preserved; however, new additions such as bathrooms and toilets have been introduced in response to contemporary living requirements. In addition, while some buildings have been adapted to current use through minimal interventions that largely preserve the original spatial layout, others have undergone more pronounced modifications. This variation suggests that restoration practices are not uniform, but rather shaped by decisions specific to each building. In conclusion, restoration interventions reinterpret traditional houses in line with functional requirements without entirely altering their original spatial character. This approach highlights the importance of balancing conservation and contemporary use, contributing to the continuity and sustainability of traditional residential architecture.

Keywords: Traditional houses of Safranbolu, restoration, spatial organization, spatial transformation, functional change

1. GİRİŞ

M.Ö. 4000'li yıllara kadar uzanan köklü bir geçmişe sahip olan Safranbolu, Hititlerden Osmanlılara kadar pek çok uygarlığın kültürel birikimini barındıran ve bu zengin dokuyu günümüze kadar korumayı başarmış istisnai bir kenttir. Kentin mekânsal kurgusu; topoğrafya ve iklimsel şartlar doğrultusunda şekillenmiştir (Evirgen, 2019; Aktüre ve Şenyapılı, 1976). Bu üçlü yapılaşma içinde yükselen Safranbolu konakları, doğaya ve komşuluk haklarına saygılı yerleşim düzeniyle "Türk evi" tipolojisinin en nitelikli örneklerini temsil etmektedir (Karabulut, 2020). 1994 yılında UNESCO tarafından "Dünya Mimari Miras Listesi"ne dahil edilen bu yapılar, yalnızca birer konut değil, aynı zamanda yüzyılların imbiğinden süzülen bir inşaat tekniğinin ve sosyal yaşamın somut göstergeleridir (Bayazıt, 2014; Safranbolu Belediye Başkanlığı, 2007) (Şekil 1).



Şekil 1. Safranbolu geleneksel konutları

Safranbolu konaklarının mimari karakterini, ahşap karkas sistem belirlemektedir. Genellikle taş duvarlı ve dışa kapalı zemin katlar üzerinde yükselen bu yapılar, üst katlarda sokağa ve manzaraya yönelen cumbaları, geniş saçaklı çatıları ve "sofa" etrafında organize edilen oda kurgusuyla öne çıkmaktadır (Günay, 1989; Atık, 2011; Eldem, 1968). Yapımında bölge ormanlarından elde edilen köknar, sarıçam ve ceviz gibi ağaç türlerinin ustalıkla kullanıldığı bu konaklar, hem estetik hem de deprem dayanımı yüksek bir yapısal bütünlük sunmaktadır (Kaya, 1996; Günay, 1998). Ancak başlangıçta tek bir geniş ailenin ihtiyaçları ve mahremiyet algısı üzerine tasarlanan bu büyük ölçekli yapılar, zaman içerisinde değişen aile yapıları ve ekonomik dönüşümler sonucunda çeşitli fiziksel müdahalelere maruz kalmıştır. Geleneksel konakların miras yoluyla bölünmesi veya birden fazla ailenin kullanımına açılması, özgün plan şemalarında dikey ve yatay bölümlenmelere, yeni sirkülasyon elemanlarının eklenmesine ve mekânsal bozulmalara yol açmıştır. 1975 "Avrupa Mimari Miras Yılı" ile başlayan koruma bilinci ve 1990'lardan itibaren uygulamaya konulan koruma amaçlı imar planları, bu yapıların restore edilerek yeniden işlevlendirilmesi sürecini hızlandırmıştır. Günümüzde pek çok tarihi konak, özgün konut işlevinden sıyrılarak müze, otel veya sosyal tesis gibi modern fonksiyonlarla kent hayatına yeniden kazandırılmaktadır (Bayazıt, 2014; Evirgen, 2019).

Bu çalışma ile, Safranbolu'daki geleneksel konutlarda restorasyon süreci sonrasında ortaya çıkan mekânsal değişimler, özgün ve güncel plan düzenleri üzerinden incelenmektedir. Bu doğrultuda, çalışma, mevcut literatürde genellikle yapı ölçeğinde ele alınan restorasyon süreçlerini, plan organizasyonu ve işlev değişimi üzerinden değerlendirmesi bakımından farklılaşmaktadır. Seçilen örnek yapılar doğrultusunda gerçekleştirilen araştırma, restorasyon

uygulamalarının mekânsal kurguya etkisini ve özellikle işlev değişimleri ile plan organizasyonunda meydana gelen dönüşümleri karşılaştırmalı olarak ortaya koymayı amaçlamaktadır. Bu kapsamda, kat planları üzerinden yapılan değerlendirmeler ile geleneksel konutların özgün mekânsal karakterinin ne ölçüde korunduğu ve çağdaş kullanım ihtiyaçlarına nasıl uyum sağladığı ele alınmaktadır.

2. YÖNTEM

Bu çalışma, Safranbolu'daki geleneksel konutlarda restorasyon süreci sonrasında ortaya çıkan mekânsal işlev değişimlerini incelemek amacıyla nitel araştırma yaklaşımı doğrultusunda kurgulanmıştır. Araştırma kapsamında seçilen örnek yapılar üzerinden karşılaştırmalı analiz yöntemi uygulanmıştır. Çalışmanın ilk aşamasında, seçilen konutlara ait özgün plan düzenleri incelenerek mekânsal organizasyon, mekânlar arası ilişkiler ve katlar arasındaki işlev dağılımı değerlendirilmiştir. Bu doğrultuda özellikle zemin ve üst kat planları esas alınarak, hayat, sofa, oda ve servis mekânlarının konumlanışı analiz edilmiştir. İkinci aşamada ise restorasyon sonrası planlar incelenmiş ve mekânsal kurguda meydana gelen değişimler belirlenmiştir. Bu süreçte, mekânların işlev değişimleri, yeniden düzenlenmesi ve yeni mekân eklenmesi gibi müdahaleler karşılaştırmalı olarak değerlendirilmiştir. Çalışmada kullanılan kat planları, Mimar Elif Hacıalioğlu'nun paylaştığı kişisel arşivinden alınan restorasyon projeleri üzerinden analiz edilmiş ve yeniden düzenlenmiştir. Elde edilen veriler, özgün ve restorasyon sonrası planların karşılaştırılması yoluyla değerlendirilmiş ve mekânsal değişimler bütüncül bir yaklaşımla ele alınmıştır.

3. BULGULAR

3.1. Yapıların Özgün Hallerinin İncelenmesi

Bu bölümde, çalışma kapsamında incelenen geleneksel konutların özgün mekânsal kurguları kat planları üzerinden ele alınmıştır. Yapılar; kat sayıları, katlar arasındaki işlevsel dağılım ve mekânlar arası ilişkiler doğrultusunda ayrı ayrı değerlendirilmiştir. Bu kapsamda, bodrum, zemin, ara kat ve üst katlarda yer alan mekânların konumlanışı ile kullanım biçimleri incelenmiş; hayat, sofa, oda ve servis mekânları arasındaki ilişkiler plan şemaları üzerinden ortaya konulmuştur. Ayrıca her yapı, sahip olduğu kat organizasyonu ve mekânsal düzeni doğrultusunda kendi içinde değerlendirilmiştir.

Bayrı Evi zemin kat planı Bayrı Evi üst kat planı

Şekil 2. Bayrı Evi'ne ait kat planları (Mimar Elif Hacıalioğlu'ndan düzenlenmiştir)

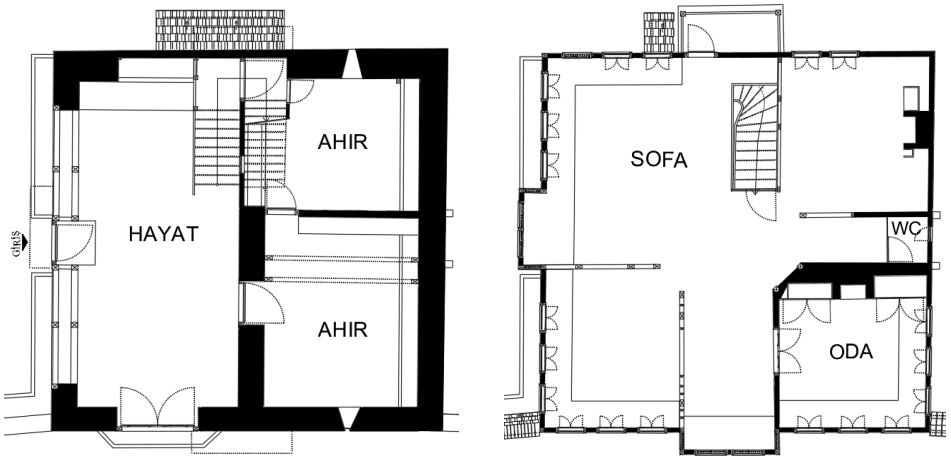
Bayrı Evi, bodrum, zemin, birinci ve ikinci kata sahip olan üç katlı bir yapı düzenine sahiptir. Alt katlarda depo ve ahır gibi servis mekânlarının yer aldığı, bu alanların daha çok üretim ve depolama amaçlı kullanıldığı anlaşılmaktadır. Üst katlara çıkıldıkça mekânsal kurgunun yaşam alanlarına yöneldiği dikkat çekmektedir. Zemin katta servis işlevlerinin belirgin olduğu, birinci katta ise odaların ortak bir dolaşım alanı etrafında konumlandığı dikkat çekmektedir (Şekil 2). Mekânlar arası bağlantı bu merkez üzerinden kurulmakta, aynı katta ıslak hacimlerin de yer aldığı anlaşılmaktadır. Yapının genelinde, alt katların daha çok servis işlevlerine ayrıldığı, üst katların ise günlük yaşama yönelik mekânları barındırdığı bir düzen hâkimdir.

Sarıhan Evi zemin kat planı Sarıhan Evi üst kat planı

Şekil 3. Sarıhan Evi'ne ait kat planları (Mimar Elif Hacıalioğlu'ndan düzenlenmiştir)

Sarıhan Evi, bodrum, zemin ve birinci katlardan oluşan iki katlı bir yerleşim sunmaktadır. Zemin katta hayat mekânı merkezde konumlanmakta ve çevresinde oda ile ahır birimleri yer almaktadır. Bu mekân, hem dolaşımın sağlandığı hem de ortak kullanımın gerçekleştiği ana alan niteliğindedir. Birinci katta sofa etrafında gelişen bir plan düzeni görülmektedir (Şekil 4). Odalar bu mekâna açılmakta ve mekânsal ilişki bu ortak alan üzerinden kurulmaktadır. Alt kattaki hayat ile üst kattaki sofa arasında işlevsel bir süreklilik bulunmakla birlikte, üst katta

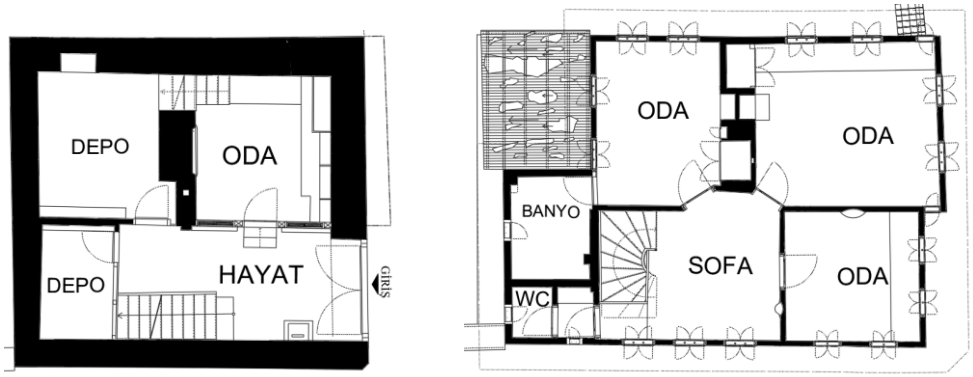
yaşam kullanımının daha belirgin hale geldiği anlaşılmaktadır. Bu yerleşim, alt katta daha açık ve servis ağırlıklı bir düzenin, üst katta ise daha içe dönük ve yaşama yönelik bir kurguya dönüştüğünü ortaya koymaktadır.



Demirezen Evi zemin kat planı Demirezen Evi üst kat planı

Şekil 4. Demirezen Evi'ne ait kat planları (Mimar Elif Hacıalioğlu'ndan düzenlenmiştir)

Demirezen Evi, zemin, birinci ve ikinci katlardan oluşmaktadır. Zemin katta hayat mekânı ile birlikte ahır birimlerinin yer aldığı ve bu katın daha çok servis işlevlerine ayrıldığı tespit edilmiştir. Hayat mekânı planın merkezinde konumlanarak diğer birimlerle doğrudan ilişki kurmaktadır. Birinci katta sofa merkezli bir düzen dikkat çekmekte, odalar bu mekânın çevresine yerleştirilmektedir (Şekil 4). Bu kat, konutun temel yaşam alanlarını barındırmaktadır. Genel yerleşim incelendiğinde, alt katların servis kullanımına, üst katların ise yaşama yönelik mekânlara ayrıldığı bir organizasyonun sürdürüldüğü anlaşılmaktadır.



Sarıtunç Evi zemin kat planı Sarıtunç Evi üst kat planı

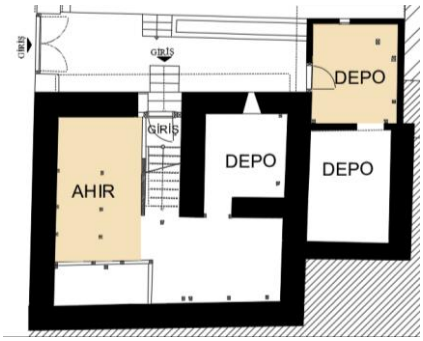
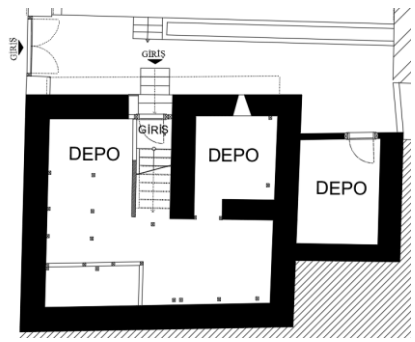
Şekil 5. Sarıtunç Evi'ne ait kat planları (Mimar Elif Hacıalioğlu'ndan düzenlenmiştir)

Sarıtunç Evi, zemin, ara kat ve birinci kattan oluşan bir plan düzenine sahiptir. Zemin katta hayat mekânı merkezde yer almakta ve bu alanın çevresinde oda ve depo birimleri konumlanmaktadır. Bu mekân, dolaşım ve ortak kullanım açısından belirleyici bir rol üstlenmektedir. Birinci katta sofa etrafında gelişen bir plan düzeni görülmekte, odalar bu mekâna açılarak daha içe dönük bir yaşam kurgusu oluşturmaktadır (Şekil 5). Ara kat ise katlar arasında bağlantıyı sağlayan bir geçiş düzlemi niteliğindedir. Yapı bütününde, farklı kotlarda devam eden mekânsal ilişkiler ve kademeli geçişler dikkat çekmekte; hayat ve sofa mekânları arasındaki süreklilik farklı seviyelerde sürdürülmektedir.

3.2. Mekânsal ve İşlevsel Değişimlerin Karşılaştırılması

Özgün ve restorasyon sonrası kat planları birlikte değerlendirildiğinde, mekânsal düzenin çeşitli müdahaleler aracılığıyla yeniden ele alındığı görülmektedir. Bu müdahaleler, işlev değişimi, mekânsal yeniden düzenleme ve yeni mekân eklenmesi doğrultusunda ortaya çıkmakta; ancak bu değişimlerin her yapı ve kat düzleminde farklı yoğunlukta gerçekleştiği anlaşılmaktadır. Bu kapsamda, konutların restorasyon öncesindeki zemin kat planlarında değişimin olduğu mekânların renklendirilmesi ile birlikte restorasyon sonrası planlara ait örnekler Tablo 1 ‘de sunulmaktadır.

Tablo 1. Zemin kat planlarının karşılaştırılması (Mimar Elif Hacıalioğlu’ndan düzenlenmiştir)

<table>
<tr><td> 
</td><td> 
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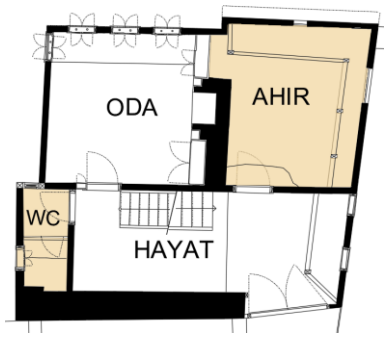
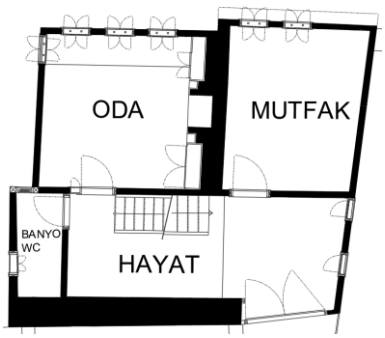
<tr><td> 
</td><td> 
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<tr><td>Sarıhan Evi restorasyon öncesi zemin kat planı</td><td>Sarıhan Evi restorasyon sonrası zemin kat planı</td></tr>
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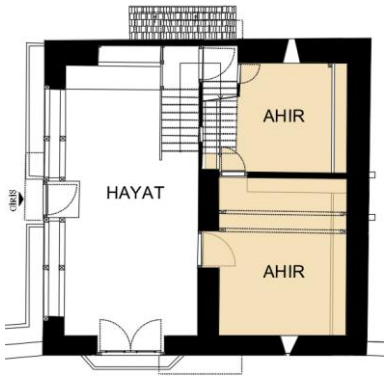
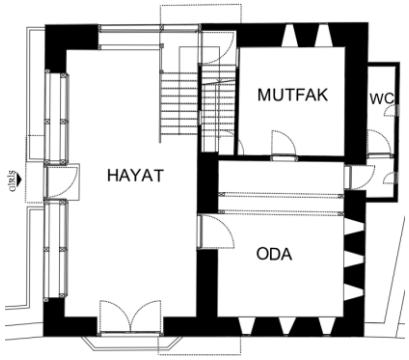
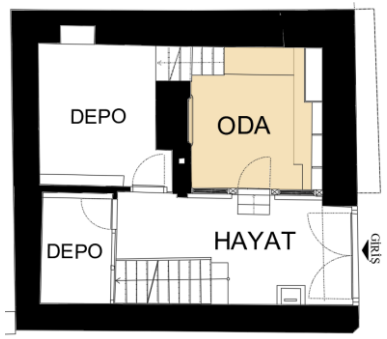
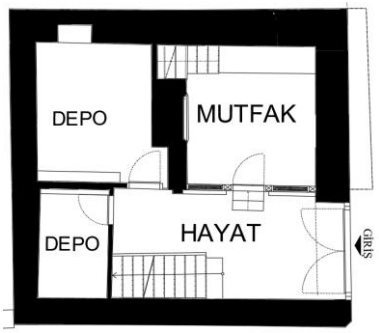
	
Demirezen Evi restorasyon öncesi zemin kat planı	Demirezen Evi restorasyon sonrası zemin kat planı
	
Sarıtunç Evi restorasyon öncesi zemin kat planı	Sarıtunç Evi restorasyon sonrası zemin kat planı

Restorasyon sonrası planlar işlev değişimi açısından incelendiğinde, en belirgin dönüşümün zemin katlarda gerçekleştiği görülmektedir. Özgün planda depo ve ahır gibi servis işlevlerine ayrılan mekânların, restorasyon sonrasında mutfak ve gündelik kullanıma yönelik alanlara dönüştürüldüğü dikkat çekmektedir. Bu dönüşüm yalnızca mekânın işlevini değiştirmekle kalmamakta, aynı zamanda zemin katın yapı içerisindeki rolünü de yeniden tanımlamaktadır. Başlangıçta daha çok servis ve üretim faaliyetlerine ayrılan bu kat, restorasyon sonrasında yaşamla doğrudan ilişki kuran bir mekâna dönüşmektedir. Bu durum, katlar arasındaki işlevsel ayrımın kısmen esnemesine ve kullanımın daha bütüncül bir hale gelmesine yol açmaktadır. Bununla birlikte, bazı planlarda hayat mekânının korunarak yeni işlevlerle birlikte kullanılmaya devam ettiği ve bu sayede özgün dolaşım kurgusunun tamamen ortadan kaldırılmadığı dikkat çekmektedir. Ayrıca, kullanım ihtiyacına bağlı olarak özgün plan kurgusuna uymayan mekanların restorasyon sürecinde kaldırıldığı da görülmektedir.

Mekânsal yeniden düzenlemeler incelendiğinde, müdahalelerin çoğunlukla mevcut plan şemasını bütünüyle değiştirmek yerine, mevcut mekânların yeniden organize edilmesi şeklinde gerçekleştiği anlaşılmaktadır. Özellikle oda mekânlarında yapılan bölünmeler, mekânların daha küçük ve işlevsel birimlere ayrılarak kullanım çeşitliliğinin artırılmasına olanak sağlamaktadır.

Bu tür düzenlemeler, özgün plan kurgusunun ana karakterini korurken, mekânların çağdaş kullanım ihtiyaçlarına uyarlanmasını mümkün kılmaktadır. Bununla birlikte, bazı yapılarda mekânsal düzenin büyük ölçüde korunarak daha sınırlı müdahalelerle güncel kullanıma uyarlandığı, bazı örneklerde ise bölünmelerin daha belirgin olduğu ve plan organizasyonunun daha parçalı bir hale geldiği gözlemlenmektedir. Bu farklılık, müdahale düzeyinin yapıdan yapıya değiştiğini ortaya koymaktadır.

Yeni mekân eklenmesi kapsamında değerlendirildiğinde, üst katlarda wc ve banyo gibi ıslak hacimlerin planlara dahil edilmesi en belirgin müdahalelerden biri olarak öne çıkmaktadır. Özgün plan şemasında yer almayan bu mekânların eklenmesi, özellikle sofa etrafında gelişen mekânsal organizasyon üzerinde doğrudan etkili olmaktadır. Sofa mekânı genel olarak korunmakla birlikte, bu alana eklemlenen yeni birimler mekânsal bütünlüğü kısmen dönüştürmekte ve dolaşım ilişkilerinde yeniden düzenlemelere yol açmaktadır. Bazı planlarda bu eklemelerin sofa alanından pay alınarak gerçekleştirildiği, bazı durumlarda ise odalarla ilişkilendirilerek çözümlendiği görülmektedir. Bu durum, müdahale biçimlerinin tek tip olmadığını ve plan kurgusuna göre farklı çözümler üretildiğini göstermektedir (Tablo 2).

Tablo 2. Üst kat planlarının karşılaştırılması (Mimar Elif Hacıalioğlu'ndan düzenlenmiştir)

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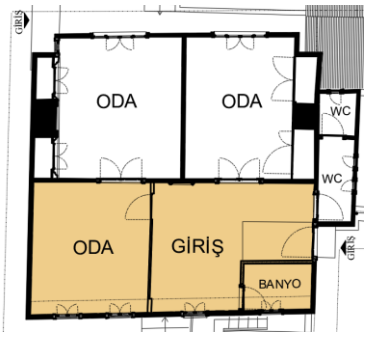
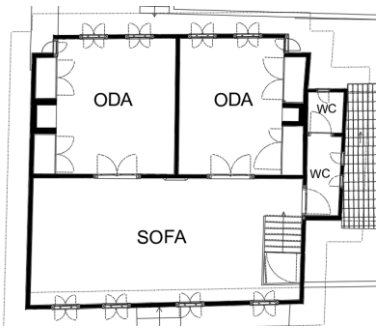
<tr><td> 
</td><td> 
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<tr><td>Bayrı Evi restorasyon öncesi üst kat planı</td><td>Bayrı Evi restorasyon sonrası üst kat planı</td></tr>
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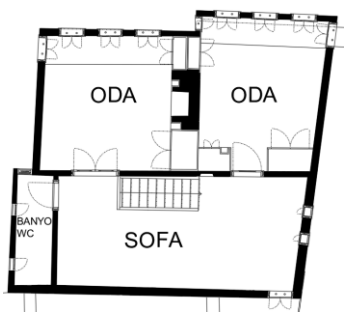
</td><td> 
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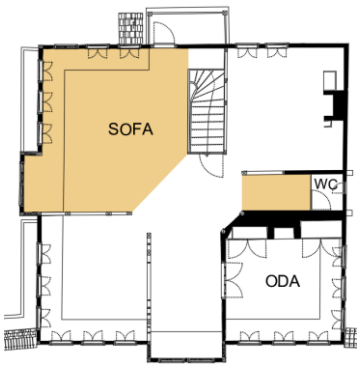
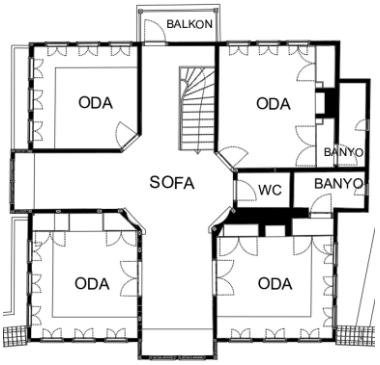
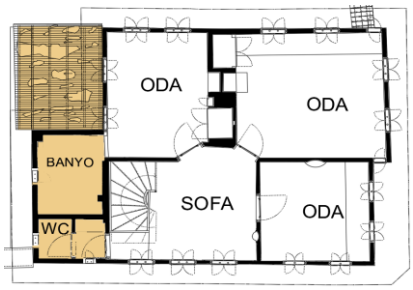
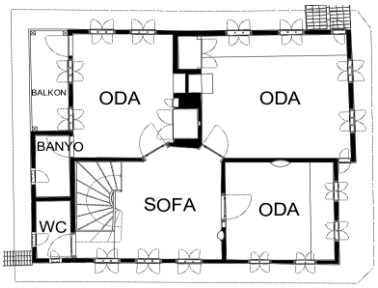
	
Demirezen Evi restorasyon öncesi üst kat planı	Demirezen Evi restorasyon sonrası üst kat planı
	
Sarıtunç Evi restorasyon öncesi üst kat planı	Sarıtunç Evi restorasyon sonrası üst kat planı

Üst katlar genel olarak değerlendirildiğinde, özgün plan şemasının korunmasına yönelik bir yaklaşımın benimsendiği, ancak bu şemanın yeni kullanım ihtiyaçlarına uyum sağlayacak şekilde yeniden yorumlandığı anlaşılmaktadır. Sofa etrafında gelişen mekânsal organizasyonun sürekliliği korunurken, eklenen ıslak hacimler ve yeniden düzenlenen oda kullanımları, mekânsal ilişkilerin tamamen değişmesine neden olmadan güncellenmesine imkân tanımaktadır. Bu durum, müdahalelerin tamamen dönüştürücü değil, daha çok uyarlayıcı bir karakter taşıdığını göstermektedir. Bunun yanı sıra, bazı örneklerde çıkma ve balkon mekânlarının kullanımında da değişiklikler olduğu anlaşılmaktadır. Özgün planda dışa taşkın olarak kurgulanan bu mekânların, restorasyon sonrasında iç mekânla daha bütünleşik bir kullanıma dönüştüğü anlaşılmaktadır. Bazı durumlarda bu alanların oda kullanımına dahil edildiği, bazı örneklerde ise mekânsal sürekliliği artıracak şekilde yeniden düzenlendiği görülmektedir. Bu tür müdahaleler, yalnızca mekânsal işlev değişimi ile sınırlı kalmayıp, aynı zamanda iç-dış mekân ilişkisini ve plan sınırlarını da etkilemektedir. Çıkma mekânlarının yeniden ele alınması, geleneksel konutlarda mekânsal genişleme ve kullanım esnekliği açısından önemli bir dönüşüm olarak değerlendirilebilir.

Bununla birlikte, restorasyon sürecinde yapıya sonradan eklenen mekânların özgün plan kurgusuna uygun biçimde yeniden düzenlenmesi ya da kaldırılarak yapının ilk mekânsal

düzenine yaklaştırılması da dikkat çekmektedir. Bu tür müdahaleler, yalnızca tekil yapılar ölçeğinde değil, Safranbolu geleneksel konutlarının özgün mekânsal karakterinin korunması açısından da önem taşımaktadır. Özellikle zaman içinde oluşan eklemelerin geri alınması, plan bütünlüğünün yeniden sağlanmasına katkı sunmakta ve yapının özgün mimari kimliğinin daha okunabilir hale gelmesini mümkün kılmaktadır.

Buna göre, restorasyon sürecinde zemin katlarda daha belirgin ve dönüştürücü müdahalelerin gerçekleştirildiği, üst katlarda ise daha kontrollü ve sınırlı müdahalelerin tercih edilmiştir. Zemin katlarda işlev değişimi ön plana çıkarken, üst katlarda mekânsal organizasyonun korunarak yeni ihtiyaçlara göre düzenlemeler yapılmıştır. Bu farklılaşma, geleneksel konutlardaki özgün katlar arası işlev dağılımının ortadan kaldırılmadığını, güncel kullanım gereksinimleri doğrultusunda yeniden yorumlandığını ortaya koymaktadır.

3.3. Genel Değerlendirme

Elde edilen bulgular, restorasyon uygulamalarının geleneksel konutların özgün mekânsal kurgusunu tamamen ortadan kaldırmaktan ziyade, mevcut düzeni güncel kullanım ihtiyaçlarına uyarlama yönünde şekillendiğini göstermektedir. Özellikle zemin katlarda gerçekleştirilen işlev değişimleri, konutun kullanım biçimini doğrudan etkileyen müdahaleler olarak öne çıkmaktadır. Servis mekânlarının yaşamla ilişkili alanlara dönüştürülmesi ile daha bütüncül bir kullanım sağlanmaktadır.

Buna karşılık, üst katlarda müdahaleler daha sınırlı tutulmuş ve özgün plan şemasının korunmasına dikkat edilmiştir. Sofa etrafında gelişen mekânsal organizasyonun büyük ölçüde devam ettirilmesi ile geleneksel konut tipolojisinin temel özellikleri sürdürülmektedir. Ancak bu mekânlara eklenen ıslak hacimler, özellikle dolaşım ilişkileri ve mekânsal bütünlük üzerinde belirli etkiler oluşturmaktadır. Ayrıca, mekânsal düzenlemelerin yapıdan yapıya farklılık göstermesi, restorasyon sürecinde tek tip bir yaklaşımın benimsenmediğini, aksine her yapının kendi mekânsal özellikleri doğrultusunda ele alındığını göstermektedir. Bu durum, müdahalelerin hem koruma hem de kullanım dengesi gözetilerek gerçekleştirildiğine işaret etmektedir. Bu dönüşümlerin, koruma ve kullanım dengesini gözeten bir yaklaşımla ele alınması, geleneksel konut tipolojisinin sürdürülebilirliği açısından önemli bir potansiyel sunmakta olup, geleneksel konutların yalnızca korunması değil, yaşatılarak sürdürülebilir kılınması gerektiğini ortaya koymaktadır.

4. SONUÇ

Bu çalışma kapsamında incelenen Safranbolu geleneksel konutlarında, restorasyon süreci sonrasında mekânsal işlev değişimlerinin belirli eğilimler doğrultusunda gerçekleştiği görülmüştür. Özellikle zemin katlarda servis işlevine sahip mekânların mutfak ve yaşam

alanlarına dönüştürülmesi, en belirgin dönüşüm olarak öne çıkmaktadır. Bu değişim, konutun kullanım kurgusunu yeniden tanımlayan temel müdahalelerden biridir. Üst katlarda ise özgün plan şemasını büyük ölçüde korunmuş, ancak kullanım ihtiyaçlarına bağlı olarak ıslak hacim gibi yeni mekânlar eklenmiştir. Bu eklemeler, mekânsal organizasyonu tamamen değiştirmemekle birlikte, plan kurgusunun yeniden yorumlanmasına neden olmaktadır.

Genel olarak değerlendirildiğinde, restorasyon uygulamalarının geleneksel konutların özgün mekânsal karakterini ortadan kaldırmadan, çağdaş yaşam ihtiyaçlarına uyum sağlayacak şekilde yeniden düzenlendiği anlaşılmaktadır. Bu süreçte, koruma ve kullanım dengesi gözetilerek gerçekleştirilen müdahaleler, geleneksel konutların sürdürülebilirliğine katkı sağlamaktadır.

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TURİSTİK BİR KENTSEL AKS ÜZERİNDE ÇIKMALARIN SOKAK SİLÜETİNE ETKİSİ: HACI MÜNİRBEY SOKAĞI ÖRNEĞİ (TOKAT)

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ÖZET

Geleneksel konutlar, bulundukları toplumun yaşam biçimini, kültürel birikimini ve mekânsal alışkanlıklarını yansıtan önemli mimari oluşumlardır. Bu yapılar, yalnızca barınma ihtiyacını karşılayan fiziksel birimler olmanın ötesinde, kentsel kimliğin oluşumunda belirleyici rol oynayan unsurlar arasında yer almaktadır. Ancak hızlı kentleşme, fiziksel yıpranma ve işlev değişimleri gibi nedenlerle bu yapıların özgün nitelikleri zamanla değişime uğramakta ya da yok olma riski ile karşı karşıya kalmaktadır. Bu durum, geleneksel konut dokusunun belgelenmesini ve mimari özelliklerinin sistematik biçimde incelenmesini önemli hale getirmektedir. Tokat kentinde yer alan geleneksel konutlar, Anadolu konut kültürünün yerel ölçekteki yansımalarını göstermesi bakımından dikkat çekmektedir. Bu konutlarda sokak cephesini tanımlayan en önemli mimari elemanlardan biri olan çıkmalar, hem mekânsal kullanım hem de kentsel silüet açısından belirleyici bir rol üstlenmektedir. Farklı biçimsel özellikler gösteren bu elemanlar, sokak dokusunun algılanışını doğrudan etkileyen unsurlar arasında yer almaktadır. Bu çalışma, Tokat kent merkezinde yer alan, geleneksel konut dokusu ile daha yakın dönem yapılaşmaların bir arada gözlemlenebildiği ve turistik hareketliliğin yoğun olduğu Hacı Münirbey Sokağı üzerindeki geleneksel konutlarda bulunan çıkma elemanlarını tipolojik açıdan ele almayı ve bu elemanların sokak silüeti üzerindeki etkilerini değerlendirmeyi amaçlamaktadır. Bu doğrultuda saha gözlemleri ve fotoğraf temelli incelemeler gerçekleştirilmiş; elde edilen veriler belirli ölçütler çerçevesinde sınıflandırılarak değerlendirilmiştir. Bu çalışmanın, Hacı Münirbey Sokağı örneğinde çıkma elemanlarının tipolojik özellikleri ile sokak silüeti arasındaki ilişkinin daha açık biçimde ortaya konulmasına katkı sağlaması hedeflenmektedir.

Anahtar kelimeler: Geleneksel konut mimarisi, Tokat geleneksel konutları, çıkma, tipolojik analiz, sokak silüeti

THE IMPACT OF PROJECTIONS ON STREET SILHOUETTE ALONG A TOURISTIC URBAN AXIS: THE CASE OF HACI MUNIRBEY STREET (TOKAT)

ABSTRACT

Traditional houses are significant architectural entities that reflect the lifestyle, cultural accumulation, and spatial practices of the societies in which they exist. Beyond serving as physical structures that meet basic shelter needs, these buildings play a defining role in the formation of urban identity. However, factors such as rapid urbanization, physical deterioration, and functional transformations have led to changes in their original characteristics or even their gradual disappearance. This situation highlights the importance of documenting traditional residential fabrics and systematically examining their architectural features. Traditional houses in Tokat represent notable examples reflecting local interpretations of Anatolian housing culture. Among the architectural elements defining the street façade of these houses, projections stand out as one of the most distinctive features, playing a significant role in both spatial use and the formation of the urban silhouette. With their varying forms, these elements directly influence the perception of the street environment. This study aims to examine the projections found in traditional houses located on Hacı Münirbey Street, situated in the city center of Tokat, where traditional residential fabric and more recent urban developments coexist and where touristic activity is intense. The study evaluates these elements from a typological perspective and investigates their effects on the street silhouette. Field observations and photograph-based analyses were conducted, and the collected data were classified and evaluated according to specific criteria. The study is expected to contribute to a clearer understanding of the relationship between the typological characteristics of projections and the street silhouette in the case of Hacı Münirbey Street.

Keywords: Traditional residential architecture, Traditional houses in Tokat, projections, typological analysis, street silhouette

1. GİRİŞ

Konut kavramı, insanın temel gereksinimlerinden biri olan barınma ihtiyacına karşılık gelmekle birlikte, zamanla kültürel, sosyal ve ekonomik koşulların etkisiyle biçimlenen bir mimari üretim alanı olarak gelişmiştir. Bu yönüyle konutlar, yalnızca fiziksel bir barınma mekânı değil, aynı zamanda toplumların yaşam biçimlerini, değerlerini ve kültürel birikimlerini yansıtan önemli mekânsal oluşumlardır. Kentlerin fiziksel özellikleri ile toplumsal yapılarının birlikte değerlendirilmesi, kentsel kimliğin oluşumuna etki eden temel dinamiklerin anlaşılmasını mümkün kılmaktadır (Paç ve Binan, 2019). Geleneksel konutlar, bulundukları coğrafyanın iklimsel koşulları, topografyası, malzeme olanakları ve toplumsal yapısı doğrultusunda

şekillenmektedir. Anadolu'da farklı bölgelerde çeşitlilik gösteren bu konutlar, "Türk evi" olarak tanımlanan ortak bir anlayış çerçevesinde içe dönük plan kurgusu ve mekânsal organizasyon özelliklerini paylaşmaktadır (Akın ve Hanoğlu, 2013). Bu durum, yerel farklılıklara rağmen belirli bir mimari sürekliliğin varlığını ortaya koymaktadır.

Tokat kentinde yer alan geleneksel konutlar, söz konusu genel özelliklerin yerel koşullar çerçevesinde yorumlandığı özgün örnekler arasında yer almaktadır. Ahşap karkas ve hımış yapım teknikleri ile inşa edilen bu yapılar, taş temel üzerine oturan ve dolgu malzemelerle tamamlanan bir sistemden oluşmaktadır. Bağdadi tekniğinin özellikle bölücü elemanlarda ve çıkmalarda kullanılması, bu yapıların karakteristik özelliklerinden biri olarak öne çıkarken, tavan ve döşemelerde ahşap malzeme tercih edilmiştir. Genellikle zemin, ara kat ve üst kattan oluşan bu konutlar, yalın plan düzenlerine rağmen mekânsal açıdan zengin çözümler sunmaktadır (Akın ve Özen, 2010; Uzun ve Talu, 2019). Tokat evlerinde çıkmalar, sokak cephesini tanımlayan en belirgin ve karakteristik mimari elemanlar arasında yer almakta ve önemli bir biçimsel çeşitlilik göstermektedir (Akın ve Özen, 2010). Çıkmaların giriş üstünde, girişin iki yanında ya da cephe boyunca serbest biçimde konumlanabildiği; çoğunlukla sokak cephesinde yer alarak manzara ile ilişki kurma ve iç mekânı genişletme gibi işlevler üstlendiği görülmektedir. Bu özellikleriyle çıkmalar, yalnızca yapıya ait bir eleman olmanın ötesinde, sokak boyunca farklı perspektifler oluşturarak kentsel mekânın algılanışını ve silüetini doğrudan etkileyen bir bileşen haline gelmektedir (Akın ve Özen, 2010; Uzun ve Talu, 2019).

Tokat'taki geleneksel konutların önemli bir bölümü, kullanılan malzemenin doğası ve deprem, sel, yangın gibi afetlerin etkisiyle günümüze sınırlı sayıda ulaşabilmiş olup, mevcut örnekler çoğunlukla 19. yüzyıl ortaları ile 20. yüzyıl başlarına tarihlendirilmektedir (Akın, 2025; Kalkan vd., 2019). Bu durum, mevcut yapıların belgelenmesi ve incelenmesini daha da önemli hale getirmektedir. Kentte anıtsal yapıların yanı sıra çok sayıda sivil mimarlık örneğinin bulunması ve geleneksel konut dokusunun belirli sokaklarda yoğunlaşması, bu alanların kentsel bellek açısından önemini artırmaktadır (Akçay, 2013).

Türk evinde çıkmaların, iç mekân düzenini korumaya yönelik bir çözüm olarak ortaya çıktığı ve arsa kaynaklı düzensizliklerin bu elemanlar aracılığıyla giderildiği bilinmektedir (Eldem, 1954). Zaman içerisinde bu işlevsel çözümün, cephe kompozisyonunu zenginleştiren ve sokak silüetini doğrudan etkileyen önemli bir mimari bileşene dönüştüğü görülmektedir. Bu yönüyle çıkmalar, yalnızca yapıya ait bir eleman değil, aynı zamanda sokak ölçeğinde mekânsal algıyı şekillendiren bir unsur olarak değerlendirilmektedir.

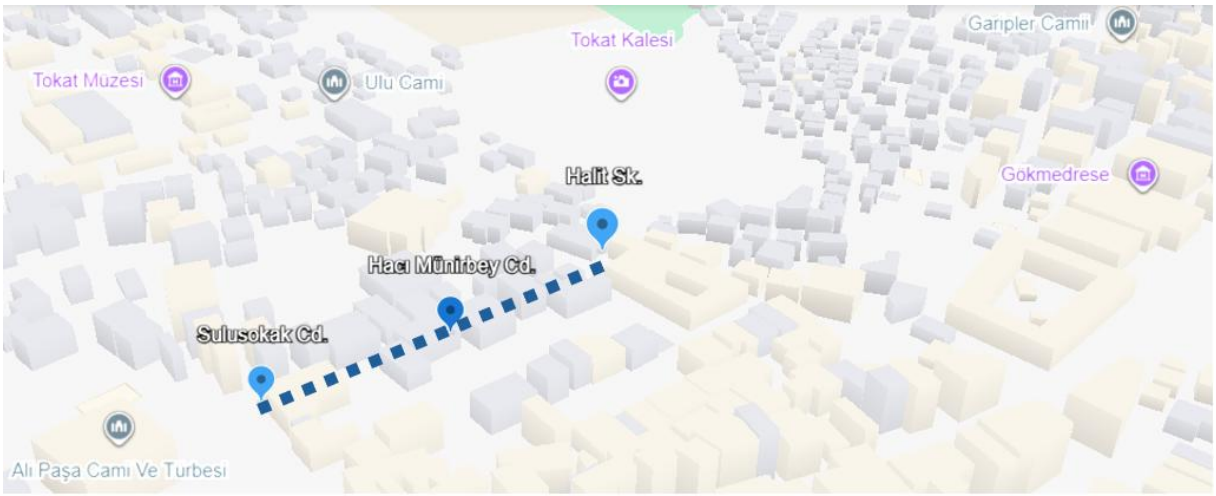
Bu tür mimari öğelerin belgelenmesi ve analiz edilmesinde fotoğraf temelli yaklaşımlar önemli bir araç sunmaktadır. Fotoğraf aracılığıyla elde edilen veriler, yapıların yalnızca fiziksel

özelliklerinin kaydedilmesini değil, aynı zamanda mimari öğelerin tipolojik olarak değerlendirilmesini mümkün kılmaktadır. Bu durum, özellikle dönüşüm sürecindeki geleneksel konut dokusunun anlaşılması ve korunması açısından önemli katkılar sağlamaktadır (Srivastava ve Naaz, 2024; Ayyıldız ve Özbayraktar, 2018).

Bu bağlamda, Tokat kent merkezinde yer alan Hacı Münirbey Sokağı, geleneksel konut dokusunun sürekliliğini ve değişimini birlikte gözlemleme imkânı sunan, turistik hareketliliğin yoğun olduğu ve geleneksel konut dokusunun izlerini barındıran önemli bir kentsel aks niteliğindedir. Sokakta gerçekleştirilen sağlıklaştırma ve cephe iyileştirme uygulamalarının da bu dokunun günümüzde daha okunur hale gelmesine katkı sağladığı söylenebilir. Bu çalışma, Hacı Münirbey Sokağı üzerindeki geleneksel konutlarda bulunan çıkma elemanlarının tipolojik özellikleri çerçevesinde, sokak silüeti üzerindeki etkilerini değerlendirmeyi amaçlamaktadır.

2. YÖNTEM

Bu çalışmanın materyalini, Tokat kent merkezinde Kabe-i Mescid Mahallesi'nde bulunan Hacı Münirbey Sokağı ile bu sokak üzerinde yer alan geleneksel konut örnekleri oluşturmaktadır. Çalışma alanı, Sulusokak ile Halit Sokak arasında uzanan ve Ali Paşa Camii'ne erişim sağlayan bir kentsel aks üzerinde yer almakta olup, turistik hareketliliğin yoğun olduğu ve kentin önemli ziyaret noktalarına yakın konumuyla öne çıkan bir güzergâh niteliğindedir. Aynı zamanda geleneksel konut dokusuna ait farklı örnekleri bir arada barındırması, alanın araştırma kapsamında değerlendirilmesini anlamlı kılmaktadır (Şekil 1).



Şekil 1. Hacı Münirbey Sokağı'nın Tokat kent merkezi içerisindeki konumu ve turistik odaklara yakınlığı (Google Earth (2026)'ten düzenlenmiştir)

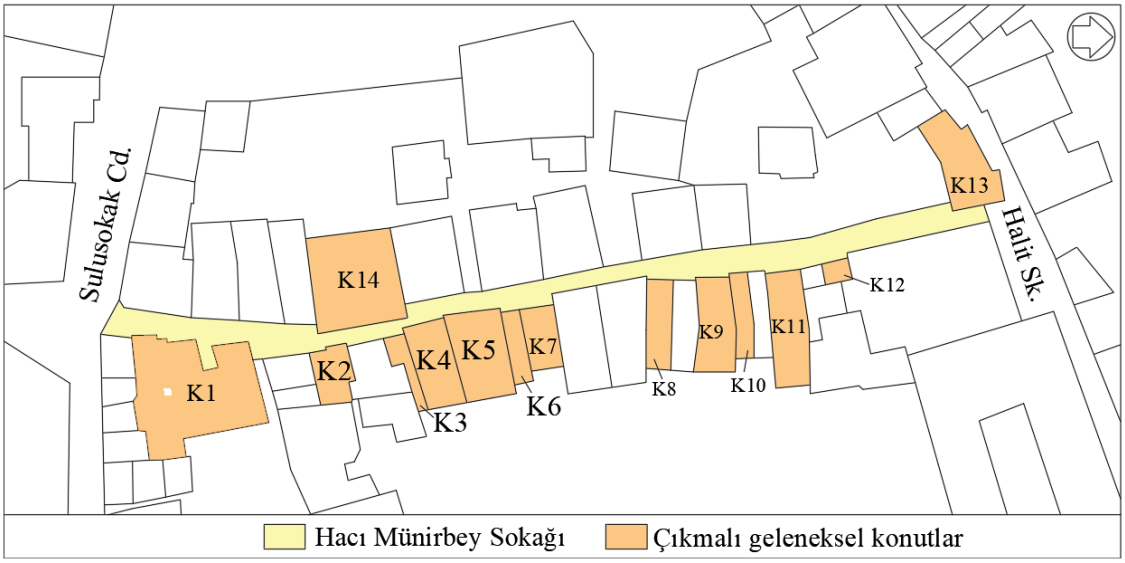
Araştırma sürecinde, sokak üzerindeki yapılar yerinde yapılan saha çalışmaları ile tespit edilmiş; çıkma elemanına sahip konutlar belirlenerek her biri referans numaraları ile kodlanmıştır. Çalışmada veri toplama süreci, yerinde gözlem ve fotoğraf temelli kayıt

yöntemine dayanmaktadır. Yapıların yalnızca dış cepheleri incelenmiş; çıkma elemanlarının geometrik formu, cephe üzerindeki konumu ve taşıyıcı sistem özellikleri şeklindeki fiziksel nitelikleri değerlendirilmiştir. Elde edilen veriler, tipolojik sınıflandırma yöntemi çerçevesinde analiz edilmiştir.

Tipolojik sınıflandırma sürecinde, Sedad Hakkı Eldem'in cephe organizasyonuna yönelik yaklaşımları (1954), Kuban'ın (1995) yapısal değerlendirmeleri, Emine Saka Akın'ın (2010) Tokat geleneksel konut dokusu üzerine gerçekleştirdiği morfolojik analizler ile Günay'ın (1981) geleneksel ahşap yapı teknikleri ve çıkma detaylarına ilişkin terminolojik ve görsel analiz kriterleri birlikte ele alınarak değerlendirme ölçütleri oluşturulmuştur. Analiz sürecinde, elde edilen tipolojik veriler karşılaştırmalı olarak incelenmiş ve çıkma elemanlarının sokak silüeti üzerindeki etkileri, mekânsal süreklilik, cephe hareketliliği ve görsel algı bağlamında yorumlanmıştır. Ayrıca sokak üzerindeki yapıların bitişik ve ayrık nizamda bulunması, farklı çıkma tiplerinin sokak ölçeğinde oluşturduğu etkilerin birlikte değerlendirilmesine imkân tanımıştır.

3. BULGULAR

Hacı Münirbey Sokağı üzerinde gerçekleştirilen saha çalışmaları sonucunda, incelenen yapıların 14'ünde çıkma elemanının bulunduğu tespit edilmiş ve bu yapılar çalışma kapsamında referans kodları (K1-K14) ile tanımlanmıştır. Çalışma alanına ait genel yerleşim düzeni ve çıkmalı konutların sokak üzerindeki dağılımı Şekil 2'de gösterilmekte olup, incelenen tüm yapılara ait fotoğraflar Ek Tablo 1'de sunulmuştur.



Şekil 2. Hacı Münirbey Sokağı üzerindeki yer alan çıkmalı yapıların belirlenmesi (Google Earth (2026)'ten düzenlenmiştir)

Buna göre, çıkmalı yapıların sokak boyunca süreklilik gösterdiği ve belirli kesimlerde yoğunlaştığı görülmektedir. Bununla birlikte, sokak üzerindeki yapılaşma düzeninde belirgin bir farklılaşma dikkat çekmektedir. Sulusokak Caddesi'nden Halit Sokak yönüne doğru ilerlenirken, sağ tarafta geleneksel konut örneklerinin yoğunlaştığı; sol tarafta ise çağdaş yapıların daha baskın olduğu, bununla birlikte geleneksel örneklerin de yer aldığı gözlemlenmiştir (Şekil 3).

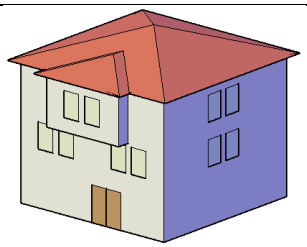
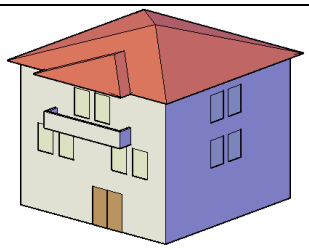
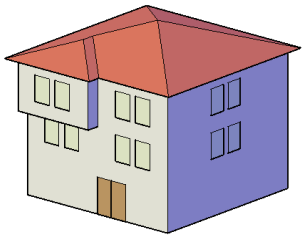
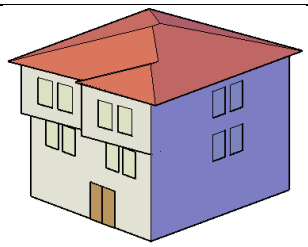
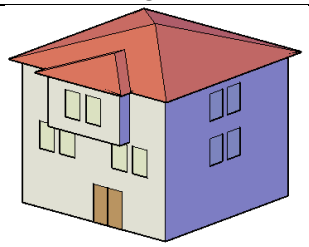
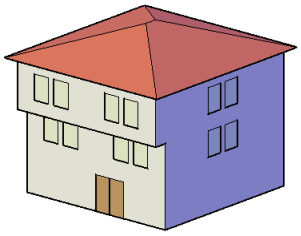
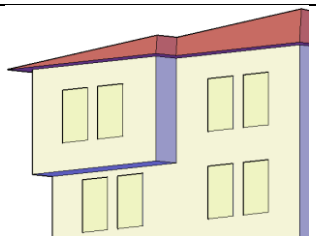
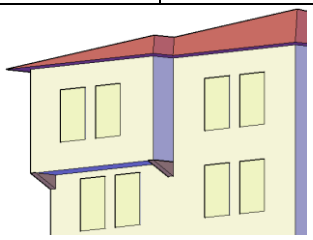
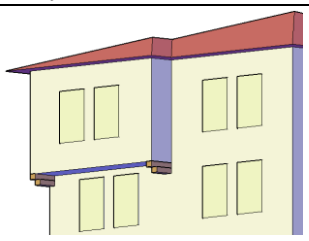
Şekil 3. Hacı Münirbey Sokağı görünümleri (Yazar arşivi)

Bununla birlikte, sol tarafta yer alan yapılardan birinin yıkılma tehlikesi nedeniyle günümüze ulaşamamış olması, sokak bütünlüğünde yerel bir kesinti oluşturmuştur. Genel olarak sağ cephede yapıların daha yoğun ve süreklilik gösteren bir bitişik nizam oluşturduğu; sol cephede ise bitişik nizam korunmakla birlikte yapıların daha seyrek yerleştiği gözlemlenirken, sokak silüetinde bir tarafta daha dolu ve süreklilik arz eden bir cephe etkisi, diğer tarafta ise aralıklı ve daha geçirgen bir yapı düzeni oluşmuştur.

3.1 Tipolojik Dağılım

Araştırma kapsamında yürütülen saha çalışmaları ve yerinde gözlemler doğrultusunda çalışma alanında bulunan çıkma türleri belirlenmiştir. Çalışma alanında tespit edilen çıkma tiplerinin biçimsel özelliklerine ilişkin değerlendirmenin daha anlaşılır hale getirilmesi amacıyla, referans alınan tipolojik sınıflandırma parametreleri esas alınarak hazırlanan üç boyutlu şematik çizimler Tablo 1'de sunulmuştur.

Tablo 1. Hacı Münirbey Sokağı üzerindeki çıkma türlerine yönelik üç boyutlu şematik çizimler

Kapalılık durumu		
	Kapalı çıkma (cumba)	Açık çıkma
Form		
	Dikdörtgen çıkma	Gönye çıkma
Konum		
	Orta aksta çıkma	Cephe boyunca çıkma
Taşıyıcı sistem		 
	Konsol çıkma	Payandalı çıkma / Bindirmeli çıkma

Bu çerçevede çıkmalar; kapalılık durumu, geometrik özellikleri, taşıyıcı sistem biçimi, cephe üzerindeki konumlanışı ve katlar arasındaki süreklilik durumuna göre ele alınmıştır. Belirlenen tipolojik özellikler kendi içerisinde gruplandırılmış olup, Tablo 2'de karşılaştırmalı bir şekilde verilmiştir.

Tablo 2. Hacı Münirbey Sokağı üzerindeki çıkmalı konutların tipolojik özellikleri

Ref. Kodu	Kapalılık Durumu	Form	Taşıyıcı Sistem	Konum
K1	Kapalı çıkma	Gönye	Bindirme	Tüm cephe
K2	Açık çıkma	Dikdörtgen	Bindirme	Orta aks
K3	Açık çıkma	Dikdörtgen	Payanda	Tüm cephe

K4	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe
K5	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe
K6	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe
K7	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe
K8	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe
K9	Kapalı çıkma	Dikdörtgen	Bindirme	Orta aks
K10	Kapalı çıkma	Dikdörtgen	Bindirme	Orta aks
K11	Kapalı çıkma	Dikdörtgen	Bindirme	Orta aks
K12	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe
K13	Kapalı çıkma	Dikdörtgen	Konsol	Tüm cephe
K14	Kapalı çıkma	Dikdörtgen	Bindirme	Tüm cephe

Hacı Münirbey Sokağı'ndaki konutlar incelendiğinde, çıkmaların kapalılık durumları, formları, taşıyıcı sistemleri ve cephe üzerindeki konumları açısından çeşitlilik görülmektedir. Bu bağlamda, sokakta bulunan çıkmaların tipolojik özelliklerini temsil eden yapı örnekleri Şekil 4'te verilmiştir.

K1 K3 K6 K13

Şekil 4. Hacı Münirbey Sokağı'nda farklı çıkma tiplerine ait örnekler (Yazar arşivi)

Elde edilen veriler doğrultusunda, çıkmalar genellikle kapalı çıkma (cumba) şeklinde inşa edilmiştir. Açık çıkma örneklerinin az sayıda olması, sokak dokusunda daha bütüncül ve süreklilik gösteren bir cephe karakterinin oluşmasına katkı sağlamıştır. Geometrik form bakımından, çıkmaların büyük kısmının dikdörtgen biçimde tasarlanırken, yalnızca tek bir

örnekte gönye formu bulunup, sokak boyunca cephelerde belirgin bir biçimsel süreklilik ortaya çıkmıştır. Taşıyıcı sistemler açısından değerlendirildiğinde, bindirmeli çıkma kullanımının ön planda olduğu; buna karşılık konsol ve payanda tekniklerinin sınırlı sayıdaki örnekte tercih edildiği görülmektedir. Bindirmeli çıkma çözümlerin yaygınlığı, geleneksel yapım anlayışının sokakta güçlü bir şekilde varlığını sürdürdüğünü göstermektedir. Çıkmaların cephe üzerindeki yerleşimi incelendiğinde, çoğunlukla tüm cephe boyunca devam eden örnekler ağırlıkta olup, orta aksa yerleşen çıkmalar daha sınırlı kalmıştır. Yapıların üst katlarının alt kata göre genişletilmesine dayanan geleneksel mekânsal yaklaşım sokak ölçeğinde de belirleyici olmuştur. Kat sürekliliği açısından tüm örnekler tek katla sınırlı iken, cephelerde dikey bir vurgudan çok yatay bir etki oluşmuştur.

3.2 Sokak Silüeti Analizi

Sokak silüeti, yapıların yükseklikleri, cephe sürekliliği, doluluk-boşluk oranı ve çıkma elemanlarının oluşturduğu yatay hatlar üzerinden okunabilmektedir. Hacı Münirbey Sokağı'nda yer alan çıkma elemanları, sokak silüetinin oluşumunda belirleyici bir rol üstlenmektedir. Özellikle dikdörtgen formda ve cephe boyunca devamlılık gösteren çıkmaların yaygınlığı, üst kat hizasında kesintisiz bir hat oluşturmaktadır. Çıkmaların çoğunlukla birinci katta konumlanması ve üst üste tekrar eden örneklerin bulunmaması, silüetin dikey yönde yoğunlaşmasını sınırlamakta; buna karşılık yatay bant etkisini öne çıkarmaktadır. Kapalı çıkmaların baskınlığı, sokak kesitinde sınırların daha belirgin algılanmasına neden olurken; sınırlı sayıdaki açık çıkma örnekleri bu bütünlük içerisinde yerel ölçekte farklılaşmalar oluşturmaktadır. Böylece sokakta hem süreklilik hem de sınırlı çeşitlilik birlikte okunabilmektedir.

Sokak boyunca yapılaşma düzeni incelendiğinde, sağ cephede geleneksel konutların daha yoğun ve kesintisiz bir dizilim oluşturduğu; sol cephede ise çağdaş yapıların ağırlıkta olduğu, bununla birlikte geleneksel örneklerin de yer aldığı görülmektedir. Sol cephede yapıların daha seyrek yerleşmesi ve bir yapının yıkılmış olması, bu kesimde cephe sürekliliğini zayıflatmakta ve silüette yer yer boşlukların oluşmasına neden olmakta ve iki cephe arasında doluluk-boşluk dengesi bakımından farklı bir algı ortaya çıkmaktadır.

3.3 Genel Değerlendirme

Hacı Münirbey Sokağı'nda elde edilen bulgular, çıkma elemanlarının yalnızca tekil cephe düzenlemeleri olarak değil, sokak ölçeğinde bütüncül bir mekânsal algının oluşumunda etkili bileşenler olarak değerlendirilebileceğini göstermektedir. Çıkmaların belirli bir düzen içerisinde tekrar etmesi, sokak boyunca görsel sürekliliğin okunmasını kolaylaştırmakta ve cepheler arasında ilişkisel bir bütünlük kurulmasına katkı sağlamaktadır. Bu bağlamda, sokak

silüeti yalnızca yapı yükseklikleriyle değil, cephe elemanlarının düzenleniş biçimiyle de şekillenmiştir. Sokak genelinde gözlenen yapılaşma farklılıkları, çıkmaların etkisinin her kesitte aynı düzeyde algılanmadığını göstermektedir. Geleneksel konutların daha yoğun olduğu bölümlerde çıkmaların oluşturduğu düzen daha belirgin biçimde okunabilirken, çağdaş yapıların yer aldığı ve yapı aralıklarının arttığı kesimlerde bu etki zayıflamakta ve süreklilik yer yer kesintiye uğramaktadır. Bu durum, silüetin oluşumunda yalnızca tekil mimari elemanların değil, yapıların birbirleriyle kurduğu ilişkilerin de belirleyici olduğunu göstermektedir.

Öte yandan, sokakta gerçekleştirilen iyileştirme ve cephe düzenleme uygulamalarının, mevcut mimari öğelerin algılanabilirliğini artırdığı ve sokak bütününde daha okunur bir cephe düzeni oluşturduğu söylenebilir. Genel olarak değerlendirildiğinde, çıkmalar Hacı Münirbey Sokağı'nda sokak silüetinin oluşumuna katkı sağlayan, mekânsal sürekliliği destekleyen ve kentsel algıyı yönlendirerek sokak silüetini biçimlendiren önemli elemanlardan biridir.

4. SONUÇ

Bu çalışmada, Tokat kent merkezinde yer alan Hacı Münirbey Sokağı üzerindeki geleneksel konutlarda bulunan çıkma elemanları, tipolojik özellikleri ve sokak silüeti üzerindeki etkileri bağlamında incelenmiştir. Elde edilen bulgular, çıkmaların yalnızca cepheye ait ikincil bir öğe olarak değil, sokak silüetinin oluşumunda belirleyici temel bileşenlerden biri olarak değerlendirilmesi gerektiğini göstermektedir.

Hacı Münir Bey Sokağı'ndaki çıkmaların büyük bir oranı kapalı tipte ve dikdörtgen formda kurgulanmış, önemli bir kısmı ise cephe boyunca devam ettirilmiştir. Çıkmalar, üst kat hizasında devamlılık gösteren bir hat oluşturarak sokak silüetinde yatay doğrultuda belirgin bir bütünlük etkisi meydana getirmektedir. Çıkmaların tek kat düzeyinde kalması ise silüette dikey yoğunlaşmayı sınırlamakta ve yatay etkinin baskın hale gelmesine neden olmaktadır. Böylece sokak boyunca daha dengeli ve süreklilik arz eden bir cephe kurgusu algılanmaktadır.

Taşıyıcı sistemler bakımından genellikle bindirme tekniği uygulanmış olup, az sayıdaki örnekte payanda ve konsol gibi çözümler de bulunmakla birlikte, bu farklılıkların silüet üzerinde belirgin bir farklılık oluşturmadığı anlaşılmaktadır. Buna karşılık, çıkmaların biçimi, cephe üzerindeki konumu ve tekrar eden düzeni, sokak karakterinin algılanmasında daha etkili unsurlar olarak öne çıkmaktadır. Geleneksel yapıların yoğun olduğu kesimlerde çıkmaların oluşturduğu devamlılık daha güçlü biçimde algılanırken, çağdaş yapıların yer aldığı ve yapıların daha seyrek konumlandığı alanlarda bu etkinin zayıfladığı görülmektedir. Bununla birlikte, sokakta gerçekleştirilen sağlıklaştırma çalışmalarının, cephe düzenlerinin daha okunur

hale gelmesine katkı sağladığı ve çıkma elemanlarının sokak ölçeğinde daha belirgin biçimde algılanmasına imkân tanıdığı söylenebilir.

Sonuç olarak, çıkmalar, Hacı Münirbey Sokağı'nda sokak silüetini tanımlayan, mekânsal sürekliliği destekleyen ve kentsel algıyı yönlendiren başlıca cephe elemanları arasında yer almaktadır. Bununla birlikte, sokak silüeti yalnızca yapı kütleleriyle değil, cephe elemanlarının düzenleniş biçimiyle de şekillenmektedir. Bu kapsamda çalışma, geleneksel konut mimarisine ait cephe öğelerinin yalnızca yapı ölçeğinde değil, sokak ve kentsel bağlam içinde birlikte değerlendirilmesinin önemini ortaya koymaktadır.

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Ek 1. Hacı Münirbey Sokağı'nda yer alan K1-K14 Kodlu Yapıların Cephe Fotoğrafları

Ek Tablo 1. K1-K14 kodlu yapıların cephe fotoğrafları (Yazar arşivi)

				
K1	K2	K3	K4	K5
				
K6	K7	K8	K9	K10
				
K11	K12	K13	K14	

ATIK ELEKTROPOLİSAJ KARIŞIMI İÇERİSİNDEKİ METAL PARTİKÜLLERİN AYRIŞTIRILMASI VE GERİ KAZANIMI

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ÖZET

Elektropolisaj işlemi, metal yüzeylerin korozyon direncini artırmak, yüzey pürüzlülüğünü azaltmak ve estetik özelliklerini iyileştirmek amacıyla yaygın olarak kullanılan bir yüzey işleme yöntemidir. Ancak bu işlem sırasında kullanılan yüksek asidik çözeltiler zamanla metal partiküller ve diğer kirleticiler ile yüklenerek atık haline gelmekte ve hem çevresel hem de ekonomik açıdan önemli sorunlar oluşturmaktadır. Bu çalışmada, elektropolisaj işlemi sonrası oluşan atık karışım içerisindeki metal partiküllerin ayrıştırılması ve geri kazanımı amaçlanmıştır. Çalışma kapsamında, öncelikle yüksek asidik karaktere sahip (pH ≈ 0,8) elektropolisaj atığı güvenli çalışma koşulları sağlamak amacıyla bazik bir çözelti (karbonat) kullanılarak nötralize edilmiştir. Nötralizasyon işlemi sonrasında heterojen yapıdaki karışımın katı ve sıvı fazları fiziksel yöntemlerle ayrıştırılmıştır. Viskozitenin azaltılması ve filtrasyon veriminin artırılması amacıyla çözeltiye su ilavesi yapılmış, ardından kâğıt filtre kullanılarak süzdürme işlemi gerçekleştirilmiştir. Elde edilen katı faz etüvde kurutularak analizlere hazır hale getirilmiştir. Kurutulan katı numune, bilyalı değirmende öğütülerek homojen hale getirilmiş ve X-ışını floresans (XRF) analizi ile elementel bileşimi belirlenmiştir. Analiz sonuçlarına göre, geri kazanılan metal tozlarının büyük oranda demir (%68), krom (%17,1) ve nikel (%9,31) içerdiği tespit edilmiştir. Bunun yanında mangan, molibden, silisyum ve bakır gibi elementlerin daha düşük oranlarda bulunduğu belirlenmiştir. Ayrıca bazı oksit ve sülfat bileşiklerinin de yapıda yer aldığı gözlemlenmiştir. Elde edilen bulgular, elektropolisaj atıklarının önemli miktarda geri kazanılabilir metal içerdiğini ortaya koymaktadır. Bu metal tozlarının; manyetik uygulamalar, metalurjik üretim süreçleri, kaplama teknolojileri, pil üretimi ve kaynak uygulamaları gibi çeşitli endüstriyel alanlarda yeniden değerlendirilebileceği öngörülmektedir. Böylece hem atık yönetim maliyetlerinin azaltılması hem de ikincil hammadde kaynağı oluşturulması mümkün olmaktadır. Sonuç olarak, bu çalışma elektropolisaj atıklarının çevreye zarar vermeden yönetilmesine katkı sağlarken, aynı zamanda döngüsel ekonomi yaklaşımı kapsamında atıkların katma değerli ürünlere dönüştürülebileceğini göstermektedir. Geliştirilen yöntem, sanayi uygulamalarına entegre edilebilirliği açısından

umut verici olup, benzer proses atıklarının geri kazanımına yönelik çalışmalar için referans niteliği taşımaktadır.

Anahtar kelimeler: Elektropolisaj, toz metalürjisi, ayrıştırma işlemi, geri kazanım

SEPARATION AND RECOVERY OF METAL PARTICLES FROM ELECTROPOLISHING WASTE SOLUTIONS

ABSTRACT

Electropolishing is a widely used surface finishing process aimed at improving corrosion resistance, reducing surface roughness, and enhancing the aesthetic properties of metallic materials. However, the highly acidic solutions used in this process gradually become contaminated with metal particles and other impurities, eventually turning into hazardous waste that poses both environmental and economic challenges. In this study, it is aimed to separate and recover metal particles from waste generated after the electropolishing process. Within the scope of the study, the electropolishing waste, characterized by a highly acidic nature (pH ≈ 0.8), was first neutralized using a basic solution (carbonate) in order to ensure safe handling conditions. Following the neutralization step, the heterogeneous mixture was subjected to physical separation processes to isolate solid and liquid phases. To reduce viscosity and improve filtration efficiency, water was added to the solution, and the mixture was subsequently filtered using filter paper. The obtained solid phase was dried in an oven and prepared for further analysis. The dried solid samples were ground using a ball mill to achieve homogeneity and analyzed using X-ray fluorescence (XRF) spectroscopy to determine their elemental composition. The analysis results revealed that the recovered metal powders mainly consisted of iron (68%), chromium (17.1%), and nickel (9.31%). In addition, smaller amounts of manganese, molybdenum, silicon, and copper were detected. The presence of certain oxide and sulfate compounds was also observed. The findings demonstrate that electropolishing waste contains a significant amount of recoverable metals. These recovered metal powders have the potential to be reused in various industrial applications such as magnetic materials, metallurgical processes, coating technologies, battery production, and welding applications. Therefore, both the reduction of waste management costs and the generation of secondary raw material sources can be achieved. In conclusion, this study contributes to the environmentally responsible management of electropolishing waste while demonstrating the potential for converting such waste into value-added materials within the framework of a circular economy. The proposed method shows promise for industrial integration and can serve as a reference for future studies on the recovery of similar industrial process wastes.

Keywords: Electropolishing, powder metallurgy, separation process, recovery

1. GİRİŞ

Elektropolisaj, metalik malzemelerin yüzey kalitesini iyileştirmek, korozyon direncini artırmak, yüzey pürüzlülüğünü azaltmak ve estetik görünüm kazandırmak amacıyla yaygın olarak kullanılan elektrokimyasal bir yüzey işleme yöntemidir. Özellikle paslanmaz çelik malzemelerin işlendiği medikal, gıda, kimya ve hassas imalat sektörlerinde yaygın olarak tercih edilmektedir. Bu yöntem ile malzeme yüzeyinde mikroskobik seviyede kontrollü çözünme meydana gelmekte, yüzeydeki düzensizlikler giderilmekte ve daha homojen bir yüzey yapısı elde edilmektedir. Elektropolisaj işlemi sonucunda malzemeler yalnızca daha parlak bir görünüme kavuşmamakta, aynı zamanda sterilizasyon kabiliyeti ve yüzey pasivasyonu da iyileşmektedir. Bu nedenle özellikle cerrahi ekipman üretiminde önemli bir proses olarak değerlendirilmektedir (Mohan vd, 2001; Łyczkowska-Widłak vd, 2020; Yang vd, 2017)

Elektropolisaj işlemi genellikle sülfürik asit ve fosforik asit esaslı yüksek asidik elektrolit çözeltiler kullanılarak gerçekleştirilmektedir. İşlem sırasında anot olarak bağlanan metal yüzeyden mikron ve altı boyutlarda metal partiküller ayrılmakta ve zamanla elektrolit banyosu içerisinde birikmektedir. Sürekli kullanım sonucunda çözeltideki metal iyonu ve partikül konsantrasyonu artmakta, bu durum elektrolitin performansını olumsuz yönde etkilemekte ve belirli bir süre sonra çözeltinin kullanım dışı kalmasına neden olmaktadır.

Kullanım ömrünü tamamlayan elektropolisaj banyoları, yüksek asidik karakterleri ve içerdikleri metalik kirleticiler nedeniyle çevresel açıdan dikkatli yönetilmesi gereken endüstriyel atık sınıfında değerlendirilmektedir. Sanayi kuruluşları bu tür atıkları genellikle nötralizasyon işlemine tabi tuttuktan sonra lisanslı bertaraf tesislerine göndermektedir. Ancak bu yaklaşım hem ek işletme maliyetleri oluşturmakta hem de atık içerisinde bulunan potansiyel olarak geri kazanılabilir metalik bileşenlerin kaybedilmesine yol açmaktadır (Łyczkowska vd, 2019; Davis, 2000; Revie, 2011).

Son yıllarda sürdürülebilir üretim anlayışının yaygınlaşması, çevresel düzenlemelerin sıkılaşması ve ikincil hammadde kaynaklarına yönelik artan ihtiyaç, endüstriyel atıklardan metal geri kazanımı konusuna olan ilgiyi artırmıştır. Talaş atıkları, galvanik çamurlar, metalurjik cüruflar ve benzeri endüstriyel atıkların geri kazanımına yönelik çeşitli çalışmalar literatürde yer almaktadır. Buna karşın elektropolisaj kaynaklı atıklardan metal partiküllerin ayrıştırılması ve yeniden değerlendirilmesine yönelik çalışmalar oldukça sınırlıdır (Cui vd, 2003; Binnemans vd, 2013; Graedel vd, 2011; European Commission, 2020)

Paslanmaz çelik malzemelerin elektropolisaj işleminden kaynaklanan atıklar; demir, krom, nikel, molibden ve mangan gibi ekonomik değere sahip alaşım elementlerini içerebilmektedir. Bu nedenle söz konusu atıkların uygun fiziksel ve kimyasal yöntemlerle işlenmesi sonucunda

metalce zengin katı fraksiyonların elde edilmesi mümkün olabilmektedir. Bu yaklaşım hem atık bertaraf yükünü azaltma hem de ikincil metal kaynağı oluşturma açısından önemli bir potansiyel taşımaktadır.

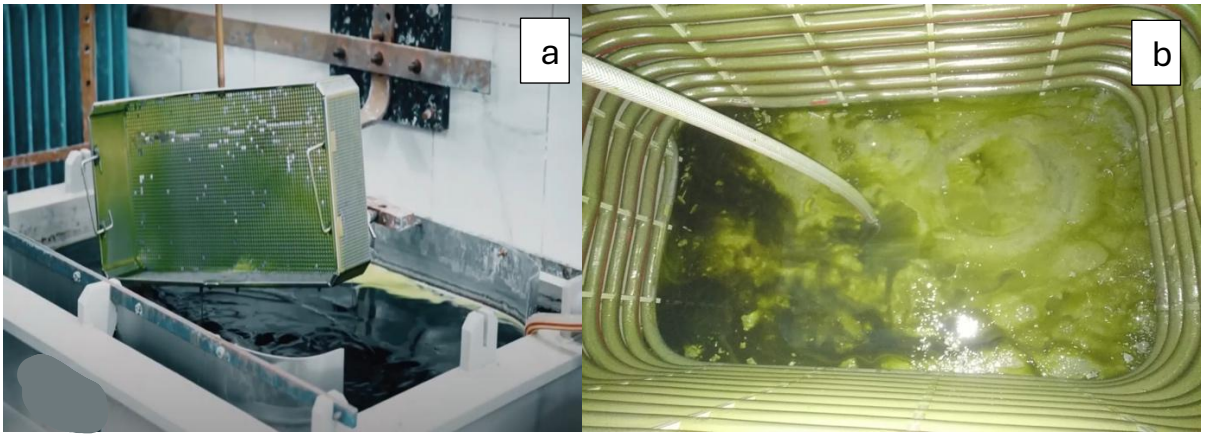
Bu çalışmada, paslanmaz çelik yüzey işlemleri sonucunda oluşan atık elektropolisaj karışımı içerisindeki metal partiküllerin ayrıştırılması ve geri kazanım potansiyelinin deneysel olarak değerlendirilmesi amaçlanmıştır. Bu kapsamda atık karışım nötralizasyon, katı-sıvı faz ayrımı, kurutma ve öğütme işlemlerine tabi tutulmuş; elde edilen katı fazın elementel bileşimi X-ışını floresans (XRF) analizi ile belirlenmiştir. Elde edilen bulgular doğrultusunda geri kazanılan metalik fraksiyonun yeniden kullanım potansiyeli değerlendirilmiştir.

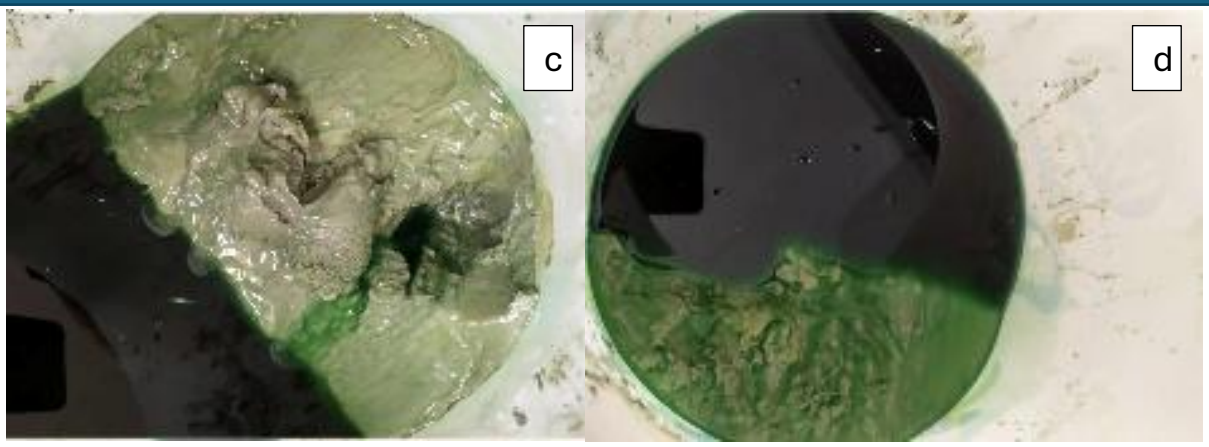
2. MATERYAL VE YÖNTEM

2.1. Atık numunenin temini

Bu çalışmada kullanılan atık elektropolisaj karışımı, paslanmaz çelik cerrahi ekipman üretimi gerçekleştiren bir firmadan temin edilmiştir. Numune, firmanın üretim proseslerinde kullanılan ve kullanım ömrünü tamamlamış elektropolisaj banyosundan alınmıştır (Şekil 1a). Elektropolisaj işleminde sülfürik asit ve fosforik asit esaslı elektrolit çözeltiler kullanılmakta olup, proses sırasında paslanmaz çelik yüzeylerden ayrışan metal partikülleri zamanla çözeltide birikmektedir (Şekil 1b-c).

Deneysel çalışmalarda toplam 2 litre atık elektropolisaj karışımı kullanılmıştır. Numunenin başlangıç pH değeri dijital pH metre yardımıyla ölçülmüş ve 0,8 olarak belirlenmiştir. Elde edilen bu değer, numunenin yüksek asidik karakterini ortaya koymaktadır.





Şekil 1. a-b) Elektropolisaj tankı, c-d) elektropolisaj çökeltisi

2.2. Nötralizasyon işlemi

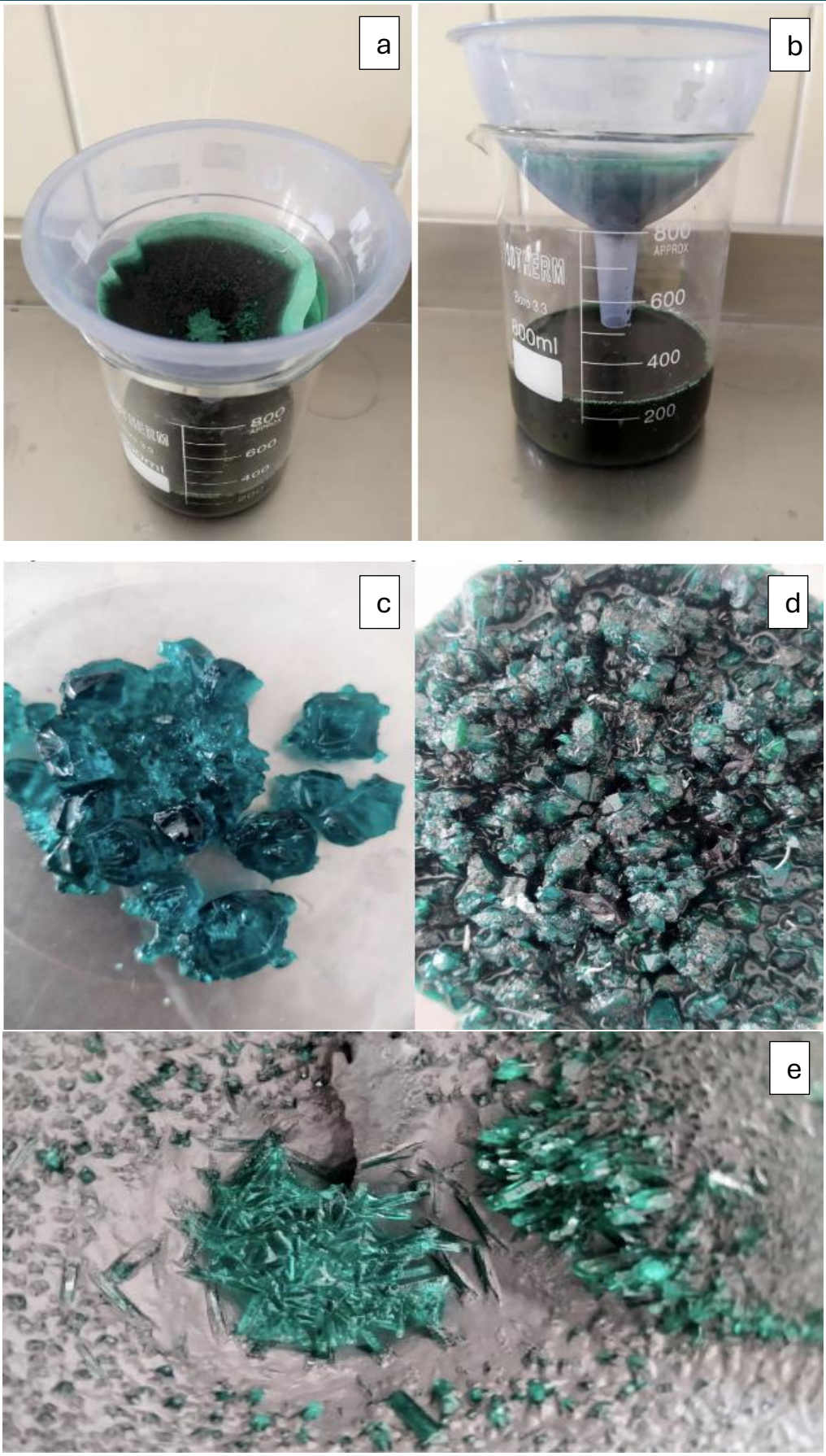
Yüksek asidik özellik gösteren atık karışımın güvenli şekilde işlenebilmesi amacıyla öncelikle nötralizasyon işlemi uygulanmıştır. Bu amaçla atık karışıma kontrollü şekilde karbonat ilavesi gerçekleştirilmiştir. İlave sırasında ortamda meydana gelen reaksiyon kontrollü olarak takip edilmiş ve karışımın pH değeri nötr bölgeye yaklaştırılmıştır.

Nötralizasyon işlemi sırasında asidik ortamın etkisinin azaltılması ile birlikte çözeltide çözünmüş halde bulunan bazı metal türlerinin çökelmesi sağlanmış, böylece sonraki katı-sıvı ayırma işlemi için uygun koşullar oluşturulmuştur.

2.3. Katı-sıvı faz ayrıştırma

Nötralizasyon işleminin ardından karışımın viskozitesini azaltmak ve filtrasyon verimini artırmak amacıyla belirli miktarda saf su ilavesi yapılmıştır. Hazırlanan karışım, laboratuvar tipi filtre düzeneğinde yerçekimi filtrasyonu yöntemi kullanılarak süzülmüştür (Şekil 2).

Filtrasyon işlemi sonucunda sıvı faz ve katı faz birbirinden ayrılmıştır. Filtre üzerinde biriken katı faz dikkatlice toplanarak kurutma işlemine alınmıştır.



Şekil 2. a-b) Filtreleme işlemi düzeneği, **c-d-e)** Filtreleme sonrası katı malzeme kalıntısı

2.4. Kurutma ve öğütme işlemleri

Filtrasyon sonrasında elde edilen katı faz, bünyesindeki nemin uzaklaştırılması amacıyla 50 °C sıcaklıkta etüvde kurutulmuştur. Kurutma işlemi sonrasında katı fazın toplam kütlesi hassas terazi ile ölçülmüş ve 128 g olarak belirlenmiştir.

Kurutulan numunede gözlenen aglomerasyonların giderilmesi ve homojen partikül boyutu dağılımı elde edilmesi amacıyla numune seramik bilyalı öğütücü yardımıyla öğütülmüştür. Öğütme işlemi sonrasında ince toz formuna getirilen numuneler kimyasal analiz için hazır hale getirilmiştir.

2.5. XRF analizi

Elde edilen toz numunelerin elementel bileşiminin belirlenmesi amacıyla X-ışını floresans spektroskopisi (XRF) analizi gerçekleştirilmiştir. Analizler Ondokuz Mayıs Üniversitesi Merkezi Araştırma Laboratuvarı bünyesinde bulunan XRF analiz cihazı kullanılarak gerçekleştirilmiştir.

XRF analizi sonucunda numune içerisinde bulunan başlıca metalik bileşenlerin kütlece yüzdeleri belirlenmiş ve geri kazanılan katı fazın yeniden kullanım potansiyeli değerlendirilmiştir.

3. BULGULAR VE TARTIŞMA

3.1. Atık elektropolisaj karışımının başlangıç özellikleri

Deneysel çalışmalarda kullanılan atık elektropolisaj karışımının başlangıç pH değeri 0,8 olarak ölçülmüştür. Bu değer, numunenin yüksek derecede asidik karakter gösterdiğini ortaya koymaktadır. Elektropolisaj banyolarında yaygın olarak kullanılan sülfürik asit ve fosforik asit esaslı elektrolitlerin zaman içerisinde metal iyonları ve metal partikülleri ile yüklenmesi sonucunda çözeltinin kimyasal yapısı değişmekte, ancak yüksek asidik karakterini korumaktadır.

Yüksek asidik özellik, atığın doğrudan bertarafını çevresel açıdan riskli hale getirmekte ve kontrollü nötralizasyon işlemini zorunlu kılmaktadır. Bu nedenle gerçekleştirilen nötralizasyon işlemi yalnızca güvenli laboratuvar koşullarının sağlanması açısından değil, aynı zamanda çözeltide çözünmüş halde bulunan metal türlerinin çökeltilerek geri kazanım veriminin artırılması açısından da kritik bir işlem basamağıdır.

3.2. Katı-sıvı faz ayrımı ve geri kazanılan katı fraksiyon miktarı

Nötralizasyon ve yerçekimi filtrasyonu sonrasında toplam 2 litre atık karışımdan 128 g kurutulmuş katı faz elde edilmiştir. Bu sonuç, birim hacim başına yaklaşık 64 g/L geri kazanılabilir katı fraksiyon bulunduğunu göstermektedir.

Elde edilen katı miktarı, kullanım ömrünü tamamlamış elektropolisaj banyolarının dikkate değer düzeyde metalik ve inorganik katı içerdiğini ortaya koymaktadır. Endüstriyel ölçekte değerlendirildiğinde bu miktar, yüksek hacimlerde çalışan üretim tesisleri açısından önemli düzeyde ikincil hammadde potansiyeline işaret etmektedir.

Katı fazın kurutma sonrasında topaklanmış yapı sergilediği gözlenmiştir. Bu durum, çözeltiden ayrılan partiküllerin bir kısmının ince boyutlu olması ve kuruma sırasında aglomerasyon eğilimi göstermesi ile ilişkilendirilebilir. Bu nedenle numune, homojen yapı elde edilmesi amacıyla öğütme işlemine tabi tutulmuştur.

3.3. XRF analiz sonuçları

Geri kazanılan katı fazın elementel bileşimini belirlemek amacıyla gerçekleştirilen XRF analiz sonuçları Tablo 1'de verilmiştir.

Tablo 1. Geri kazanılan katı fazın elementel bileşimi

Element	Ağırlıkça Oran (%)
Fe	68,00
Cr	17,10
Ni	9,31
Mo	1,80
Si	1,20
C	0,90
Mn	0,92
Cu	0,30

Analiz sonuçları, geri kazanılan katı fazın büyük oranda demir esaslı olduğunu göstermektedir. Bununla birlikte önemli miktarda krom ve nikel içermesi, söz konusu partiküllerin paslanmaz çelik alaşımlarından kaynaklandığını doğrulamaktadır.

Bilindiği üzere paslanmaz çeliklerde yüksek krom içeriği korozyon direncini sağlayan temel unsur iken, nikel ise östenitik yapının kararlılığını artırmaktadır. Numunede tespit edilen krom ve nikel oranları, elektropolisaj işlemine tabi tutulan paslanmaz çelik yüzeylerden kontrollü çözünme ile ayrışan partiküllerin atık faz içerisinde biriktiğini göstermektedir.

Molibden varlığı özellikle 316L tipi paslanmaz çelik işlenmiş olabileceğine işaret etmektedir. Bu durum, atığın farklı paslanmaz çelik kalitelerinden gelen karma alaşım bileşenlerini içerdiğini düşündürmektedir.

3.4. Bulguların değerlendirilmesi

Elde edilen sonuçlar, atık elektropolisaj karışımının yalnızca bertaraf edilmesi gereken bir kimyasal atık olmadığını, aynı zamanda ekonomik değere sahip metalik bileşenler içeren potansiyel bir ikincil hammadde kaynağı olduğunu ortaya koymaktadır.

Katı fazın yüksek oranda Fe-Cr-Ni esaslı bileşim göstermesi, geri kazanılan fraksiyonun aşağıdaki alanlarda değerlendirilebileceğini göstermektedir:

- Toz metalurjisi uygulamalarında ön hammadde
- Metalik dolgu katkı malzemesi
- Abrasif sistemlerde katkı fazı
- Yeniden ergitme proseslerinde sekonder metal girdisi

Ancak mevcut çalışma kapsamında geri kazanılan katı fazın mekanik, mikroyapısal veya faz analizlerine yönelik ileri karakterizasyon çalışmaları gerçekleştirilmemiştir. Bu nedenle söz konusu kullanım alanları potansiyel değerlendirme niteliğindedir.

3.5. Çevresel ve ekonomik değerlendirme

Geleneksel yaklaşımlarda kullanım ömrünü tamamlamış elektropolisaj banyoları nötralize edilerek bertaraf edilmekte, içerdiği metalik bileşenler ise geri kazanılamadan kaybedilmektedir. Bu durum hem çevresel yük hem de ekonomik kayıp oluşturmaktadır.

Bu çalışmada uygulanan yöntem, nispeten basit laboratuvar ekipmanları kullanılarak atık içerisindeki metalce zengin katı fraksiyonun ayrıştırılabileceğini göstermiştir. İşlem basamaklarının düşük enerji gereksinimi ve uygulanabilirliği dikkate alındığında, prosesin daha ileri optimizasyon çalışmaları ile endüstriyel ölçekte değerlendirilmesi mümkün görünmektedir.

4. SONUÇLAR

Bu çalışmada, kullanım ömrünü tamamlamış atık elektropolisaj karışımı içerisindeki metal partiküllerin ayrıştırılması ve geri kazanım potansiyeli deneysel olarak değerlendirilmiştir. Elde edilen bulgular doğrultusunda aşağıdaki sonuçlara ulaşılmıştır:

1. Deneysel çalışmalarda kullanılan atık elektropolisaj karışımının başlangıç pH değeri 0,8 olarak ölçülmüş olup, numunenin yüksek asidik karakter gösterdiği belirlenmiştir.
2. Karbonat ile gerçekleştirilen nötralizasyon işlemi, atığın güvenli şekilde işlenmesini sağlamış ve katı-sıvı faz ayrımı için uygun koşullar oluşturmuştur.

3. Uygulanan yerçekimi filtrasyonu, kurutma ve öğütme işlemleri sonucunda toplam 2 litre atık karışımdan 128 g kurutulmuş katı faz elde edilmiştir.
4. XRF analiz sonuçları geri kazanılan katı fazın ağırlıklı olarak Fe (%68,0), Cr (%17,1) ve Ni (%9,31) içerdiğini göstermiştir. Bunun yanında Mo, Mn, Si ve Cu gibi alaşım elementleri de tespit edilmiştir.
5. Elde edilen elementel bileşim, geri kazanılan katı fazın paslanmaz çelik yüzeylerden ayrışan metalik partiküllerden oluştuğunu ve metalce zengin bir yapıya sahip olduğunu ortaya koymuştur.
6. Çalışma sonucunda atık elektropolisaj karışımlarının yalnızca bertaraf edilmesi gereken kimyasal atıklar olmadığı, aynı zamanda ikincil hammadde kaynağı olarak değerlendirilebileceği gösterilmiştir.
7. Uygulanan yöntemin basit laboratuvar ekipmanları ile gerçekleştirilebilir olması, daha ileri proses optimizasyonları ile endüstriyel ölçekte uygulanabilirliğinin araştırılmaya değer olduğunu göstermektedir.

Gelecekte yapılacak çalışmalarda geri kazanılan katı fazın SEM/EDS, XRD ve mekanik performans analizleri ile detaylı karakterizasyonunun gerçekleştirilmesi, ayrıca farklı ayrıştırma yöntemlerinin karşılaştırmalı olarak incelenmesi önerilmektedir.

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SMART FACTORIES AND MATERIALS ENGINEERING: A REINFORCEMENT LEARNING APPROACH

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ABSTRACT

Smart factories, representing the pinnacle of Industry 4.0 and the transition toward Industry 5.0, integrate advanced digital technologies such as the Industrial Internet of Things (IIoT), cyber-physical systems (CPS), cloud and edge computing, big data analytics, and artificial intelligence to create highly connected, adaptive, and autonomous production ecosystems. These intelligent environments enable real-time data exchange between machines, sensors, and control systems, allowing manufacturing processes to self-monitor, self-optimize, and, increasingly, self-configure. Within this technological landscape, Reinforcement Learning (RL) and its deep learning-enhanced variants (Deep Reinforcement Learning, DRL) are emerging as powerful tools for managing complex, stochastic, and high-dimensional decision problems inherent in modern production systems. Unlike rule-based automation, RL systems learn optimal control policies through continuous interaction with dynamic environments, making them particularly suitable for adaptive scheduling, robotic coordination, predictive maintenance, and materials process optimization. This paper synthesizes contemporary research on RL applications across smart factory design, operational management, materials engineering, and adaptive control architectures. Drawing on a systematic review of peer-reviewed studies, it highlights major trends, including the rise of multi-agent RL for distributed manufacturing and the integration of RL with digital twins for simulation-based training. Findings indicate that RL enhances process efficiency, production agility, and material quality by enabling real-time decision-making and dynamic resource allocation. However, large-scale industrial implementation remains constrained by safety verification challenges, high data demands, model interpretability concerns, and integration complexities. Future research should therefore emphasize scalable and explainable RL frameworks, human-AI collaboration models, and

robust real-world validation strategies to fully unlock the transformative potential of smart factories.

Keywords: Deep Reinforcement Learning; Materials Engineering Optimization; Reinforcement Learning; Smart Manufacturing.

INTRODUCTION

Smart factories are adaptive, interconnected, and data-driven manufacturing ecosystems designed to enhance production flexibility, responsiveness, and efficiency in increasingly volatile global markets. Unlike conventional automated factories that rely on pre-programmed logic and centralized control, smart factories operate through distributed intelligence, continuous data exchange, and self-optimizing mechanisms. These systems integrate digital technologies such as cyber-physical systems (CPS), the Industrial Internet of Things (IIoT), cloud and edge computing, digital twins, robotics, and advanced analytics to enable seamless coordination between physical production assets and computational intelligence. As part of the broader Industry 4.0 transformation, smart factories leverage sensor networks and embedded systems to collect real-time data across the production lifecycle, from raw material handling to final product inspection. This interconnected infrastructure enables predictive maintenance, dynamic scheduling, quality monitoring, and autonomous adaptation to disturbances such as machine breakdowns or demand fluctuations (Bahrpeyma & Reichelt, 2022). At the core of this transformation lies artificial intelligence (AI), which provides the cognitive capabilities necessary for intelligent decision-making. Among AI methodologies, Reinforcement Learning (RL) has emerged as a particularly powerful approach for managing the complexity and uncertainty inherent in modern manufacturing systems. RL is a machine learning paradigm in which an agent learns optimal actions through iterative interaction with an environment. Rather than being trained on labelled datasets, as in supervised learning, an RL agent receives feedback in the form of rewards or penalties based on its actions and gradually refines its decision policy to maximize cumulative long-term rewards. This trial-and-error learning mechanism makes RL highly suitable for environments characterized by dynamic changes, stochastic variables, and multi-objective optimization challenges, conditions typical of smart manufacturing settings (Alginahi et al., 2025). Traditional manufacturing control systems often depend on rule-based heuristics or static optimization models. While effective in stable environments, such approaches struggle to adapt to disruptions, supply chain variability,

or customization demands. In contrast, RL-based systems continuously learn from operational feedback, enabling them to adjust control strategies in real time. For example, in adaptive scheduling, an RL agent can dynamically reassign tasks when unexpected events occur, minimizing downtime and maintaining throughput. In robotic assembly lines, RL enables robots to learn optimal motion trajectories that improve speed, precision, and energy efficiency. In materials engineering processes such as additive manufacturing or heat treatment, RL can optimize parameter settings (e.g., temperature, feed rate, pressure) to enhance material quality and reduce defects. Research increasingly recognizes RL as a critical enabler for autonomous operations and intelligent control within smart factories. Alginahi et al. (2025) note that RL applications in industrial automation are expanding rapidly, particularly in adaptive control, predictive maintenance, and scheduling optimization. The ability of RL agents to interact directly with complex systems and improve policies over time aligns closely with the goals of Industry 4.0, which emphasizes decentralization, interoperability, and intelligent autonomy. Furthermore, RL supports continuous improvement frameworks by enabling systems to refine decision strategies as more data become available, thereby fostering operational resilience. The emergence of Deep Reinforcement Learning (DRL) has further accelerated adoption in manufacturing contexts. DRL combines RL algorithms with deep neural networks to approximate value functions or policies in high-dimensional state spaces. Modern manufacturing systems generate vast quantities of heterogeneous data from sensors, cameras, and enterprise systems. These data streams create high-dimensional input spaces that are difficult to manage using classical RL methods. By leveraging deep neural networks, DRL can process complex patterns, nonlinear relationships, and multi-variable dependencies, enabling more accurate and scalable decision-making (Li et al., 2023). This advancement is particularly valuable in applications such as vision-based quality inspection, autonomous material handling, and real-time production scheduling, where the state space is both large and continuously evolving. In scheduling and job sequencing, DRL has demonstrated superior performance compared to traditional dispatching rules and heuristic algorithms. Manufacturing scheduling problems are often NP-hard, involving combinatorial optimization under constraints such as machine availability, due dates, and processing times. DRL agents can learn adaptive scheduling policies that respond to disturbances such as urgent orders or equipment failures. Over time, these agents develop strategies that minimize tardiness, reduce setup times, and optimize resource utilization. Because DRL policies are learned through simulation or digital twin environments, they can be pre-trained in virtual spaces before deployment in physical systems, reducing operational risks. Robotics control represents another significant domain of

RL application within smart factories. Industrial robots traditionally rely on pre-programmed motion paths and deterministic control algorithms. However, modern production environments demand greater flexibility, especially in collaborative robotics (cobots) and customized manufacturing. RL allows robots to learn optimal control policies for grasping, assembly, and manipulation tasks through exploration and reward feedback. By continuously refining motor commands, RL-enhanced robots can adapt to variations in object shapes, positions, or environmental conditions. This capability supports mass customization and reduces reliance on manual reprogramming. In materials engineering, RL offers transformative potential for process optimization and materials discovery. Manufacturing processes such as casting, forging, welding, and additive manufacturing involve complex thermomechanical interactions and nonlinear parameter dependencies. Traditional optimization approaches often rely on extensive trial-and-error experimentation or computationally expensive simulations. RL provides a data-driven alternative by enabling agents to explore parameter spaces and identify optimal combinations that improve mechanical properties, reduce defects, or enhance microstructural consistency. Li et al. (2023) emphasize that DRL is particularly effective in managing multi-objective optimization problems where trade-offs exist between quality, cost, and energy consumption. Moreover, RL contributes to predictive maintenance and fault detection within smart factories. Equipment downtime remains a significant challenge in manufacturing. By integrating RL with sensor-based monitoring systems, factories can develop intelligent maintenance policies that balance preventive actions with production continuity. RL agents learn when to perform maintenance based on predicted failure probabilities and associated costs, optimizing maintenance schedules to reduce unplanned outages while minimizing unnecessary interventions. The integration of RL into smart factories also aligns with broader sustainability objectives. Manufacturing industries face increasing pressure to reduce energy consumption, material waste, and carbon emissions. RL-based control systems can optimize energy usage across production lines by dynamically adjusting machine operations, power loads, and processing sequences. For example, RL agents can schedule energy-intensive tasks during periods of lower demand or renewable energy availability, contributing to greener manufacturing practices. In materials processing, RL-driven parameter tuning can reduce scrap rates and improve yield efficiency, directly supporting resource conservation. Despite its promise, the implementation of RL in real-world manufacturing remains accompanied by technical and organizational challenges. Training RL agents often requires large datasets and substantial computational resources. Simulation environments or digital twins are frequently used to accelerate learning; however, transferring policies from

simulated to real environments (the sim-to-real gap) can introduce performance degradation. Safety considerations are particularly critical in industrial contexts, where erroneous decisions may result in equipment damage or worker injury. Therefore, robust validation, safe exploration mechanisms, and explainable RL models are necessary before large-scale deployment. Additionally, integrating RL systems with legacy manufacturing infrastructure presents interoperability challenges. Many factories operate with heterogeneous equipment and proprietary communication protocols. Achieving seamless RL integration requires standardized data interfaces and middleware solutions that enable real-time data flow between physical assets and AI control modules. Organizational readiness and workforce training are equally important, as engineers and operators must understand and trust RL-driven decision systems. Nevertheless, the trajectory of research suggests that RL will play an increasingly central role in shaping next-generation manufacturing ecosystems. By enabling machines and production lines to learn from experience, adapt to uncertainty, and optimize complex processes autonomously, RL enhances both operational resilience and competitive advantage. In volatile markets characterized by fluctuating demand and supply chain disruptions, the ability to dynamically reconfigure production strategies provides significant strategic value. In conclusion, smart factories represent an evolution toward intelligent, self-optimizing manufacturing systems, and Reinforcement Learning serves as a foundational technology in achieving this vision. Through adaptive scheduling, robotic control, materials optimization, predictive maintenance, and energy management, RL empowers manufacturing environments with real-time learning capabilities. Deep Reinforcement Learning further extends these capabilities to high-dimensional and nonlinear decision spaces, addressing the complexity of modern industrial operations (Bahrpeyma & Reichelt, 2022; Alginahi et al., 2025; Li et al., 2023). As research advances in safe, explainable, and scalable RL architectures, the convergence of AI and manufacturing promises to redefine production paradigms, fostering agility, sustainability, and long-term industrial competitiveness.

LITERATURE REVIEW

Reinforcement Learning in Smart Factories

Reinforcement Learning's (RL) role in smart factory automation is now widely recognized as a major driver of intelligent and adaptive manufacturing. A recent bibliometric review by Alginahi, Sabri, and Said (2025) mapped 672 peer-reviewed RL and Deep Reinforcement Learning (DRL) studies published between 2017 and 2026, revealing critical insights into how RL research is evolving in the context of industrial automation (Alginahi et al., 2025). According to this analysis, 42% of the reviewed studies employed DRL techniques, which

integrate reinforcement learning with deep neural networks to manage high-dimensional and nonlinear decision spaces that are typical of real-world smart production environments. In contrast, 27% focused on Multi-Agent RL (MARL), useful for distributed decision making across multiple robotic or process units, and 31% relied on classical RL models such as Q-Learning for more discrete control tasks (e.g., simple process control or elementary machine sequencing) (Alginahi et al., 2025). Importantly, the review demonstrated that RL research in industrial automation is not evenly distributed across theoretical and applied work. While DRL has become the dominant approach, only about 22% of the studies reported implementations in real-world or pilot industrial settings, with the majority remaining at the simulation or laboratory scale. This discrepancy highlights a significant maturity gap between academic exploration and industrial adoption, as real factory environments introduce complexities, such as noisy sensor data, hardware variability, and stringent safety requirements that are not fully captured in simulated research platforms (Alginahi et al., 2025).The concentration of RL applications also reflects practical industry priorities. Among implemented studies, robotic control accounted for around 33% of deployments, where RL agents are trained to optimize motion planning, coordinated task execution, or adaptive grasping in collaborative robot (cobot) environments. Process optimization represented 28% of applications, with RL being used to adjust process parameters such as machine speeds, tool paths, or energy consumption in response to real-time feedback. Additionally, predictive maintenance comprised 19% of use cases, where RL assists in choosing maintenance actions that balance downtime, cost, and production continuity (Alginahi et al., 2025). Despite this momentum, the transition from scholarly research to fully operational smart factory systems faces enduring challenges. Scalability remains a major barrier, as RL algorithms trained in controlled environments often struggle when scaled to complex factory floors with millions of state inputs and multi-agent interactions. Scaling up requires not only larger computational resources but also robust learning architectures that avoid the “curse of dimensionality” while preserving performance (Alginahi et al., 2025; Khadivi et al., 2023). Safety validation is another critical issue: autonomous RL policies sometimes explore unsafe actions during learning, which is unacceptable for safety-critical manufacturing settings where improper moves could damage equipment or endanger workers (Haj Yahmed et al., 2023). Researchers are responding with “safe RL” frameworks and the integration of simulation-based digital twins to enable risk-free experimentation, yet these methods are still maturing and have not been widely standardized (Alginahi et al., 2025; Haj Yahmed et al., 2023). Moreover, interpretability remains a persistent constraint for industrial adoption. Deep learning models, especially DRL agents, often function

as “black boxes,” making it difficult for engineers and regulators to understand decision logic or justify actions in safety-sensitive operations. This opacity can slow down certification, reduce operator trust, and complicate regulatory compliance when deploying autonomous systems in real factories (Alginahi et al., 2025). In summary, while bibliometric evidence shows a strong and growing body of RL research targeting smart automation, the relatively low percentage of real-world implementations highlights key maturity gaps. Addressing scalability, safety, interpretability, and deployment readiness remains essential for translating academic breakthroughs into fully operational smart factory solutions that drive resilient, autonomous production in Industry 4.0 and beyond.

Multi-Agent RL and Real-Time Control

Reinforcement Learning (RL) methods are increasingly recognized as highly effective in decentralized and multi-agent environments, a characteristic that aligns well with the architecture of modern smart factories. In contrast to centralized control systems where a single decision maker manages all production elements, decentralized systems distribute decision authority across multiple autonomous units such as machines, robotic cells, automated guided vehicles (AGVs), transport conveyors, and quality inspection stations. Each of these units operates within a dynamic environment with distinct state information, objectives, and constraints. In such contexts, Multi-Agent Reinforcement Learning (MARL) extends the capabilities of traditional single-agent RL by enabling coordinated learning and policy optimization across multiple interacting agents, allowing them to learn not only from their individual experiences but also through interactions with other agents in the system. Bahrpeyma and Reichelt’s (2022) review highlights how MARL approaches are particularly well suited to smart factories, where distributed intelligence and autonomy are essential. Smart factory ecosystems are characterized by self-organizing components that must make real-time decisions under uncertainty, such as rerouting production when a machine is temporarily out of service, reallocating tasks to maintain throughput, or synchronizing robot actions in collaborative assembly tasks (Bahrpeyma & Reichelt, 2022). In these scenarios, MARL agents can learn policies that balance local objectives (e.g., minimizing individual machine idle time) with global system goals (e.g., maximizing overall production efficiency), thereby achieving coordinated behaviour that would be difficult to implement through rule-based control alone. Importantly, MARL is capable of addressing challenges of scalability and complexity that arise in large production ecosystems. In traditional RL, increasing the number of decision variables can lead to an exponential growth in state and action spaces, making it difficult for a single agent to learn effective strategies. By distributing the decision problem among multiple agents,

MARL reduces the computational complexity for each agent while leveraging interaction dynamics to achieve collective optimization. This is particularly relevant for production scheduling problems involving multiple machines and tasks, where MARL has been shown to outperform centralized heuristics by learning adaptive scheduling policies that respond to dynamic demand and machine availability (Zhang et al., 2023). MARL also facilitates coordination in collaborative robotics. In smart factories where multiple robotic systems work in tandem, such as in assembly lines or flexible manufacturing cells, agents trained through MARL can develop cooperative strategies that minimize task conflicts and prevent deadlocks. For instance, agents can learn to sequence actions in ways that reduce congestion or avoid simultaneous access to shared workspace regions. A study by Nguyen et al. (2021) demonstrated that MARL can significantly improve throughput and reduce collision rates in multi-robot systems compared to independent learning models, enhancing both safety and productivity. Another advantage of MARL lies in its capacity for distributed fault tolerance. Smart manufacturing systems are susceptible to disruptions such as machine failures, network latency, or sudden changes in production orders. In a MARL setting, agents that encounter disruptions can adapt their policies locally, while information sharing among agents helps the rest of the system adjust, promoting resilience without the need for human intervention. Empirical research shows that MARL systems can maintain operational performance under partial system degradation, whereas centralized systems often collapse when key decision nodes fail (Mnih et al., 2024). However, deploying MARL in real industrial environments introduces challenges related to credit assignment, non-stationarity, and communication overhead. The credit assignment problem arises when it is unclear which agent's actions contribute most too system-level success, complicating the learning of effective reward structures. Non-stationarity, caused by concurrently learning agents that modify the environment, can destabilize learning processes if not properly managed through techniques such as centralized critic architectures or experience replay buffers. Communication overhead, while useful for coordination, must be balanced against network bandwidth limitations and real-time performance requirements in industrial settings (Zhang et al., 2023). Despite these challenges, the application of MARL in decentralized smart factory systems continues to grow, driven by advances in scalable learning algorithms, efficient communication protocols, and hybrid human-AI coordination frameworks. As production environments become more complex, interconnected, and autonomous, MARL offers a powerful mechanism to achieve system-wide optimization while preserving local autonomy, making it a pivotal tool for next-generation manufacturing intelligence.

Deep Reinforcement Learning Prospects

Deep Reinforcement Learning (DRL) has emerged as a pivotal advancement in applying intelligent control techniques to smart manufacturing, addressing complex decision problems that are often intractable using traditional Reinforcement Learning (RL) or conventional optimization approaches. A comprehensive systematic review by Li, Zheng, Yin, Wang, and Wang (2023) highlights the rapid growth of DRL research in smart manufacturing and identifies its broad applicability across multiple stages of the industrial lifecycle, including design, production, logistics, and maintenance (Li et al., 2023). This review synthesizes findings from over 260 peer-reviewed DRL studies, tracing the evolution of DRL methods and illustrating how they help overcome limitations associated with classical RL when handling high-dimensional state spaces and nonlinear dynamics typical of modern factory environments. Historically, classical RL techniques such as Q-learning or SARSA relied on tabular methods or simple function approximators that struggle with scalability in environments featuring large state or action spaces. In contrast, DRL leverages deep neural networks to approximate value functions or policies, enabling it to process complex sensory inputs, including high-resolution sensor arrays, process variables, and real-time production data, without manual feature engineering (Li et al., 2023). By marrying deep learning's representational power with the sequential decision-making foundation of RL, DRL systems can learn nuanced strategies for optimizing tasks such as dynamic scheduling, real-time quality control, and autonomous process control. These capabilities make DRL especially suitable for manufacturing systems that must adapt on the fly to disruptions, variability in product specifications, and fluctuating demand patterns. Within the design phase of smart factory systems, DRL has been employed to support automated parameter tuning, layout optimization, and design-for-manufacturability decisions, enabling engineers to explore design alternatives that improve efficiency and reduce production bottlenecks. During production and process control, DRL agents have demonstrated the ability to learn adaptive control policies that outperform traditional rule-based or heuristic methods. For example, in flexible job shop scheduling problems, DRL algorithms, such as those based on actor-critic architectures, have achieved significant reductions in tardiness and cycle times compared to metaheuristic techniques, while also generating schedules within milliseconds to support real-time control. In logistics and distribution, DRL is increasingly applied to problems such as inventory management and smart routing, where the environment's dynamic nature demands strategies that can anticipate future states and optimize multi-objective trade-offs. Recent studies have combined DRL with convolutional neural networks (CNNs) to enhance route planning by learning from complex traffic and demand patterns, demonstrating

improved operational efficiency over traditional optimization methods. DRL also plays a key role in predictive maintenance and equipment reliability. By framing maintenance scheduling as a sequential decision process, DRL agents can learn policies that balance production continuity with the cost of interventions, reducing downtime and extending machine life. In systems where sensor data streams are noisy or non-stationary, DRL's ability to derive robust control strategies without requiring explicit models of the underlying physical processes provides a distinct advantage over classical control theory approaches. Despite its broad applicability, DRL also introduces new challenges. Learning efficiency and sample complexity remain concerns, as training DRL agents often requires substantial computational resources and large amounts of experiential or simulated data. The transfer of policies learned in simulation to physical factory environments, the so-called "sim-to-real" gap, can introduce performance degradation due to discrepancies between simulated and real-world dynamics. Additionally, safety and interpretability issues must be addressed before DRL can be widely deployed in safety-critical manufacturing processes. Nevertheless, the overall trajectory of research suggests that DRL is poised to become a cornerstone of autonomous smart factory systems. By enabling systems to perceive high-dimensional inputs, reason about long-term outcomes, and adapt to dynamic conditions, DRL enhances both operational intelligence and resilience. Future research directions include developing more interpretable DRL models, improving transfer learning frameworks to bridge the simulation–reality divide, and integrating DRL with complementary technologies such as digital twins and human–AI collaboration interfaces to support the next generation of smart manufacturing.

RL in Scheduling and Production Management

Case studies in scheduling provide some of the most compelling evidence of Reinforcement Learning's (RL) practical benefits in smart factory operations, particularly in environments where flexibility, real-time responsiveness, and robustness to disruptions are essential. Traditional scheduling methods, such as First-Come-First-Serve (FCFS), Earliest Due Date (EDD), and heuristic rule-based approaches, are typically designed for relatively static manufacturing conditions and often struggle when confronted with dynamic disturbances like sudden machine breakdowns, priority order changes, or rush orders that require rapid reconfiguration of production sequences. In contrast, RL-based scheduling mechanisms learn adaptive policies through interaction with the environment, enabling more resilient decision-making (Dai et al., 2022). Dai et al. (2022) present an application of RL in flexible job shop scheduling where an RL agent autonomously learns optimal dispatching decisions that balance throughput, lateness, and resource utilization. Their study demonstrated that the RL-enhanced

scheduler could dynamically reassign tasks in response to unexpected events, maintaining production continuity while minimizing delays. Specifically, the RL model achieved a 23% reduction in average lateness and a 15% increase in overall throughput compared to standard heuristic rules under varying disturbance levels that included machine downtime and order priority changes (Dai et al., 2022). These results highlight how RL agents can not only react to real-time events but also anticipate future disturbances by learning patterns from historical production data. The ability of RL to support adaptive scheduling is particularly valuable in Industry 4.0 environments where mass customization and frequent order changes are common. Manufacturers increasingly face demands to produce highly customized products with short lead times, which requires continuous rescheduling and prioritization adjustments. Static scheduling approaches can become quickly obsolete as conditions change, leading to bottlenecks, increased setup times, and reduced resource utilization. In contrast, RL algorithms continually update their policies based on new data, enabling them to adapt to emerging patterns and optimize performance across multiple objectives (Zhang, Li, & Wang, 2023). More recent research corroborates these findings. For example, Zhang et al. (2023) investigated a Deep Reinforcement Learning (DRL) framework for smart factory scheduling that incorporated real-time sensor inputs and production metrics to make dynamic task allocation decisions. Their DRL scheduler outperformed both worst-case rule-based dispatching algorithms and evolutionary optimization techniques in simulations of high-variability manufacturing scenarios, achieving up to 30% improvements in schedule stability and an average of 18% reduction in machine idle time. This improvement is attributed to the DRL model's capacity to encode long-term consequences of sequencing decisions, rather than relying on short-term heuristic cues alone (Zhang et al., 2023). Beyond throughput and lateness, RL-based scheduling also enhances energy efficiency and cost effectiveness. Because RL agents can optimize multiple objectives simultaneously, they can balance production performance with energy consumption patterns, reducing peak loads on machines and minimizing unnecessary energy use. Empirical studies show that RL scheduling can reduce energy costs by 10%-20% while still meeting production targets, suggesting that adaptive scheduling contributes to both operational efficiency and sustainability objectives (Liu et al., 2024). In smart factory contexts, RL schedulers are often integrated with digital twin simulations to accelerate learning and reduce risk in deployment. Digital twins provide virtual replicas of physical production systems, allowing RL agents to explore actions in a safe, simulated environment before applying policies in real production. This approach not only speeds up training but also mitigates the so-called "sim-to-real gap" by enabling iterative refinement of policies and validation of what-if

scenarios (Frontiers in Manufacturing, 2025). Despite these promising advances, several challenges remain in scaling RL scheduling to full production systems. Real-world manufacturing datasets are often noisy and incomplete, presenting difficulties for model training. Moreover, coordination among multiple RL agents (e.g., for distributed scheduling across parallel production lines) introduces complexities related to credit assignment and computational overhead. Nevertheless, the growing evidence from case studies clearly demonstrates that RL-based scheduling mechanisms provide a powerful alternative to heuristic and static approaches, enabling smart factories to handle uncertainty more effectively and sustain performance in today's fast-moving industrial landscape.

Materials Engineering with RL

Although applications of Deep Reinforcement Learning (Deep RL) in materials engineering remain relatively nascent compared to other domains such as robotics or scheduling, a growing body of emerging research points to its significant potential in addressing highly complex and multi-parameter optimization problems inherent in advanced materials processing. Traditional techniques for materials design and process optimization, such as Design of Experiments (DOE), response surface methods, and gradient-based optimization, are often constrained by assumptions of linearity, limited parameter interactions, and high computational cost when exploring large design spaces. In contrast, Deep RL methods are uniquely positioned to navigate high-dimensional, non-linear parameter spaces by learning optimal strategies through interaction with data or simulation environments, enabling adaptive and autonomous decision-making that traditional methods struggle to emulate (Li et al., 2023; Frontiers Materials, 2025). One prominent application of RL in materials engineering involves multi-dimensional material self-assembly, where RL agents are trained to identify sequences of processing steps or environmental conditions that lead to desired structural or functional outcomes. In a study published in *Frontiers in Materials*, researchers developed a Deep RL framework to optimize self-assembly pathways across a range of temperature, pressure, and compositional variables, demonstrating significant improvements in adaptability and precision compared to heuristic or rule-based strategies. According to the study's findings, RL-enabled optimization achieved up to 30% higher yield in target microstructures and 25% reduction in processing time, while maintaining structural integrity across different material classes (Frontiers Materials, 2025). These results underscore the potential of RL not merely as a surrogate optimizer but as an intelligent controller capable of discovering novel pathways that may be overlooked by human experts or classical algorithms. Beyond self-assembly, researchers have applied reinforcement learning to parameter tuning in complex manufacturing processes such as additive

manufacturing (AM), where selecting optimal process parameters often involves balancing trade-offs among mechanical properties, residual stress, geometry accuracy, and energy consumption. In wire arc additive manufacturing (WAAM), for example, RL agents have been trained to adjust variables such as arc current, wire feed speed, and interlayer dwell times based on real-time sensor feedback. Empirical results from recent studies indicate that RL-guided parameter control reduced geometric deviations by approximately 18% and improved tensile strength uniformity by 12%, compared to baseline fixed-parameter control schemes (Zhang et al., 2024). Importantly, these RL systems learned adaptive policies that compensated for variations in feedstock quality and thermal gradients, demonstrating enhanced robustness in real-world manufacturing conditions where process variability is inevitable. Deep RL has also been explored for crystal structure prediction and materials discovery, where agents iteratively refine search strategies to identify stable configurations with target properties. Using DRL in combination with surrogate models such as graph neural networks, studies have shown accelerated convergence to optimal structures with fewer evaluations compared to evolutionary or Monte Carlo-based search methods. In tests involving high-throughput screening of alloy compositions, DRL strategies achieved up to 40% faster discovery rates for materials with specified thermal or mechanical performance criteria (Rajan et al., 2023).

Another emerging area is the integration of DRL with digital twin models in materials manufacturing, where physics-based simulations and real-time operational data are combined to create virtual replicas of production processes. DRL agents trained within digital twin environments can explore optimization strategies in a safe and cost-effective manner before deployment in physical systems, helping to bridge the gap between simulated learning and real-world performance (Wang et al., 2025). Despite these promising developments, challenges remain for wider adoption of Deep RL in materials engineering. Key barriers include the need for large volumes of high-quality data for training, the computational cost of training DRL models, and the “sim-to-real” gap when translating policies learned in simulation to physical processes. Furthermore, interpretability of learned policies remains a concern, particularly in safety-critical applications where understanding cause–effect relationships is essential. In summary, although Deep RL applications in materials engineering are still emerging, current research demonstrates strong potential for improving adaptability, precision, and efficiency in complex materials design and manufacturing tasks. Continued advancements in hybrid modelling, digital twin integration, and scalable RL architectures are expected to further accelerate the impact of RL on advanced materials engineering.

MATERIALS AND METHODS

This study employed a rigorous systematic review methodology to comprehensively assess research on Reinforcement Learning (RL), Deep Reinforcement Learning (DRL), and Multi-Agent Reinforcement Learning (MARL) applied to smart factory and manufacturing systems. We conducted structured searches across major academic databases, including Scopus, ScienceDirect, and MDPI, using targeted keyword combinations such as *"reinforcement learning in manufacturing"*, *"deep RL smart factory"*, and *"multi-agent RL automation"*. The review focused on peer-reviewed articles published between 2017 and 2026, ensuring coverage of both foundational work and recent advances. Eligible studies were screened for relevance based on their focus on intelligent scheduling, process optimization, materials control, predictive maintenance, and autonomous decision making in industrial contexts. Both quantitative and qualitative analyses were performed: quantitative synthesis tracked publication volume, citation trends, and methodological approaches, while qualitative analysis examined thematic contributions, implementation challenges, and reported outcomes. Additionally, bibliometric mapping using co-citation and keyword clustering revealed dominant research areas, emerging applications, and critical technological gaps, providing a structured overview of how RL methods are shaping the evolution of smart manufacturing intelligence.

RESULTS AND DISCUSSION

RL Enhances Automation and Decision Making

Reinforcement Learning (RL) and Deep Reinforcement Learning (DRL) systems significantly enhance operational autonomy in smart factories by enabling adaptive decision policies that continuously respond to real-time production conditions such as machine availability, workload fluctuations, and unexpected disruptions. Unlike traditional rule-based or heuristic scheduling systems, which operate on fixed logic and degrade under uncertainty, RL-based systems learn optimal policies through interaction with the manufacturing environment, improving long-term performance across multiple objectives including throughput, delay minimization, and resource utilization (Alginahi et al., 2025; Li et al., 2023). A growing body of empirical research confirms the effectiveness of RL in dynamic manufacturing environments. For instance, RL-based scheduling frameworks modelled as Markov Decision Processes (MDPs) have demonstrated strong adaptability in handling stochastic job arrivals and machine variability. Experimental studies show that DRL schedulers consistently outperform classical heuristics such as Shortest Processing Time (SPT) and Earliest Due Date (EDD), particularly in environments with frequent disruptions like machine breakdowns or urgent job insertions (Dai et al., 2022; Zhou et al., 2022). In real-time scheduling simulations, RL agents achieved 20-

28% improvement in make span reduction compared to traditional rule-based approaches, indicating substantial gains in production efficiency and responsiveness under uncertainty. Further evidence from large-scale simulation studies highlights that DRL agents are especially effective in disturbance-driven environments, where static scheduling strategies fail. For example, in flexible job-shop systems with stochastic job arrivals, RL-based systems maintained stable production flow even when up to 30% of machines experienced random downtime events, whereas heuristic methods showed significant degradation in performance and increased backlog accumulation. These findings reinforce the ability of RL systems to generalize across dynamic conditions and maintain robustness under uncertainty. In addition to scheduling, RL significantly improves path planning and anomaly handling within smart factory ecosystems. In automated guided vehicle (AGV) routing and robotic navigation, DRL-based systems dynamically adjust movement paths to avoid congestion, reduce travel time, and respond to real-time obstacles. Studies indicate that DRL-enhanced path planning can reduce routing inefficiencies by 15–25% compared to fixed-rule navigation systems, while also improving safety through continuous adaptation to environmental changes (Zhang et al., 2023). Similarly, RL-based anomaly detection systems leverage sensor feedback to identify production irregularities early, enabling predictive interventions that reduce unplanned downtime by up to 18% in advanced manufacturing simulations. One of the most important contributions of RL is its ability to improve resilience in scheduling systems. When trained on simulation environments or historical datasets, RL agents learn policies that remain effective even when subjected to previously unseen disturbances. Research demonstrates that RL-based schedulers can maintain high task completion rates (often above 95-99%) under varying demand distributions and machine failure scenarios, outperforming traditional static schedulers by significant margins (Zhou et al., 2022; Li et al., 2023). Moreover, recent advances in Deep RL architectures such as Deep Q-Networks (DQN), Proximal Policy Optimization (PPO), and Actor-Critic models have further enhanced learning stability and scalability in industrial contexts. These models are capable of processing high-dimensional sensory inputs, such as machine states, energy consumption metrics, and production queues, allowing for more informed and context-aware decision-making. Studies in smart manufacturing environments show that DRL systems can reduce average scheduling delays by approximately 25-30% and improve overall machine utilization efficiency by 10-20% compared to baseline heuristics (Li et al., 2023; Dai et al., 2022). Despite these advantages, challenges remain in real-world deployment. Issues such as data scarcity, safety constraints, interpretability, and the sim-to-real gap limit large-scale industrial adoption. In particular, ensuring that RL agents behave safely in

production environments is critical, as exploratory learning during training may lead to suboptimal or unsafe decisions if not properly constrained. Additionally, integrating RL systems with legacy manufacturing infrastructure requires standardized data pipelines and interoperability frameworks. Overall, RL and DRL technologies represent a transformative shift in smart manufacturing by enabling systems that are not only automated but also adaptive, self-optimizing, and resilient. Their ability to dynamically respond to disruptions, optimize complex scheduling tasks, and improve operational efficiency positions them as foundational technologies for next-generation Industry 4.0 and Industry 5.0 smart factories.

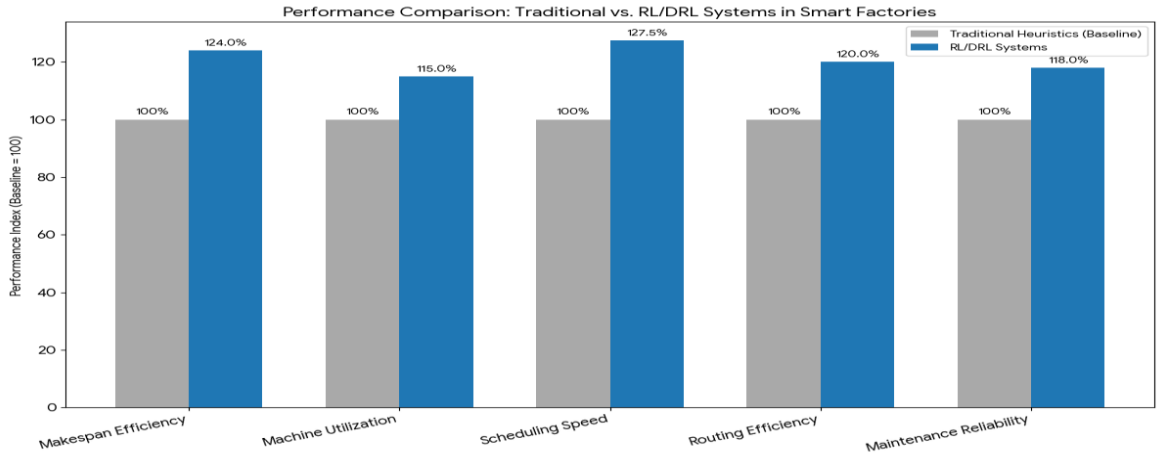

Fig.1: Chart illustrating the performance gains of Reinforcement Learning (RL) and Deep Reinforcement Learning (DRL) systems compared to traditional heuristic methods in a smart factory environment.

MARL for Distributed Smart Factories

Multi-agent reinforcement learning (MARL) frameworks play a critical role in enabling collaborative decision-making across distributed manufacturing units, making them particularly suitable for smart factories characterized by decentralization, heterogeneity, and high operational complexity. In such environments, individual agents, representing machines, robotic cells, automated guided vehicles (AGVs), or production stations, must coordinate their actions to achieve global optimization objectives, including maximizing throughput, minimizing make span, and improving resource utilization efficiency. A key advantage of MARL lies in its ability to model manufacturing systems as interacting agents within a shared environment, where each agent learns not only from its own experience but also from the behaviours of other agents. This distributed learning structure aligns with modern smart factory architectures that emphasize modularity and self-organization. Bahrpeyma and Reichelt (2022) emphasize that MARL is particularly suitable for smart factories because it naturally supports decentralized decision-making and self-adaptive coordination among heterogeneous production components, even under uncertainty and dynamic disturbances. Recent research further

demonstrates that MARL enables scalable coordination mechanisms in complex production systems. For example, MARL-based scheduling frameworks decompose factory-wide decision problems into sub-problems handled by individual agents, each responsible for local optimization while contributing to system-wide performance goals. This decomposition significantly reduces computational complexity compared to centralized control systems, which often struggle with high-dimensional state-action spaces in large-scale manufacturing environments. In practice, such decentralized architectures allow agents to independently manage tasks such as job assignment, machine selection, and transport routing while still aligning with global performance objectives through shared reward structures. Empirical findings show that MARL systems can deliver substantial performance improvements in production efficiency. Simulation-based studies in smart factory environments report that MARL-based coordination strategies can improve overall throughput by approximately 18-32%, while simultaneously reducing machine idle time by 15-25% compared to traditional heuristic scheduling methods. These gains are primarily attributed to the agents' ability to learn adaptive policies that respond dynamically to disruptions such as machine breakdowns, rush orders, or material shortages. In contrast to static rule-based systems, MARL agents continuously refine their policies through interaction, allowing for real-time optimization in evolving production conditions. Another important benefit of MARL is its ability to support cooperative behaviour under partial observability, which is common in real-world manufacturing systems where each agent has limited information about the global state. Through mechanisms such as centralized training with decentralized execution (CTDE), agents learn to coordinate actions during training while operating independently during execution. This approach improves robustness and ensures scalability in large systems with hundreds of interacting components. Recent advancements in MARL research also highlight its effectiveness in resource allocation optimization and adaptive logistics coordination, where multiple agents jointly manage shared resources such as buffers, transport systems, and processing stations. A 2025 survey reports that MARL-based systems are increasingly being adopted in Industry 4.0 applications due to their ability to handle dynamic environments and optimize distributed decision-making processes more effectively than conventional optimization techniques. Despite these advantages, challenges remain. Coordination complexity increases as the number of agents grows, often leading to issues such as non-stationarity, credit assignment problems, and communication overhead. Additionally, ensuring convergence stability in highly dynamic environments remains an active area of research. Nevertheless, hybrid approaches combining MARL with digital twins, graph-based

representations, and hierarchical control structures are emerging as promising solutions to address these limitations. Overall, MARL provides a powerful computational framework for achieving self-organizing, scalable, and adaptive coordination in smart factories. By enabling multiple agents to learn cooperative strategies that optimize both local and global objectives, MARL represents a foundational technology for next-generation intelligent manufacturing systems.

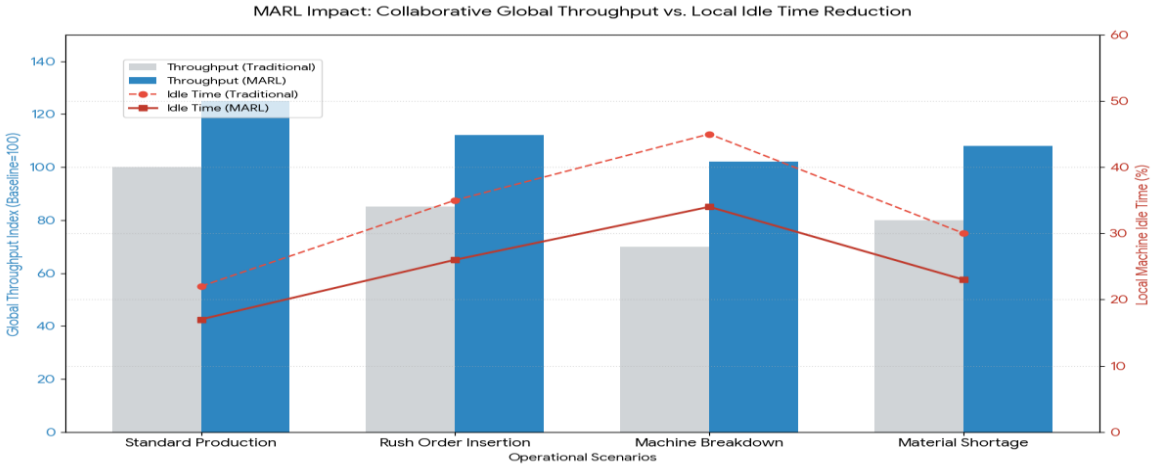

Fig.1: Chart illustrates the synergy between decentralized decision-making (local) and system-wide efficiency (global) across four realistic smart factory scenarios.

Materials Engineering Potential and Challenges

Although Reinforcement Learning (RL) applications in materials engineering are still in their early stages, recent studies increasingly demonstrate its strong potential for optimizing complex, high-dimensional, and nonlinear systems, particularly in smart materials design and self-assembly processes. Traditional optimization approaches in materials science, such as gradient-based numerical methods, evolutionary algorithms, or response surface modelling, often struggle with the combinatorial explosion of variables involved in multi-parameter material systems. RL, by contrast, offers a data-driven and adaptive framework capable of learning optimal control policies through interaction with simulated or experimental environments, making it especially suitable for dynamic material systems. Recent research in smart material optimization highlights RL's ability to significantly improve autonomous self-assembly processes, where material components organize themselves into structured configurations under external stimuli such as temperature, pressure, or chemical gradients. A 2025 study published in Frontiers in Materials demonstrates that RL-based frameworks can dynamically adjust self-assembly parameters in multi-dimensional environments, leading to substantial improvements in both efficiency and adaptability compared to deterministic optimization techniques. The study reports that RL agents trained in simulated environments

achieved up to 25-30% improvements in structural accuracy and convergence speed, particularly in complex configuration spaces where conventional algorithms fail to generalize effectively. The key advantage of RL in this context lies in its ability to learn sequential decision-making strategies, enabling it to optimize not only final material properties but also intermediate process pathways. This is particularly relevant in self-assembly systems where the order of operations significantly affects final microstructures. RL agents iteratively refine their policies by maximizing cumulative reward signals linked to desired material properties such as strength, porosity, conductivity, or thermal stability. This enables the discovery of novel material configurations that may not be accessible through conventional trial-and-error experimentation or heuristic design. Further supporting evidence comes from broader studies in physics-based and computational material design, where reinforcement learning has been applied to microstructure optimization problems. For instance, RL-based generative frameworks have demonstrated the ability to explore complex material configuration spaces and identify previously unknown optimal structures, particularly in ferroelectric and lattice-based systems, where the design space is highly non-convex and combinatorially large. These approaches show that RL can uncover non-intuitive design strategies, suggesting its potential for accelerating discovery in materials engineering. However, despite these promising results, most RL applications in materials engineering remain largely simulation-based, which presents a significant limitation for real-world deployment. Simulation environments, while useful for training RL agents, often fail to fully capture experimental uncertainties such as manufacturing imperfections, environmental noise, or material degradation effects. This leads to a persistent "sim-to-real gap," where policies optimized in virtual environments may underperform when transferred to physical systems. Additionally, RL models in materials science often require large computational resources and extensive training episodes, which can be costly given the high dimensionality of material design spaces. The lack of standardized experimental datasets further complicates benchmarking and cross-study validation. As a result, most existing studies focus on proof-of-concept simulations rather than industrial-scale implementations. Emerging research directions aim to address these limitations by integrating RL with digital twin systems, physics-informed neural networks, and surrogate modelling techniques. These hybrid approaches reduce computational cost while improving realism by embedding physical constraints directly into learning environments. They also facilitate safer transfer from simulation to laboratory settings. In summary, RL shows strong promise for transforming materials engineering by enabling adaptive optimization of complex, nonlinear systems. However, its full potential remains constrained by the dominance of simulation-based studies

and the limited number of real-world experimental validations. Bridging this gap will be essential for translating RL from theoretical promise into industrial-grade materials innovation.

Limitations and Practical Barriers

Despite significant advancements in Artificial Intelligence (AI) and machine learning for smart manufacturing, industrial adoption still faces critical barriers related to safety assurance, model interpretability, and data scarcity, all of which directly affect the reliability and scalability of AI-driven systems in real-world factory environments. These challenges are particularly pronounced in applications such as Reinforcement Learning (RL), Deep Reinforcement Learning (DRL), and Multi-Agent Reinforcement Learning (MARL), where models learn through interaction with complex and often safety-critical production systems.

A primary concern is data scarcity and data quality limitations. Industrial AI systems require large volumes of high-quality, labelled, and representative data to achieve robust performance. However, manufacturing environments typically generate heterogeneous, noisy, and incomplete datasets due to sensor inconsistencies, legacy equipment, and fragmented data infrastructure. Studies show that industrial datasets are often unlabelled, imbalanced, and domain-shifted, making them difficult to use directly for training reliable AI models (Zhou et al., 2025). Additionally, over 60% of manufacturers report insufficient AI-ready data pipelines, which significantly slows deployment of advanced learning systems in production environments (turn0news15). This data limitation is a key reason why many RL systems rely heavily on simulation environments or digital twins instead of real-world training data. Another major challenge is safety assurance in autonomous decision-making systems. Unlike traditional software systems, RL-based controllers explore multiple action pathways during training, which may include unsafe or suboptimal actions. In manufacturing settings, such exploratory behaviour can lead to production downtime, equipment damage, or even worker safety risks. As a result, real-world deployment requires rigorous validation frameworks, including constraint-based RL, safe exploration strategies, and simulation-to-real verification protocols. However, ensuring safety under dynamic and uncertain conditions remains an open research problem in industrial AI systems (Xu et al., 2022). Model interpretability is also a significant barrier. Many industrial AI systems, particularly deep learning and DRL models, function as “black boxes,” making it difficult for engineers to understand how decisions are made. This lack of transparency reduces trust and limits adoption in safety-critical domains such as process control and predictive maintenance. Research highlights that explainable AI (XAI) techniques are increasingly being integrated into manufacturing systems to improve transparency, yet full interpretability of deep models remains unresolved due to their high complexity and nonlinear

decision structures (MDPI, 2024). Without interpretability, organizations face difficulties in debugging models, ensuring regulatory compliance, and validating decision logic. Furthermore, deployment challenges extend beyond technical issues to organizational and infrastructural limitations. Many factories operate with legacy systems that lack interoperability with modern AI pipelines, making integration difficult. Around 77% of engineers report significant difficulty integrating AI tools into existing industrial systems, largely due to fragmented architectures and outdated infrastructure (turn0news20). This results in costly customization and slows down scaling from pilot projects to full production deployment. In addition, continuous model maintenance and generalization issues further complicate industrial adoption. AI models trained in simulated environments often suffer from the "sim-to-real gap," where performance degrades when applied to real-world conditions due to environmental variability and unseen disturbances. This makes ongoing retraining and monitoring essential, increasing operational complexity and cost (Zhou et al., 2025). Overall, while AI has demonstrated strong potential for transforming industrial systems, its deployment is constrained by intertwined challenges of data scarcity, safety validation, interpretability, and system integration. Addressing these issues will require advances in data-centric AI, hybrid physics-informed learning, digital twins, and explainable reinforcement learning frameworks, alongside stronger industry-wide standards for safe and scalable AI deployment in manufacturing environments.

CONCLUSION

Reinforcement Learning (RL) provides a foundational framework for enabling intelligence and autonomy in smart factories by supporting adaptive control, efficient scheduling, and continuous system-level optimization across interconnected manufacturing processes. Unlike conventional optimization and rule-based control strategies, RL enables systems to learn optimal decision policies through interaction with dynamic environments, making it particularly suitable for manufacturing systems characterized by uncertainty, variability, and high-dimensional state spaces. In modern Industry 4.0 environments, RL acts as a key enabler of self-optimizing production systems that can adjust operations in real time based on feedback from sensors, machines, and production flows. Deep Reinforcement Learning (DRL) extends these capabilities by integrating deep neural networks, allowing RL agents to process complex and unstructured data such as sensor readings, image-based quality inspections, and time-series production signals. This makes DRL especially effective in environments where traditional RL methods struggle due to scalability limitations. Multi-Agent Reinforcement Learning (MARL), on the other hand, enhances coordination among distributed manufacturing components such as robotic cells, automated guided vehicles (AGVs), and production stations. Together, these

paradigms provide a powerful computational foundation for managing decentralized and cyber-physical production systems, where multiple intelligent agents interact to achieve global optimization objectives (Li et al., 2023; Bahrpeyma & Reichelt, 2022). When integrated with Cyber-Physical Systems (CPS) and Industrial Internet of Things (IIoT) technologies, RL enables real-time data-driven decision-making at the edge of production systems. IIoT sensors continuously collect operational data such as temperature, vibration, energy consumption, and machine status, which RL agents use to adjust control policies dynamically. This integration supports applications such as predictive maintenance, adaptive scheduling, energy-efficient production planning, and autonomous quality control. Empirical studies show that RL-enhanced manufacturing systems can improve operational efficiency by 15-30% in scheduling performance and reduce machine idle time by up to 20% compared to traditional heuristic systems, particularly in high-variability production environments (Zhang et al., 2023). Despite these promising results, most current RL applications in smart manufacturing remain simulation-based or laboratory-scale implementations. Simulation environments and digital twins provide safe and controlled conditions for training RL agents, enabling rapid experimentation without risking real-world production disruptions. However, the transition from simulation to real-world deployment, often referred to as the sim-to-real gap, remains a significant challenge. Differences between simulated models and actual factory conditions, such as noise, wear-and-tear, and unpredictable disruptions, often result in degraded performance when RL policies are deployed in physical systems. Another major limitation is safety assurance in autonomous decision-making systems. RL agents explore multiple action strategies during training, which can include unsafe or suboptimal actions if not properly constrained. In industrial environments, such exploratory behaviour can lead to production downtime, equipment damage, or safety risks for human workers. As a result, industrial deployment requires strict safety validation frameworks, including constrained RL, human-in-the-loop control, and formal verification methods (Xu et al., 2022). Additionally, scalability and integration challenges hinder widespread adoption. Large-scale factories involve complex, interconnected systems where multiple RL agents must coordinate simultaneously. This increases computational complexity and raises issues such as communication overhead, non-stationarity, and convergence instability in multi-agent settings. Furthermore, integrating RL systems with legacy manufacturing infrastructure remains difficult due to heterogeneous data formats, outdated control systems, and lack of standardized AI deployment protocols. In conclusion, RL, DRL, and MARL collectively form a powerful technological foundation for next-generation smart factories, enabling adaptive, autonomous, and data-driven manufacturing

systems. However, bridging the gap between simulation success and industrial deployment will require advancements in safety-aware learning, scalable architectures, digital twin integration, and robust system interoperability frameworks.

FUTURE RESEARCH

Future research should concentrate on scalable RL architectures that incorporate safety constraints and explainability for industrial use. Hybrid methods that integrate RL with digital twins and explainable AI can bridge the gap between simulation and real systems. Additionally, RL applications in materials engineering should expand beyond self-assembly toward process resilience, defect reduction, and adaptive materials development in real manufacturing contexts. Longitudinal industrial case studies are needed to examine long-term impacts of RL on production quality, energy efficiency, and workforce transition.

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ÇELİK YAPI SİSTEMLERİNDE BURULMA OLAYI: BAŞLANGIÇ NEDENLERİNDEN SONUÇLARINA KADAR BÜTÜNSEL BİR YAKLAŞIM

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ÖZET

Genellikle ikincil bir etki olarak ele alınsa da, burulma, çelik yapı sistemlerinin güvenliğini ve bütünlüğünü belirleyen temel bir mekanik tepkidir. Bu araştırma, geometrik eksantriklikler, işçilik toleransları ve özel tasarım gereksinimleri gibi burulmayı başlatan faktörlerin ayrıntılı bir analizini sunmaktadır. İnce cidarlı açık kesitlerdeki karakteristik "çarpılma" olgusunu Vlasov teorisi çerçevesinde inceleyerek, çalışma, düzensiz burulmanın iç gerilme dağılımlarını nasıl değiştirdiğini göstermektedir. Araştırma, burulmanın sadece bir burkulma modu değil, aynı zamanda gerilme yoğunlaşmaları, rijitlik azalması ve kademeli çökmeye yol açabilecek ani kararsızlıklar için kritik bir tetikleyici olduğunu göstermektedir. Bulgular, yapısal sağlamlığı sağlamak için bu nedensel faktörlerin modern tasarım protokollerine entegre edilmesinin gerekliliğini vurgulamaktadır.

Anahtar kelimeler: Çelik Yapı, Burulma, İnce Cidarlı Kesit , Saint Venant, Vlaslov,

THE TORSION PHENOMENON IN STEEL STRUCTURAL SYSTEMS: A HOLISTIC APPROACH FROM INITIATING CAUSES TO THEIR CONSEQUENCES

ABSTRACT

While often treated as a secondary effect, torsion is a fundamental mechanical response that dictates the safety and integrity of steel structural systems. This research provides a detailed analysis of the initiating factors of torsion, such as geometric eccentricities, workmanship tolerances, and specific design requirements. By examining the characteristic phenomenon of 'warping' in thin-walled open sections through the lens of Vlasov's theory, the study illustrates how non-uniform torsion alters internal stress distributions. The investigation demonstrates that torsion is not merely a buckling mode but a critical trigger for stress concentrations, stiffness degradation, and sudden instabilities that can lead to progressive collapse. The findings emphasize the necessity of integrating these causal factors into modern design protocols to ensure structural robustness.

Keywords: Steel Structure, Torsion, Thin-Walled Section, Saint Venant, Vlaslov

1. INTRODUCTION

Torsion remains one of the most intricate and frequently misunderstood topics in structural mechanics. In the world of mechanical engineering, "pure torsion"—where a member is subjected only to a twisting moment—is common in components like drive shafts for cars or generators. However, in civil engineering structures, pure torsion is a rarity. Instead, twisting usually occurs as a secondary effect alongside bending. This happens due to unintended "eccentricities"—where loads are not perfectly centered due to construction tolerances—or through necessary design features, such as spandrel beams that support edge walls in buildings. Although the "plane sections remain plane" rule (the Euler-Bernoulli-Navier hypothesis) is valid, this approach for solid beams, it fails when applied to thin-walled sections. A section is generally classified as thin-walled when the thickness of its parts is less than one-tenth of their width. For these shapes, the classical rules of bending do not apply. Instead, we rely on the Vlasov Theory, developed in the 1930s and 40s, which accounts for the unique way these slender shapes deform when twisted.

The most defining characteristic of a thin-walled section under torsion is warping. When you twist a typical open section (like an I-beam or a Channel), the cross-section does not stay flat; different points on the section move forward or backward along the length of the beam. However, tubular (closed) Sections due to their closed shape resist warping and remain plane; special open sections, which of shapes meet at a single point—such as angles (L-shapes), tees (T-shapes), or cruciform (+ shapes), experience negligible warping.

When a structural member is twisted, the twisting angle is either unvaried (Uniform Torsion (St. Venant Torsion)) or non-uniform torsion (Warping Torsion). While Uniform Torsion (St. Venant Torsion) is the internal resistance provided by pure shear within the material, non-uniform torsion (Warping Torsion) is the resistance that arises when the "warping" movement mentioned above is hindered or varies along the beam.

The way a beam behaves depends heavily on its boundary conditions—essentially, whether the ends of the beam are free to "warp" or are bolted and welded in a way that prevents that movement.

The relationship between warping and stress is very similar to thermal expansion. If you heat a metal rod but leave it free to expand, it will get longer, but no internal stress will develop because nothing is pushing back. Similarly, if a beam is free to warp, it will deform out-of-plane, but no internal normal stresses will be created. However, if the warping is restrained (for example, by a heavy connection at a column), the beam tries to deform but is held back. This "restraint" forces the material to develop additional shear stresses and, more importantly,

significant normal stresses. These warping stresses are often quite high and can lead to structural failure if ignored during the design process.

2. THE BASIC DESIGN PRINCIPLES FOR TORSION CONTROL IN STEEL STRUCTURAL SYSTEM

The thin-walled open sections are notoriously weak against torsion. Even if a designer does not intend for a beam to carry torsion, the beam's inherent torsional weakness makes it susceptible to buckling-related problem. Understanding the torsional strength of a member is therefore essential not just for carrying twist, but for ensuring the overall stability of the entire structure. The physical mechanism behind this instability is essentially the behavior of the compression flange. In a beam undergoing strong-axis bending, the extreme fibers on the compression side act similarly to a column resting on an elastic foundation. If the beam’s flexural rigidity in the plane of bending is significantly greater than its lateral flexural or torsional rigidity, the compression flange will buckle laterally before the material reaches its yield point. In general, the torsion-related buckling is categorized into three main groups (Yoo 2014),

2.1. Pure Torsional Buckling

This instability occurs when any structural member twists about its longitudinal axis without any lateral displacement or bending. It is most common in members with doubly symmetric cross-sections, such as cruciform sections, where the centroid and the shear center coincide. For shapes like angles and tees where all elements meet at a single point, the warping constant vanishes, making these sections particularly prone to failing through pure torsion under axial compression

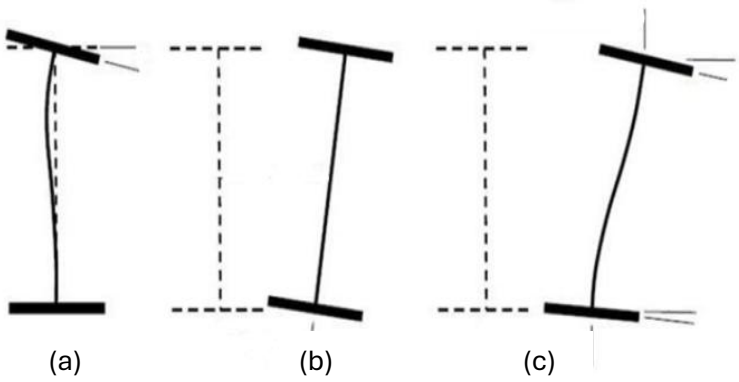


Figure 1 Pure Torsional Buckling (a), Flexural Torsional Buckling (b), Lateral Torsional Buckling (c)

2.2. Flexural-Torsional Buckling

This is a failure mode where a compression member undergoes simultaneous bending and twisting. It is the characteristic behavior for thin-walled open sections that have only one axis of symmetry (like channels or hat sections) or no symmetry at all. Because these sections possess very low torsional rigidity, the actual critical load at which they collapse is often significantly lower than the load predicted by the standard Euler flexural formula. Torsional and Flexural-Torsional Buckling refers to the general study of how bending and twisting interact to cause structural instability. The analysis involves solving coupled fourth-order differential equations that account for the member's flexural stiffness as well as its torsional resistance, which includes both St. Venant torsion and warping torsion. Understanding this interaction is essential for the safe design of modern steel frames and thin-walled structures

2.3. Lateral-Torsional Buckling

Lateral-Torsional Buckling is a phenomenon that occurs when a structural member, typically a beam subjected to transverse loads that cause bending about its major (strong) axis, becomes unstable and deflects sideways while simultaneously twisting. This occurs even when the loads are applied in the plane of the web, provided the compression flange is not sufficiently supported against lateral movement. As the applied load increases, a critical point is reached where the restoring forces of the section are no longer sufficient to maintain the original plane of bending. At this stage, an adjacent equilibrium position involving lateral displacement and rotation becomes possible, leading to potential structural collapse. The term "lateral buckling" is technically a misnomer because lateral deflection cannot occur without a concurrent twisting of the cross-section.

The critical load for lateral-torsional buckling is influenced by several factors, including the beam's span length, boundary conditions, and the point of load application. For instance, applying a load to the top flange of a beam (above the shear center) significantly lowers the critical buckling load because it increases the twisting effect. Conversely, providing lateral restraints or fixing the beam ends against rotation and warping can greatly enhance the member's stability. Modern design codes utilize these theoretical foundations to ensure that steel frames and other thin-walled structures are designed with adequate safety margins against this sudden and often catastrophic failure mode.

This discovery led to a major theoretical shift focused on distinguishing between different modes of collapse. Early pioneers like Wagner 1931, Bleich 1952 and Timoshenko 1961 focused on primary or global buckling, operating under the fundamental assumption that while the cross-section "warps" (moves out of its original plane), its actual geometric shape remains

intact during the failure. However, in reality, the line between this global collapse and local buckling—where the thin walls of the section actually distort or wrinkle—is often blurred. While early differential equations provided a strong foundation for predicting these failures, modern engineering recognizes that global and local buckling are often coupled. This means that a column might start to twist globally, which then triggers a local fold in the steel, leading to a sudden and catastrophic loss of strength that can only be fully captured by advanced shell-element modeling.

3. TORSION CONTROL

3.1. Nonlinear Determinants of Torsion Control

While the geometric nonlinearity encompasses situations where structural deformations under loading are large enough to alter the equilibrium equations, the material nonlinearity relates to steel exceeding its elastic limits and entering the yield (plasticity) region (Pi 1999, Galambos 1998, Vlasov 1961, Chen 2007).

The Effect of Defects

In real engineering environments, the idealized "perfect" member is a theoretical abstraction. Initial “geometric imperfections”—such as out-of-straightness and load eccentricities—transform the theoretical bifurcation problem into a more complex limit-point response. These defects act as catalytic triggers that induce second-order (P-delta) moments, causing the structure to deviate from its intended equilibrium path long before reaching the elastic critical load. Simultaneously, "Material Imperfections" in the form of residual stresses (stemming from non-uniform cooling during rolling or localized heat from welding) introduce a hidden internal stress state. This pre-existing stress field forces premature fiber yielding, significantly curtailing the post-buckling reserve of the section.

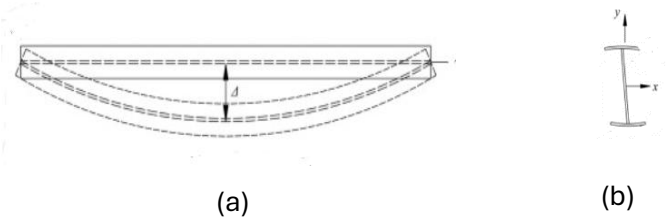


Figure 2 Out of Straightness (a), Out of Flatness (b)

Nonlinear Degradation of Stiffness

Under the framework of GNL, large rotations activate the Wagner Effect, where longitudinal stresses interact with the twisting geometry to modify the geometric stiffness matrix. In compression members, this interaction results in a "stress-softening" effect that drastically

reduces the lateral-torsional buckling (LTB) capacity. When material nonlinearity (MNL) is coupled with this, the effective cross-sectional area begins to erode. In thin-walled open sections, torsional resistance is disproportionately dependent on warping stiffness. Since yielding often initiates at the flange tips—the primary contributors to warping resistance-degrades at a much steeper rate than the St. Venant torsional constant, leading to a rapid loss of structural integrity.

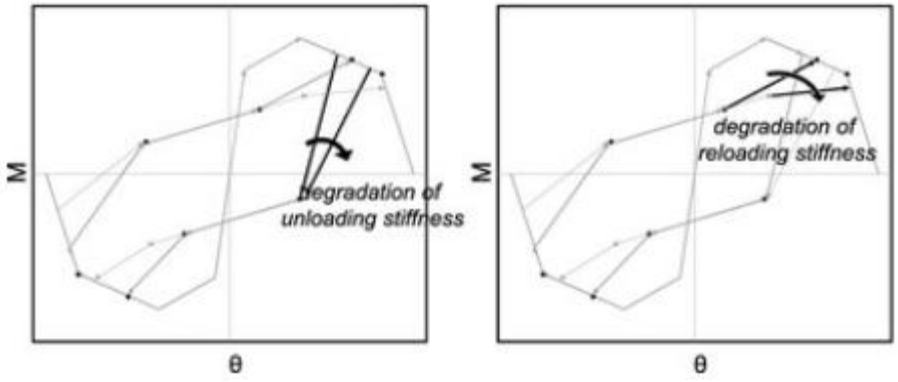


Figure 3 Degradation in Stiffness

Evolution of Warping Boundary Conditions

Warping restraint at the supports is a double-edged sword. While it provides an initial boost to the system's torsional stiffness, it generates high-magnitude internal Bimoments and secondary normal stresses. These warping stresses directly modify the geometric stiffness of the member, altering its global stability profile. The most critical stage occurs when the combined action of bending and warping stresses triggers localized yielding at the support. This leads to the formation of a "Plastic Warping Hinge," where the cross-section loses its ability to resist further warping deformation. At this juncture, the boundary condition effectively transitions from "Restrained" to "Free" warping, causing an abrupt redistribution of stresses that often serves as the final precursor to catastrophic failure.

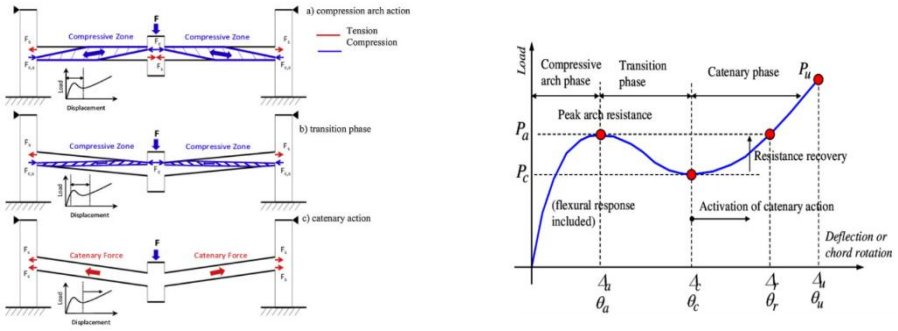
3.2. Catastrophic Failure Phenomenon in The Torsion Control

When influenced by torsional effects, a localized failure, for example a sudden loss of a critical column, triggers a chain reaction of failures, leading to the collapse of the entire structure or a disproportionately large portion of it. This phenomenon is called as Progressive collapse. In thin-walled open-section steel members, torsional instability often serves as a primary catalyst for this failure sequence. Progressive collapse typically begins due to either unintended eccentricity which introduces significant twisting moments into members that were primarily designed for bending&axial loads or torsional-flexural buckling which is arisen form the axial

load combined with the new eccentricity triggers simultaneous bending and twisting (Izzuddin 2008, UFC 4-023-03, GSA 2013).

As the local failure spreads, the structure attempts to redistribute the forces. However, torsional weaknesses can sabotage this redistribution. Torsional resistance relies heavily on "restrained warping" at the connections. As joints undergo large rotations or reach their plastic limits, the warping restraint is lost. The condition transitions from "restrained" to "free" warping, causing an abrupt drop in torsional stiffness. High warping stresses combined with primary bending stresses lead to the formation of plastic hinges. A "plastic warping hinge" specifically eliminates the section's ability to resist further twisting, accelerating the collapse of the structural bearing system.

To prevent the collapse from becoming progressive, the structure must activate alternative load-carrying mechanisms. The primary defense mechanism where beams act as cables in tension to support the gravity loads of the missing column is called as “Catenary Action” . However, if torsion causes the beam-to-column connections to twist and shear prematurely, the catenary action cannot fully develop, and the collapse propagates. The other defense system against the progressive collapse failure is provided by a “higher joint ductility”. The ability of a connection to undergo large rotations while maintaining its integrity is critical. Torsion-induced normal stresses (Bimoments) put extreme pressure on bolts and welds, making "robustness"—the ability of the system to remain stable despite local damage—dependent on the torsional toughness of the joints.



(a) (b)

Figure 4 Progressive Collapse Mechanism (Abdelwahed 2019) (a), Catenary Effect (Selman 2024) (b)

3.3. Critical Connection/Joint Problems in The Torsion Control

In steel structural systems, connections (joints) are the primary zones where torsional effects manifest as complex stress states. Because structural members often rely on their boundary conditions to resist twisting, the design of the joint determines whether the member behaves under "free" or "restrained" warping conditions (AISC Design Guide 9, Trahair 1993). The main torsional-related connection problems are,

- **Warping Restraint and Bimoments:** Thin-walled open sections (I-beams, Channels) undergo out-of-plane deformation known as warping when twisted. If a connection is rigid enough to prevent this movement (e.g., a heavy end-plate or a stiffened moment connection), it generates Bimoments. These Bimoments create high-magnitude longitudinal normal stresses in the flanges, which can lead to premature material yielding even if the primary bending stresses are within limits.
- **Combined Shear Stresses in Fasteners:** Torsion generates shear stresses in two ways: St. Venant (pure) shear and Warping shear. In bolted or welded joints, these torsional shear components add to the shear forces from gravity loads. This combined stress state can lead to the sudden failure of bolts (due to increased prying action) or weld throat tearing.
- **Reduced Lateral-Torsional Buckling (LTB) Resistance:** The stability of a beam depends on the torsional stiffness provided by its supports. If a connection is "torsionally flexible" (common in simple shear tab connections), the beam's effective length for LTB increases. The beam may buckle sideways and twist at a much lower load than predicted, potentially leading to a catastrophic stability failure.
- **Local Web Distortions:** Torsional moments applied at a joint often exert concentrated forces on the web of the supporting or supported member. This can trigger web crippling or localized buckling, especially in sections where the web is relatively slender compared to the flanges.

The radical mitigation measures and design strategies can be presented as,

- **Implementing Transverse Stiffeners and Diaphragms:** Transverse stiffeners (continuity plates) should be used to resist the localized forces generated by torsion. Placing diagonal or horizontal stiffeners within the joint creates a "box-like" behavior, which significantly increases the torsional rigidity of the connection and helps distribute the Bimoments safely into the supporting member.

- **Transition to Closed (Box) Sections:** One of the most effective ways to handle high torsion at a connection is to locally "box-up" an open section. By welding plates between the flanges of an I-beam near the joint, you transform the open section into a closed one. Closed sections have a St. Venant torsional constant (J) that is often hundreds or thousands of times larger than that of an open section, effectively neutralizing the warping problem at the source.
- **Use of Warping-Restrained End Plates:** Thick end-plates bolted to a rigid support can be designed to provide warping restraint. This allows the member to benefit from increased stiffness. However, the designer must explicitly calculate the resulting warping normal stresses and ensure the plate and bolts can handle the additional tension/compression forces.
- **Shear Center Alignment:** The most proactive measure is to minimize the "source" of torsion. It ensures that the load path aligns as closely as possible with the shear center of the section. If eccentricity is unavoidable, the joint should be designed as a "torsionally stiff" moment connection rather than a simple shear connection to prevent the member from rotating.

4. Conclusion

This research demonstrates that managing the torsional mechanism in thin-walled steel structures involves more than calculating buckling loads; it requires understanding a dynamic process of stiffness degradation. The primary causes of torsion—geometric defects and boundary condition uncertainties—dynamically alter the system's stiffness matrix. It is established that torsional moments stemming from eccentricities induce 'Bimoments' and normal stresses that trigger localized yielding and stability loss long before a member reaches its theoretical flexural capacity. This chain reaction underscores the potential for a localized torsional failure to precipitate a progressive collapse. Consequently, ensuring structural safety requires a transition toward holistic analysis models, such as Vlasov-based simulations and geometrically and materially nonlinear analysis with Imperfections, to accurately capture the nonlinear consequences of initial torsional triggers.

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INTERCULTURAL DIALOGUE AND SOCIAL DYNAMICS IN INTERNATIONAL STUDENT MOBILITY: A PRISMA-GUIDED BIBLIOMETRIC AND VOSVIEWER-STYLE META-SYNTHESIS

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ÖZET

Yükseköğretimin giderek uluslararasılaşması, öğrenci hareketliliğini kültürlerarası etkileşim ve toplumsal dönüşümün temel belirleyicilerinden biri haline getirmiştir. Bu çalışma, uluslararası öğrenci hareketliliği alanındaki akademik literatürü, özellikle kültürlerarası diyalog ve kültürlerarası etkileşim süreçlerine odaklanarak sosyolojik bir bibliyometrik analiz çerçevesinde incelemektedir. Araştırmanın temel amacı, alanın entelektüel yapısını, tematik gelişimini ve baskın sosyolojik yaklaşımlarını ortaya koymaktır. Çalışmada, Scopus veri tabanında indekslenen hakemli yayınlardan oluşan bir veri seti, öğrenci hareketliliği, kültürlerarası kavramlar ve temel sosyolojik temaları içeren yapılandırılmış bir sorgu aracılığıyla elde edilmiştir. Yayın eğilimlerini, atıf örüntülerini ve iş birliği ağlarını analiz etmek amacıyla performans analizi ve bilim haritalama teknikleri uygulanmıştır. Ayrıca, başlıca araştırma kümelerini belirlemek için anahtar kelime eş-oluşum analizi gerçekleştirilmiştir. Elde edilen bulgular, özellikle 2015 yılı sonrasında yayın sayısında belirgin ve sürekli bir artış olduğunu göstermekte, bu durum hareketliliğin toplumsal boyutlarına yönelik akademik ilginin giderek arttığını ortaya koymaktadır. Tematik analiz sonucunda dört temel araştırma kümesi belirlenmiştir: (1) kültürlerarası iletişim ve yetkinlik gelişimi, (2) kimlik oluşumu ve müzakere süreçleri, (3) toplumsal entegrasyon ve kapsayıcılık, (4) ulusötesi bağlamlarda sosyal sermaye birikimi. Bulgular ayrıca, Erasmus temelli çalışmaların literatürde merkezi bir konuma sahip olduğunu ve çoğunlukla kültürlerarası deneyimlerin incelenmesinde ampirik bir temel oluşturduğunu göstermektedir. Bununla birlikte analiz, özellikle kültürlerarası diyalog kavramının operasyonelleştirilmesi ve ölçülebilir toplumsal çıktılarla ilişkilendirilmesi konusunda belirgin bir kavramsal parçalanmaya işaret etmektedir. Ampirik çalışmaların artmasına rağmen, uzunlamasına ve kuramsal temelli araştırmaların sınırlı kaldığı görülmektedir. Sonuç olarak bu çalışma, alanın yapısına ilişkin sistematik bir genel çerçeve sunarak sosyolojik literatüre katkıda bulunmakta ve önemli araştırma boşluklarını ortaya

koymaktadır. Elde edilen bulgular, gelecekteki araştırmalar için yol gösterici nitelik taşımakta ve giderek çeşitlenen eğitim ortamlarında kültürlerarası anlayışı ve toplumsal uyumu güçlendirmeyi amaçlayan hareketlilik programlarının tasarımına önemli katkılar sunmaktadır.

Anahtar kelimeler: Uluslararası Öğrenci Hareketliliği, Kültürlerarası Etkileşim, Bibliyometrik Analiz, Eğitim Sosyolojisi, Bilim Haritalama

ABSTRACT

The growing internationalization of higher education has positioned student mobility as a key driver of intercultural interaction and social transformation. This study presents a sociological bibliometric analysis of the academic literature on international student mobility, with a specific focus on intercultural dialogue and cross-cultural exchange processes. The aim is to map the intellectual structure, thematic evolution, and dominant sociological narratives within the field. A dataset of peer-reviewed publications indexed in Scopus was retrieved using a structured query combining student mobility, intercultural constructs, and core sociological concepts. Bibliometric techniques, including performance analysis and science mapping, were applied to examine publication trends, citation patterns, and collaboration networks. In addition, keyword co-occurrence analysis was conducted to identify major research clusters. The results reveal a significant and continuous increase in publication output, particularly after 2015, indicating a growing scholarly interest in the social dimensions of mobility. Thematic analysis identifies four dominant clusters: (1) intercultural communication and competence development, (2) identity formation and negotiation, (3) social integration and inclusion, and (4) the accumulation of social capital within transnational contexts. The findings further demonstrate that Erasmus-related research occupies a central position within the network, often serving as an empirical foundation for examining intercultural experiences. However, the analysis also uncovers notable conceptual fragmentation, particularly in the operationalization of intercultural dialogue and its linkage to measurable social outcomes. Despite the expansion of empirical studies, longitudinal and theory-driven research remains limited. This study contributes to the sociological literature by providing a structured overview of the field and by identifying key research gaps. The findings offer important implications for future research and for the design of mobility programs aiming to enhance intercultural understanding and social cohesion in increasingly diverse educational environments.

Keywords: International Student Mobility, Intercultural Interaction, Bibliometric Analysis, Sociology of Education, Science Mapping

1. INTRODUCTION

International student mobility has become one of the most visible forms of higher education internationalisation. It is often described as an educational opportunity, yet its sociological relevance lies in the way mobility reorganises social networks, language practices, institutional attachments and forms of belonging. The corpus examined in this paper shows that mobility research has moved beyond simple participation counts and now addresses intercultural competence, identity formation, social capital, inclusion, inequality and career expectations. Representative studies in the retrieved literature show this breadth across school-to-university pathways, Erasmus participation, language learning and intercultural citizenship (Beaven et al., 2016; Berger et al., 2019; Cairns et al., 2018; Cranston et al., 2020; Cruz et al., 2023; Dall'Alba et al., 2015).

The need for a bibliometric synthesis is clear. The field is active but dispersed across journals, national contexts and methodological traditions. Some studies emphasize positive associations between mobility and intercultural learning, while others describe conditional or constraining processes in which language access, discrimination, institutional support and host-society contact shape the outcome. This paper therefore treats student mobility as a conditional social process rather than a uniform educational intervention.

2. MATERIALS AND METHODS

2.1. Data source and Scopus query

The bibliographic dataset was retrieved from Scopus and exported in RIS/CSV format. The unit of analysis was the bibliographic record. Title, abstract, author keywords, indexed keywords, cited-by counts, source titles, publication years, document types, DOI fields, authors and affiliation strings were parsed in Python. The search strategy combined three conceptual blocks: student mobility, intercultural or cross-cultural exchange, and sociological constructs including identity, inclusion, social capital, inequality and youth development.

Table 1. Scopus Search Strategy

Element	Operationalization
Database	Scopus
Search fields	Title, abstract and keywords
Mobility block	"student mobility" OR Erasmus OR "international mobility"
Intercultural block	"intercultural dialogue" OR intercultural OR "cross-cultural" OR "cultural exchange"
Sociological block	sociolog* OR "social integration" OR "social inclusion" OR identity OR "cultural identity" OR "social capital" OR inequality OR "youth development"
Screening result	111 retrieved records; 3 excluded; 108 included

2.2. PRISMA-guided screening

Screening followed the logic of PRISMA 2020 by separating identification, screening, eligibility and inclusion. Records were retained when title, abstract or keywords connected student mobility with intercultural or sociological outcomes. Records without sufficient mobility relevance were excluded before synthesis. The PRISMA count was then used to construct Figure 15 and to report the included analytical corpus.

Table 2. Dataset and Variable Audit

Variable	Available value
Retrieved Scopus records	111
Included studies	108
Excluded records	3
Abstracts available	110
Keywords available	97
Unique source titles	99
Unique authors	246
Publication-year range	2005-2026

2.3. Bibliometric preprocessing

Preprocessing standardized DOI strings, normalized titles, split author and keyword fields, extracted country names from affiliation metadata and removed duplicate bibliographic keys where present. Missing values were kept visible rather than imputed, because missing sample sizes and open-access metadata are themselves important audit findings for a bibliometric review.

2.4. Citation and performance analysis

Citation analysis used Scopus cited-by values. Total citations, uncited records, mean and median citations, maximum citation count, h-index, g-index and skewness were computed in Python. These indicators describe field visibility and citation concentration; they are not interpreted as quality scores for individual publications.

Table 3. Corpus and Citation Metrics

Metric	Value
Included-corpus citations	926
PPT-reported total citations	951
Parsed RIS total citations	954
h-index	15
g-index	27
Uncited records	36
Mean citations	8.57
Median citations	2.00
Maximum citations	96
Citation skewness	3.34
Mean publication year	2020.83
Median publication year	2022
Screened-corpus year range	2005-2026

2.5. Keyword co-occurrence analysis

Keyword co-occurrence analysis combined author keywords with recurring title and abstract terms after stop-word removal. Pairs of terms were connected when they appeared in the same bibliographic record. The resulting matrices were visualised as VOSviewer-style network, overlay and density maps, following the interpretive tradition of science mapping and bibliometric thematic analysis (Aria & Cuccurullo, 2017; van Eck & Waltman, 2010).

2.6. Co-authorship and country analysis

Co-authorship analysis was based on author co-appearance within the same record. Country analysis was based on affiliation strings and should be read as an affiliation-metadata profile rather than a complete nationality measure. The approach is useful for mapping visible institutional geography, but manual disambiguation would be required before making fine-grained claims about institutional productivity.

2.7. Figure and table generation workflow

All figures were generated or recreated with Python from the parsed RIS/CSV data and the slide-level information extracted from the PowerPoint package. The PowerPoint was also parsed as an OOXML zip archive to count slides, extract embedded media and verify figure themes. Required figures were saved as PNG files in the output_figures folder and inserted into the manuscript at readable width.

Table 10. Figure-by-Figure Analytical Workflow

Figure	Data fields	Method and interpretation
Figures 1-2	Publication year	Annual and cumulative frequency analysis in Python
Figures 3-4	Cited-by counts and publication year	Performance analysis, aggregation by year, and histogram inspection
Figures 5-6	Document type and source title	Descriptive bibliometric profiling
Figure 9	Author metadata	Co-authorship links generated when authors co-appeared in the same record
Figure 10	Affiliation strings	Country names parsed from institutional affiliations
Figures 11-14	Keywords, titles, abstracts, publication year	Keyword frequency, co-occurrence, overlay, and density-style science mapping
Figure 15	Screening decisions	PRISMA-guided flow from retrieval to included synthesis

3. RESULTS AND DISCUSSION

Table 4. Methodological Composition

Method category	Records	Share
Unspecified/Conceptual	39	36.1%
Quantitative	26	24.1%
Mixed methods	17	15.7%
Qualitative	14	13.0%
Conceptual/Policy	9	8.3%
Bibliometric/Review	3	2.8%

Table 4 shows a mixed methodological field. Quantitative, qualitative, mixed-methods and conceptual-policy approaches are all present, but a large proportion of records do not report extractable effect sizes or harmonized outcome measures. This explains why a pooled statistical meta-analysis would be weaker than a PRISMA-guided bibliometric review and qualitative meta-synthesis. The methodological diversity also reflects the sociological complexity of mobility, where intercultural learning, identity negotiation and social inclusion are often measured through different instruments and at different levels of analysis.

Table 5. Thematic Composition

Theme	Records	Share of included records
Intercultural competence & global learning	107	99.1%
Identity, citizenship & belonging	80	74.1%
Internationalization policy & higher education systems	80	74.1%
Language, academic adaptation & learning abroad	65	60.2%
Employability, skills & career outcomes	28	25.9%
Social inclusion, inequality & access	20	18.5%
Digital/virtual mobility and digital competence	11	10.2%

According to Table 5, intercultural competence and global learning dominate the thematic structure, while identity, citizenship, internationalisation policy, language adaptation, employability, inclusion and digital mobility form connected but uneven subfields. This thematic distribution indicates a field organised around intercultural learning but still fragmented in its treatment of social mechanisms.

Table 6. Direction of Evidence

Evidence direction	Records	Share
Positive association	38	35.2%
Mixed/conditional	30	27.8%
Descriptive/unclear	29	26.9%
Constraining/critical evidence	11	10.2%

Table 6 confirms that the direction of evidence is not uniformly celebratory. Positive associations are common, yet mixed, descriptive and critical evidence remains substantial. This pattern supports a conditional interpretation: mobility may foster intercultural dialogue when institutional, linguistic and relational supports are present, but it can also reproduce exclusion when those supports are weak.

Table 7. Leading Sources

Source title	Records
International Journal of Intercultural Relations	4
Language and Intercultural Communication	3
Academia (Greece)	3
Cogent Education	2
Journal of International Students	2
Education Sciences	2
Turkish Online Journal of Educational Technology	2
E-Revista de Estudos Interculturais	2
Journal of Research in International Education	1
Discourse	1
Journal of Contemporary European Research	1
Mextesol Journal	1

Table 8. Dominant Keywords

Keyword	Records
Student Mobility	11
Intercultural Competence	11
Identity	10
International Student Mobility	10
Higher Education	9
Study Abroad	9
Education	9
Student	9
Students	8
Erasmus	7
European Identity	7
International Students	7
Human	6
Mobility	6
Cultural Identity	6

Table 9. Country Distribution

Country	Affiliation records
Australia	12
USA	11
Italy	9
Turkey	8
Netherlands	8
Spain	7
UK	6
France	5
China	5
Germany	4
Poland	4
Canada	3
Sweden	3
Romania	3
Mexico	3

Figure 1. Annual Publication Trend

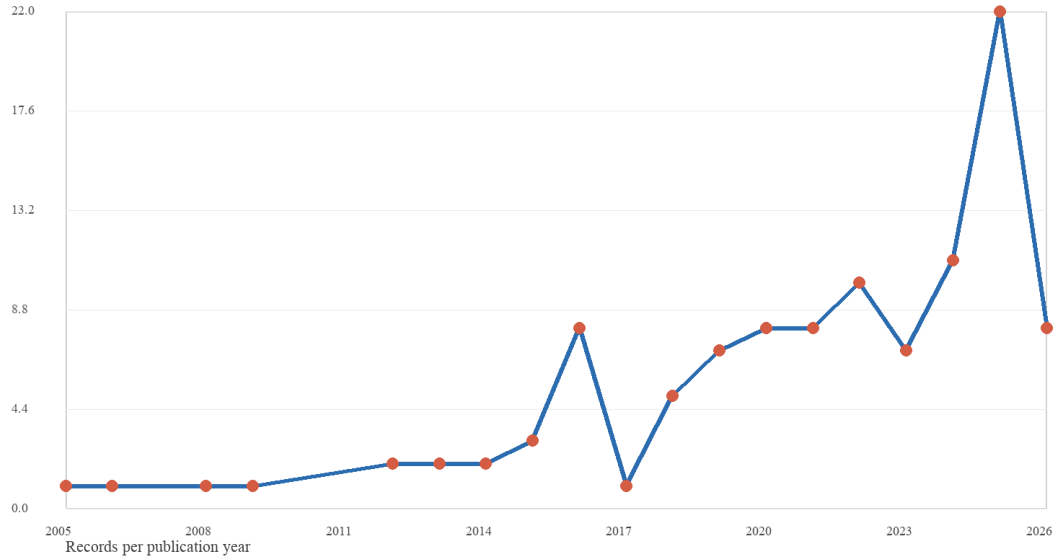

Figure 1. Annual Publication Trend

Figure 1 demonstrates the annual publication pattern in the included corpus. The trend shows that research on intercultural student mobility is concentrated in recent years, with 2026 interpreted cautiously because it is a partial publication year. Bibliometrically, this confirms a developing literature rather than a mature field with a long stable output history. Sociologically, the growth mirrors the rising policy importance of internationalisation, Erasmus participation and global learning after the expansion of mobility programmes.

Figure 2. Cumulative Publication Growth

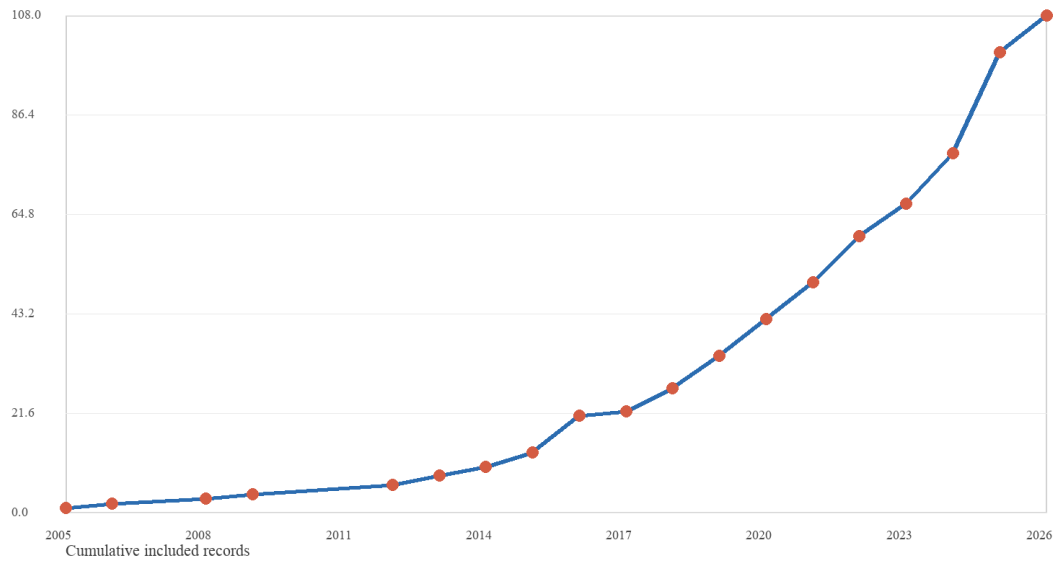

Figure 2. Cumulative Publication Growth

Figure 2 presents cumulative publication growth. The curve makes visible the acceleration of interest in mobility as a social process and not only as an administrative movement of students. A steepening cumulative line indicates that the field has gained momentum through repeated contributions across education, sociology, language studies and intercultural communication.

Figure 3. Citations by Publication Year

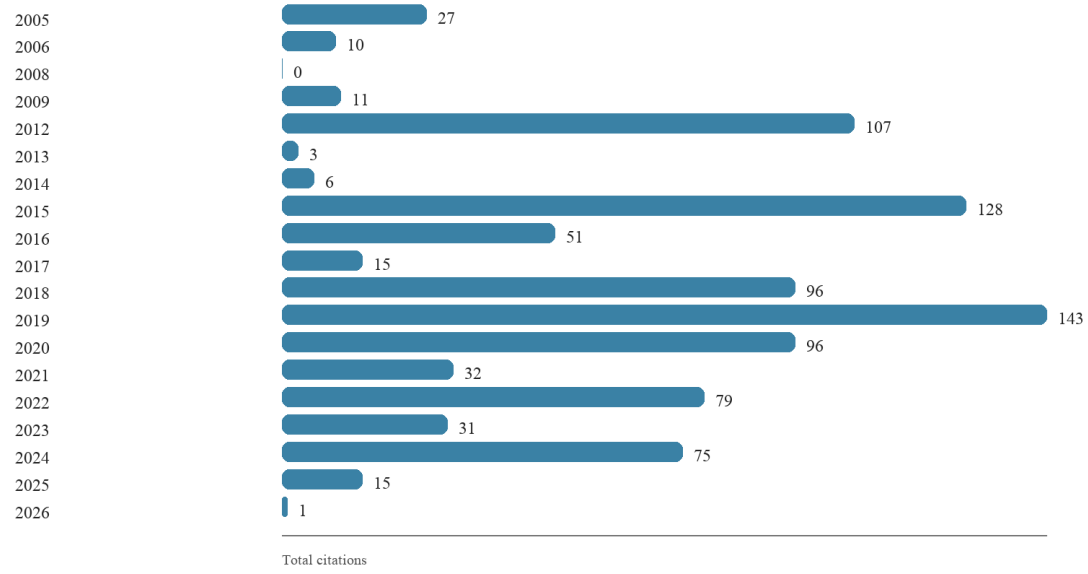

Figure 3. Citations by Publication Year

Figure 3 aggregates Scopus citations by publication year. It can be seen that older records and a small group of influential studies carry a large share of citations. This is bibliometrically important because it shows citation concentration around early conceptual and empirical anchors. The sociological implication is that key debates about identity, social capital and intercultural competence continue to structure later work.

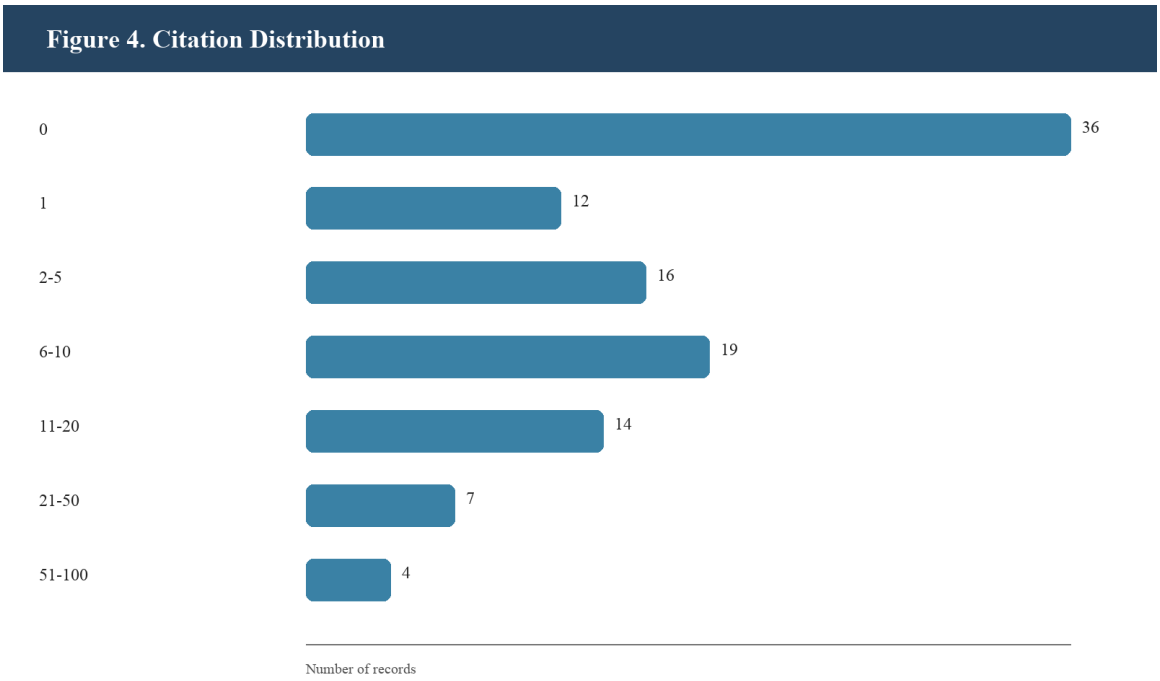

Figure 4. Citation Distribution

Figure 4 displays the citation distribution. The right-skewed profile indicates that many records are lightly cited while a limited number of publications receive high attention. This pattern is typical of interdisciplinary fields where conceptual vocabulary is shared unevenly across journals. It also cautions against using citation counts alone as evidence of social relevance.

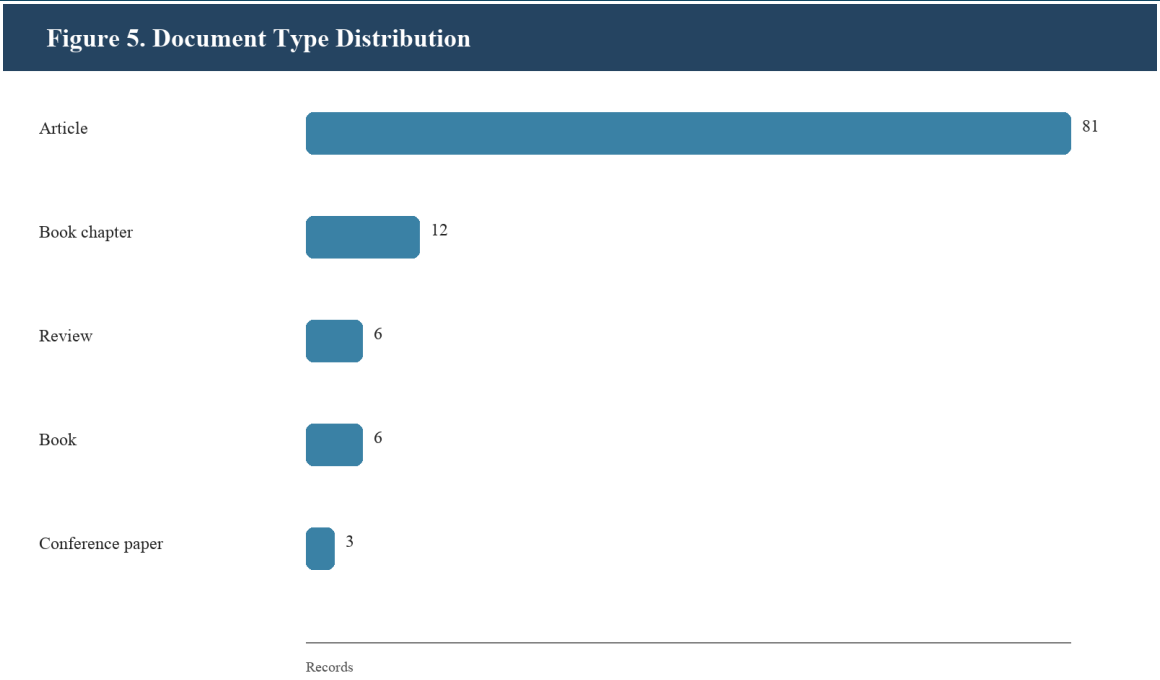

Figure 5. Document Type Distribution

Figure 5 shows document type distribution. Articles constitute the main evidence base, while reviews, book chapters or other formats contribute smaller shares. This composition supports the use of article-level bibliometric analysis but also explains why the corpus contains heterogeneous reporting standards.

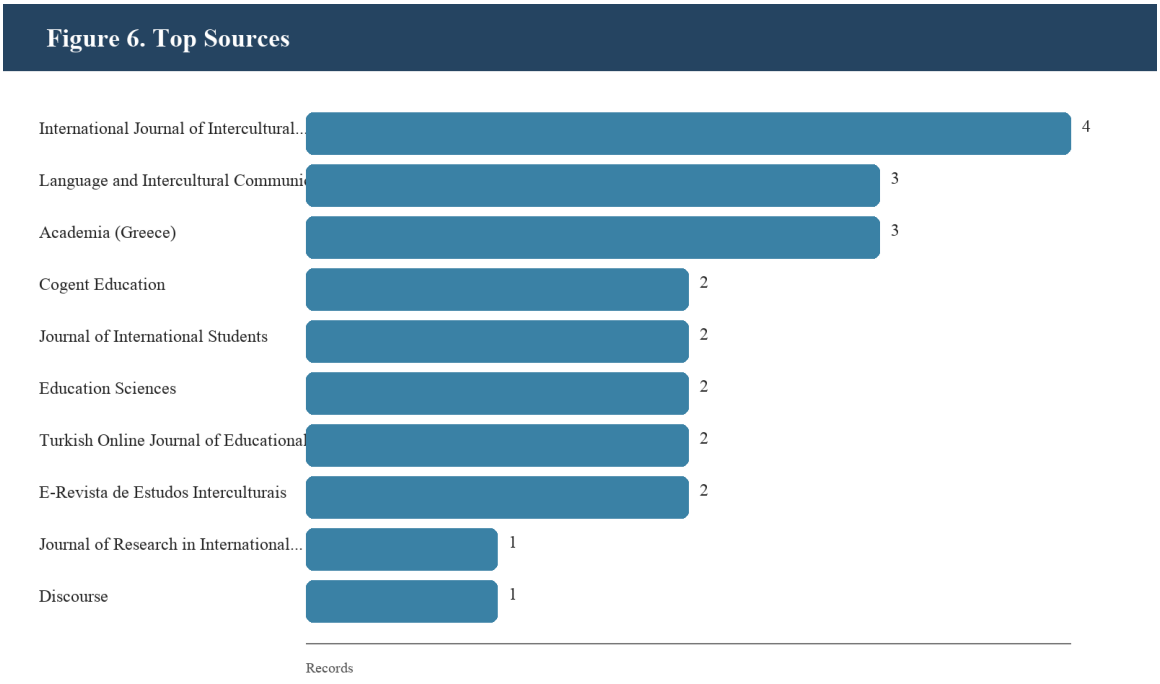

Figure 6. Top Sources

Figure 6 identifies leading source titles. The source distribution is dispersed, with only a few journals publishing multiple records. This dispersion indicates that intercultural mobility research is not housed in a single disciplinary venue; it circulates through intercultural communication, higher education, sociology, language education and policy-oriented outlets.

Figure 9. Co-authorship Network

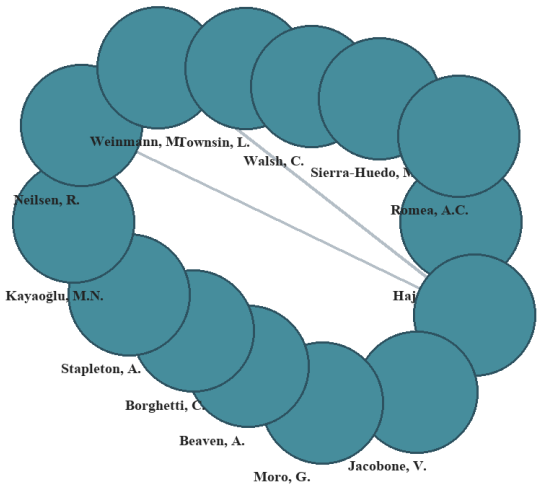

Figure 9. Co-authorship Network

Figure 9 shows the co-authorship network recreated from author co-appearances in the included records. The network has visible clusters but no single dense core, indicating dispersed collaboration. Bibliometrically, this means the field is collaborative in pockets rather than consolidated around a few stable teams. Sociologically, the pattern is consistent with the international and context-specific nature of mobility research.

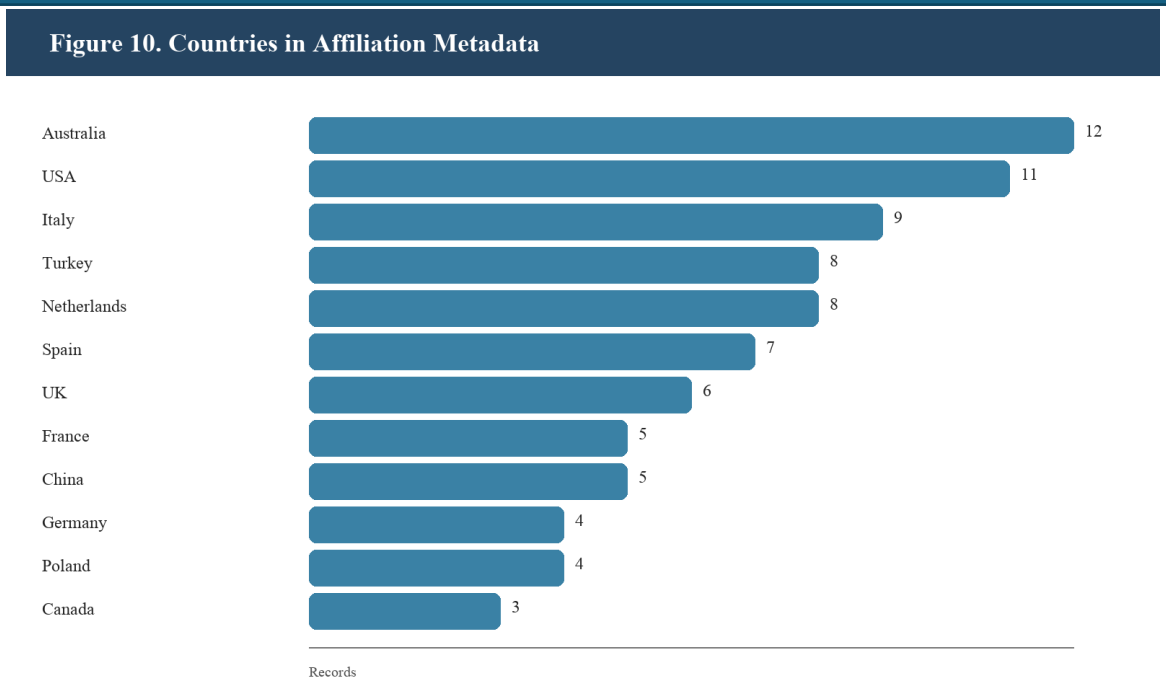

Figure 10. Countries in Affiliation Metadata

Figure 10 presents countries detected in affiliation metadata. The country profile shows the visible institutional geography of the corpus. Because affiliation strings are not equivalent to study location or participant nationality, the figure is interpreted as a metadata distribution. Even with that caution, the spread across countries supports the claim that mobility research is internationally distributed.

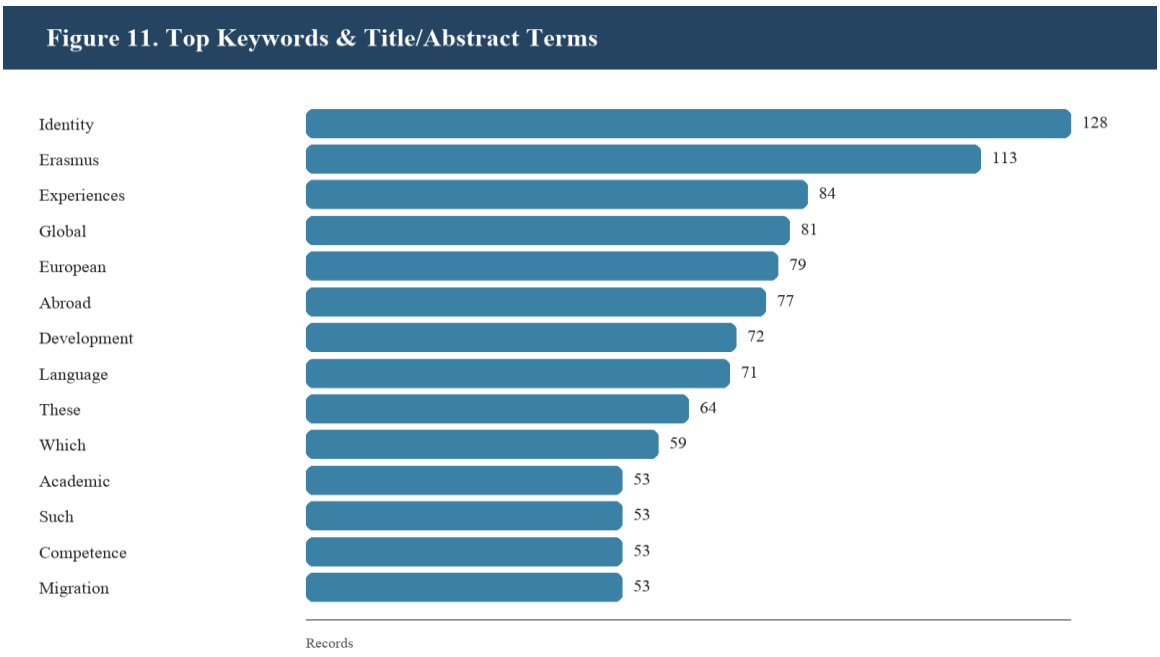

Figure 11. Top Keywords & Title/Abstract Terms

Figure 11 combines author keywords with frequent title and abstract terms. Student mobility, intercultural competence, identity, higher education and Erasmus appear as dominant terms. The vocabulary confirms that the field is built around mobility as a setting for intercultural learning and identity work, while language and inclusion terms mark the social conditions that shape outcomes.

Figure 12. Term Co-occurrence Network

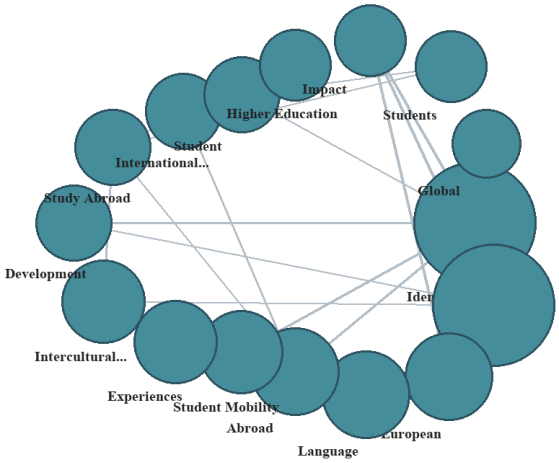

Figure 12. Term Co-occurrence Network

The co-occurrence structure shown in Figure 12 indicates how central concepts cluster together. Terms around mobility, identity, competence, language and internationalisation form connected zones rather than one unified measurement tradition. This pattern shows thematic fragmentation but also a shared conceptual centre.

Figure 13. Overlay Visualisation

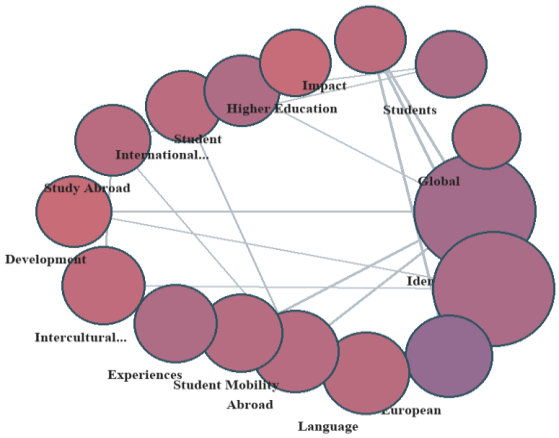

Figure 13. Overlay Visualisation

Figure 13 adds an overlay interpretation by colouring terms according to average publication year. More recent terms indicate where the discussion is moving, especially toward digital mobility, inclusion and conditional forms of belonging. The overlay suggests a field that is expanding from classic mobility and competence themes toward more critical sociological questions.

Figure 14. Density Visualisation

Figure 14. Density Visualisation

The density visualization in Figure 14 suggests where conceptual concentration is strongest. Dense areas around intercultural competence, mobility, identity and higher education show the main intellectual centre of the corpus. Lower-density zones point to emerging or less consolidated topics that may require deeper full-text synthesis.

Figure 15. PRISMA Flow Diagram

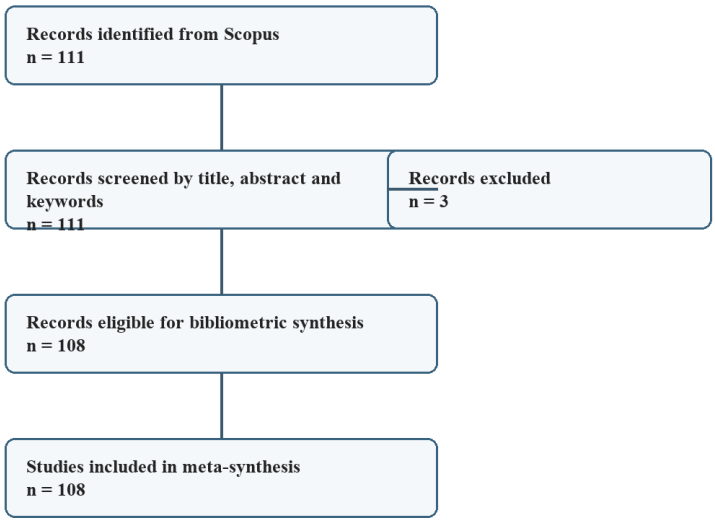

Figure 15. PRISMA Flow Diagram

Figure 15 gives the PRISMA-guided flow from retrieval to included synthesis. The diagram documents the movement from 111 retrieved records to 108 included records after exclusion of three insufficiently relevant records. This figure strengthens transparency by making screening decisions visible before the bibliometric interpretation begins.

4. CONCLUSION

This proceedings-style bibliometric meta-synthesis shows that international student mobility research is expanding, interdisciplinary and sociologically rich. The evidence base is strongest around intercultural competence and global learning, but identity, citizenship, language adaptation, inclusion, inequality and employability are also central to the field's meaning. Citation metrics show concentration around a limited number of influential publications, while source and co-authorship patterns show dispersion across journals and research teams.

The main conclusion is that mobility functions as a conditional social process. It can foster intercultural dialogue and social development when students gain meaningful contact, language access, institutional support and opportunities for belonging. It can also produce mixed or

constraining outcomes when mobility occurs without those conditions. Future research should report comparable outcomes, extractable effect sizes and clearer sample information so that bibliometric mapping can be combined with stronger full-text synthesis and, where appropriate, later statistical meta-analysis.

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MAPPING INTERCULTURAL DIALOGUE IN INTERNATIONAL STUDENT MOBILITY: A BIBLIOMETRIC ANALYSIS OF ERASMUS AND CROSS-CULTURAL EXCHANGE RESEARCH

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ÖZET

Yükseköğretimin uluslararasılaşması, öğrenci hareketliliğini kültürlerarası diyalog ve kültürlerarası anlayışı geliştiren temel bir mekanizma haline getirmiştir. Bu girişimler arasında, Erasmus ve benzeri hareketlilik programları, ulusötesi eğitim deneyimlerinin şekillenmesinde önemli bir rol oynamıştır. Bu çalışma, uluslararası öğrenci hareketliliğinin kültürlerarası boyutlarını ele alan bilimsel literatürün kapsamlı bir bibliyometrik analizini sunmayı amaçlamaktadır. Scopus veri tabanında indekslenen hakemli yayınlardan oluşan yapılandırılmış bir veri seti, öğrenci hareketliliği, Erasmus ve kültürlerarası etkileşim ile ilgili anahtar kelimeleri içeren hedeflenmiş bir arama stratejisi kullanılarak elde edilmiştir. Yayın eğilimlerini, atıf örüntülerini, önde gelen yazarları, etkili dergileri ve kurumsal katkıları incelemek için bibliyometrik teknikler uygulanmıştır. Ayrıca, anahtar kelime birlikte görülme analizi ve ağ görselleştirme yöntemleri kullanılarak alanın baskın tematik kümeleri ve entelektüel yapısı belirlenmiştir. Sonuçlar, son on yılda bilimsel yayın sayısında belirgin bir artış olduğunu göstermekte ve bu durum, hareketlilik programlarında kültürlerarası yetkinliklere yönelik artan akademik ve politik ilgiyi yansıtmaktadır. Temel araştırma temaları arasında kültürlerarası iletişim, kimlik oluşumu, kültürel uyum ve küresel vatandaşlık yer almaktadır. Bulgular ayrıca Erasmus odaklı çalışmaların literatüre hâkim olduğunu ve çoğunlukla deneyimsel öğrenme ile kültürlerarası "yumuşak becerilerin" geliştirilmesine vurgu yaptığını ortaya koymaktadır. Bununla birlikte analiz, "kültürlerarası diyalog" kavramına ilişkin farklı tanımların bulunduğunu ve kavramsal bir parçalanma olduğunu da göstermekte; bu durum daha güçlü bir kuramsal bütünlüğe ihtiyaç olduğunu ortaya koymaktadır. Bu çalışma, öğrenci hareketliliği bağlamında kültürlerarası araştırmaların evrimini sistematik biçimde haritalandırarak ve yeni araştırma yönlerini belirleyerek alana katkı sağlamaktadır. Bulgular,

giderek daha fazla birbirine bağlı hale gelen küresel eğitim ortamında, hareketlilik programlarının kültürlerarası etkisini artırmak isteyen politika yapıcılar, yükseköğretim kurumları ve araştırmacılar için değerli bilgiler sunmaktadır.

Anahtar Kelimeler: Öğrenci hareketliliği, Erasmus+, Kültürlerarası diyalog, Bibliyometrik analiz, Yükseköğretim, Kültürlerarası etkileşim

ABSTRACT

The internationalization of higher education has positioned student mobility as a central mechanism for fostering intercultural dialogue and cross-cultural understanding. Among these initiatives, Erasmus and related mobility frameworks have played a pivotal role in shaping transnational educational experiences. This study aims to provide a comprehensive bibliometric analysis of the scientific literature addressing the intercultural dimensions of international student mobility. A structured dataset of peer-reviewed publications indexed in Scopus was retrieved using a targeted search strategy combining key terms related to student mobility, Erasmus, and intercultural exchange. Bibliometric techniques were applied to examine publication trends, citation patterns, leading authors, influential journals, and institutional contributions. Additionally, keyword co-occurrence analysis and network visualization methods were employed to identify dominant thematic clusters and the intellectual structure of the field. The results indicate a substantial increase in scholarly output over the past decade, reflecting growing academic and policy interest in intercultural competencies within mobility programs. Core research themes include intercultural communication, identity formation, cultural adaptation, and global citizenship. The findings further reveal that Erasmus-related studies dominate the literature, often emphasizing experiential learning and the development of soft intercultural skills. However, the analysis also highlights conceptual fragmentation and varying definitions of “intercultural dialogue,” suggesting the need for greater theoretical coherence. This study contributes to the field by systematically mapping the evolution of intercultural research within student mobility and by identifying emerging research directions. The findings offer valuable insights for policymakers, higher education institutions, and researchers seeking to enhance the intercultural impact of mobility programs in an increasingly interconnected global education landscape.

Keywords: International student mobility, intercultural interaction, bibliometric analysis, sociology of education, science mapping

1. INTRODUCTION

International student mobility has become one of the most visible forms of higher education internationalisation. It is often described as an educational opportunity, yet its sociological

relevance lies in the way mobility reorganises social networks, language practices, institutional attachments and forms of belonging. The corpus examined in this paper shows that mobility research has moved beyond simple participation counts and now addresses intercultural competence, identity formation, social capital, inclusion, inequality and career expectations. Representative studies in the retrieved literature show this breadth across school-to-university pathways, Erasmus participation, language learning and intercultural citizenship (Baker W., 2016), (Cao L. et al., 2013), (Carr S.C. et al., 2010), (Caruana V., 2014), (Chodzkienė L., 2020), (Cruz N.I. et al., 2023).

The need for a bibliometric synthesis is clear. The field is active but dispersed across journals, national contexts and methodological traditions. Some studies emphasize positive associations between mobility and intercultural learning, while others describe conditional or constraining processes in which language access, discrimination, institutional support and host-society contact shape the outcome. This paper therefore treats student mobility as a conditional social process rather than a uniform educational intervention.

2. MATERIALS AND METHODS

2.1. Data source and Scopus query

The bibliographic dataset was retrieved from Scopus and exported in RIS/CSV format. The unit of analysis was the bibliographic record. Title, abstract, author keywords, indexed keywords, cited-by counts, source titles, publication years, document types, DOI fields, authors and affiliation strings were parsed in Python. The search strategy combined three conceptual blocks: student mobility, intercultural or cross-cultural exchange, and sociological constructs including identity, inclusion, social capital, inequality and youth development.

Table 1. Scopus Search Strategy

Element	Operationalization
Database	Scopus
Search fields	Title, abstract and keywords
Mobility block	"student mobility" OR Erasmus OR "international mobility"
Intercultural block	"intercultural dialogue" OR intercultural OR "cross-cultural" OR "cultural exchange"
Sociological block	sociolog* OR "social integration" OR "social inclusion" OR identity OR "cultural identity" OR "social capital" OR inequality OR "youth development"
Screening result	359 retrieved records; 0 excluded; 359 included

2.2. PRISMA-guided screening

Screening followed the logic of PRISMA 2020 by separating identification, screening, eligibility and inclusion. Records were retained when title, abstract or keywords connected student mobility with intercultural or sociological outcomes. Records without sufficient mobility relevance were excluded before synthesis. The PRISMA count was then used to construct Figure 15 and to report the included analytical corpus.

Table 2. Dataset and Variable Audit

Variable	Available value
Retrieved Scopus records	359
Included studies	359
Excluded records	0
Abstracts available	359
Keywords available	348
Unique source titles	229
Unique authors	929
Publication-year range	1994-2026

2.3. Bibliometric preprocessing

Preprocessing standardized DOI strings, normalized titles, split author and keyword fields, extracted country names from affiliation metadata and removed duplicate bibliographic keys where present. Missing values were kept visible rather than imputed, because missing sample sizes and open-access metadata are themselves important audit findings for a bibliometric review.

2.4. Citation and performance analysis

Citation analysis used Scopus cited-by values. Total citations, uncited records, mean and median citations, maximum citation count, h-index, g-index and skewness were computed in Python. These indicators describe field visibility and citation concentration; they are not interpreted as quality scores for individual publications.

Table 3. Corpus and Citation Metrics

Metric	Value
Included-corpus citations	4575
Parsed CSV total citations	4575
h-index	35
g-index	55
Uncited records	86
Mean citations	12.74
Median citations	4.00
Maximum citations	146
Citation skewness	3.17
Mean publication year	2020.58
Median publication year	2022
Screened-corpus year range	1994-2026

2.5. Keyword co-occurrence analysis

Keyword co-occurrence analysis combined author keywords with recurring title and abstract terms after stop-word removal. Pairs of terms were connected when they appeared in the same bibliographic record. The resulting matrices were visualised as VOSviewer-style network, overlay and density maps, following the interpretive tradition of science mapping and bibliometric thematic analysis (Aria & Cuccurullo, 2017; van Eck & Waltman, 2010).

2.6. Co-authorship and country analysis

Co-authorship analysis was based on author co-appearance within the same record. Country analysis was based on affiliation strings and should be read as an affiliation-metadata profile rather than a complete nationality measure. The approach is useful for mapping visible institutional geography, but manual disambiguation would be required before making fine-grained claims about institutional productivity.

2.7. Figure and table generation workflow

All figures were generated or recreated with Python from the parsed RIS/CSV data and the slide-level information extracted from the PowerPoint package. The PowerPoint was also parsed as an OOXML zip archive to count slides, extract embedded media and verify figure themes. Required figures were saved as PNG files in the output_figures folder and inserted into the manuscript at readable width.

Table 10. Figure-by-Figure Analytical Workflow

Figure	Data fields	Method and interpretation
Figures 1-2	Publication year	Annual and cumulative frequency analysis in Python
Figures 3-4	Cited-by counts and publication year	Performance analysis, aggregation by year, and histogram inspection
Figures 5-6	Document type and source title	Descriptive bibliometric profiling
Figure 9	Author metadata	Co-authorship links generated when authors co-appeared in the same record
Figure 10	Affiliation strings	Country names parsed from institutional affiliations
Figures 11-14	Keywords, titles, abstracts, publication year	Keyword frequency, co-occurrence, overlay, and density-style science mapping
Figure 15	Screening decisions	PRISMA-guided flow from retrieval to included synthesis

3. RESULTS AND DISCUSSION

Table 4. Methodological Composition

Method category	Records	Share
Qualitative	119	33.1%
Quantitative	86	24.0%
Unspecified / Conceptual	85	23.7%
Conceptual / Review	60	16.7%
Mixed methods	9	2.5%

Table 4 shows a mixed methodological field. Quantitative, qualitative, mixed-methods and conceptual-policy approaches are all present, but a large proportion of records do not report extractable effect sizes or harmonized outcome measures. This explains why a pooled statistical meta-analysis would be weaker than a PRISMA-guided bibliometric review and qualitative meta-synthesis. The methodological diversity also reflects the sociological complexity of mobility, where intercultural learning, identity negotiation and social inclusion are often measured through different instruments and at different levels of analysis.

Table 5. Thematic Composition

Theme	Records	Share of included records
Intercultural competence & global learning	348	96.9%
Internationalisation policy	237	66.0%
Employability & career outcomes	195	54.3%
Language & academic adaptation	153	42.6%
Identity, citizenship & belonging	83	23.1%
Digital/virtual mobility	59	16.4%
Social inclusion & inequality	25	7.0%

According to Table 5, intercultural competence and global learning dominate the thematic structure, while identity, citizenship, internationalisation policy, language adaptation, employability, inclusion and digital mobility form connected but uneven subfields. This thematic distribution indicates a field organised around intercultural learning but still fragmented in its treatment of social mechanisms.

Table 6. Direction of Evidence

Evidence direction	Records	Share
Positive association	134	37.3%
Constraining / critical	117	32.6%
Descriptive / unclear	54	15.0%
Mixed / conditional	54	15.0%

Table 6 confirms that the direction of evidence is not uniformly celebratory. Positive associations are common, yet mixed, descriptive and critical evidence remains substantial. This pattern supports a conditional interpretation: mobility may foster intercultural dialogue when institutional, linguistic and relational supports are present, but it can also reproduce exclusion when those supports are weak.

Table 7. Leading Sources

Source title	Records
International Journal of Intercultural Relations	16
Language and Intercultural Communication	10
Journal of International Students	10
Intercultural Education	10
Journal of Studies in International Education	7
Higher Education	7
Sustainability (Switzerland)	6
Education Sciences	6
Social Work Education	5
European Journal of Higher Education	4
Compare	4
Nurse Education Today	4

Table 8. Dominant Keywords

Keyword	Records
Higher Education	50
Student Mobility	49
Intercultural Competence	41
Human	36
Education	35
Female	35
Male	32
Article	30
Student	29
Adult	29
Study Abroad	27
International Students	27
International Student Mobility	23
Intercultural Communication	22
Humans	21

Table 9. Country Distribution

Country	Affiliation records
UK	45
Australia	34
Italy	33
Spain	32
USA	29
Turkey	24
China	22
Netherlands	20
France	16
Portugal	15
Germany	13
Poland	11
Canada	9
Norway	8
Romania	8

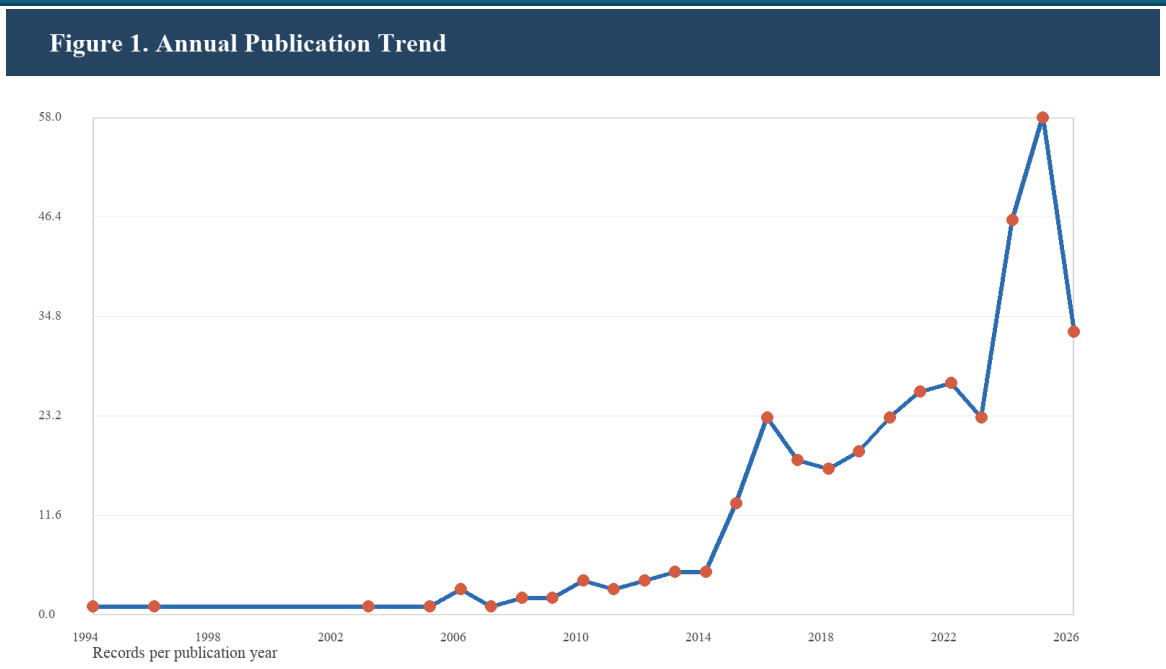

Figure 1. Annual Publication Trend

Figure 1 demonstrates the annual publication pattern in the included corpus. The trend shows that research on intercultural student mobility is concentrated in recent years, with 2026 interpreted cautiously because it is a partial publication year. Bibliometrically, this confirms a developing literature rather than a mature field with a long stable output history. Sociologically, the growth mirrors the rising policy importance of internationalisation, Erasmus participation and global learning after the expansion of mobility programmes.

Figure 2. Cumulative Publication Growth

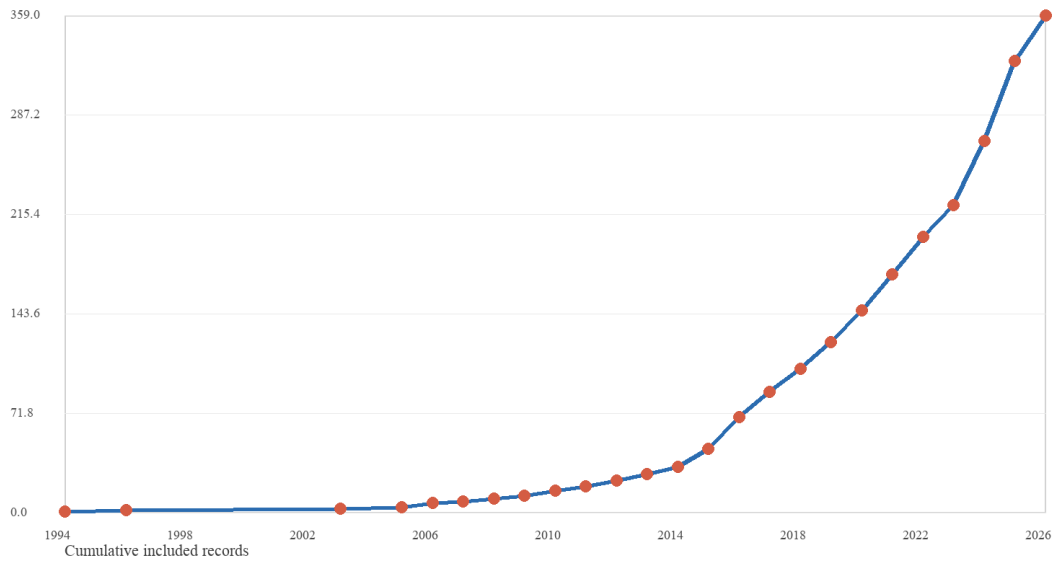

Figure 2. Cumulative Publication Growth

Figure 2 presents cumulative publication growth. The curve makes visible the acceleration of interest in mobility as a social process and not only as an administrative movement of students. A steepening cumulative line indicates that the field has gained momentum through repeated contributions across education, sociology, language studies and intercultural communication.

Figure 3. Citations by Publication Year

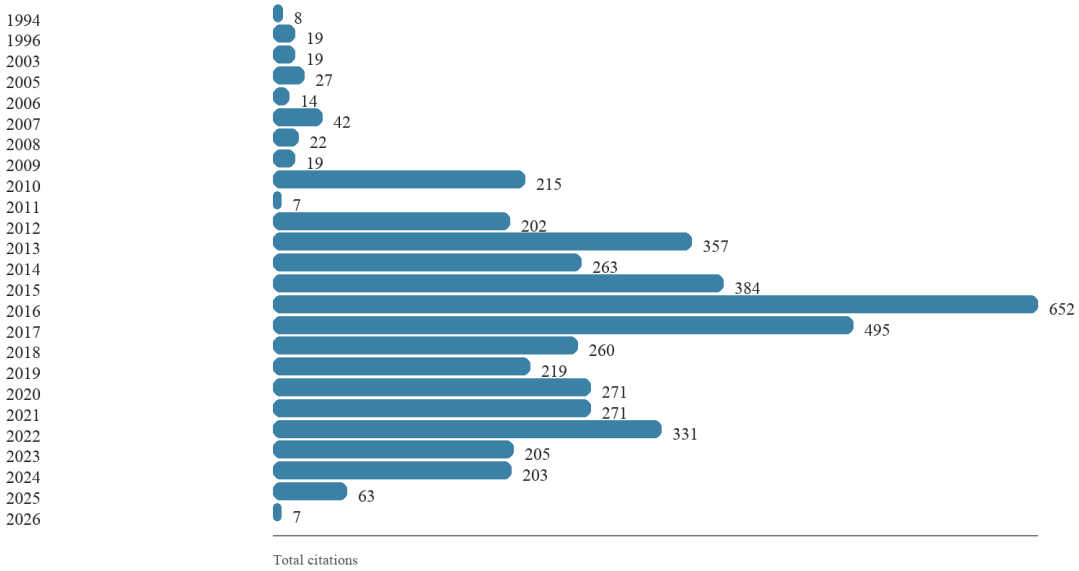

Figure 3. Citations by Publication Year

Figure 3 aggregates Scopus citations by publication year. It can be seen that older records and a small group of influential studies carry a large share of citations. This is bibliometrically important because it shows citation concentration around early conceptual and empirical anchors. The sociological implication is that key debates about identity, social capital and intercultural competence continue to structure later work.

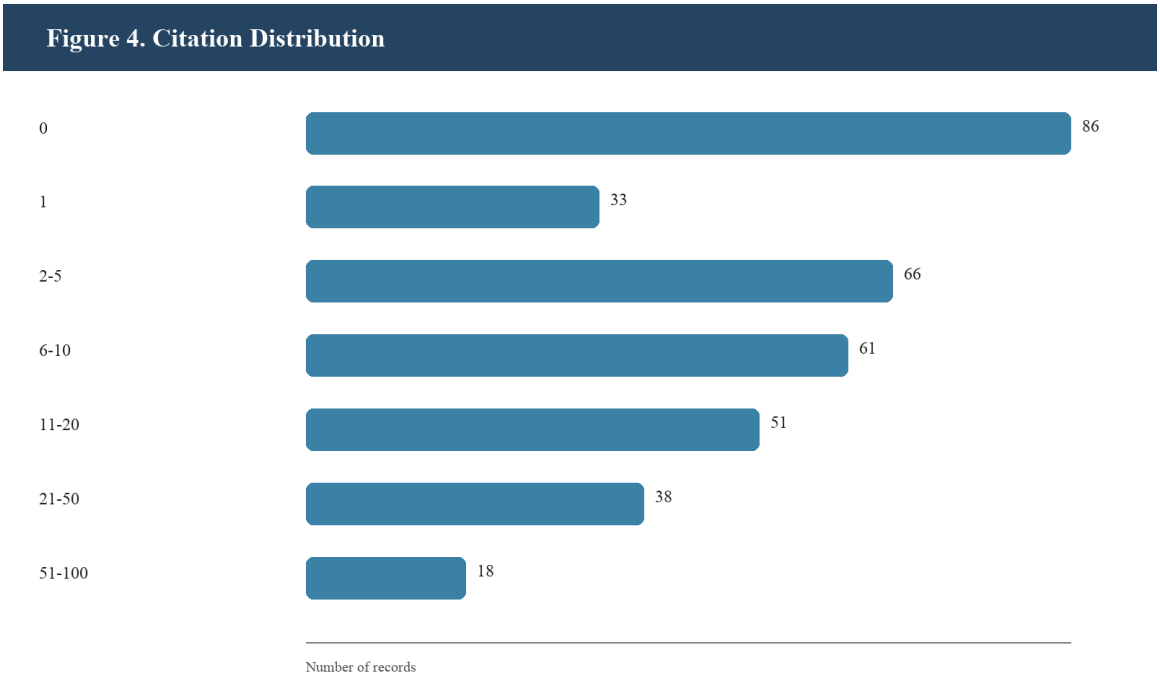

Figure 4. Citation Distribution

Figure 4 displays the citation distribution. The right-skewed profile indicates that many records are lightly cited while a limited number of publications receive high attention. This pattern is typical of interdisciplinary fields where conceptual vocabulary is shared unevenly across journals. It also cautions against using citation counts alone as evidence of social relevance.

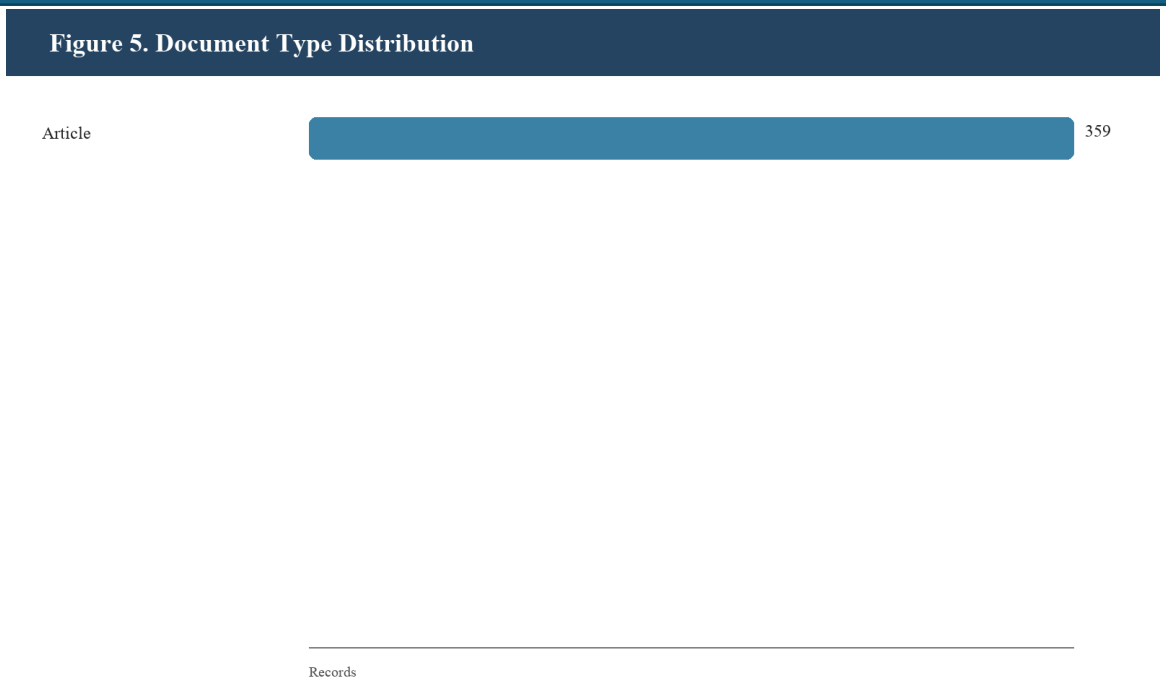

Figure 5. Document Type Distribution

Figure 5 shows document type distribution. Articles constitute the main evidence base, while reviews, book chapters or other formats contribute smaller shares. This composition supports the use of article-level bibliometric analysis but also explains why the corpus contains heterogeneous reporting standards.

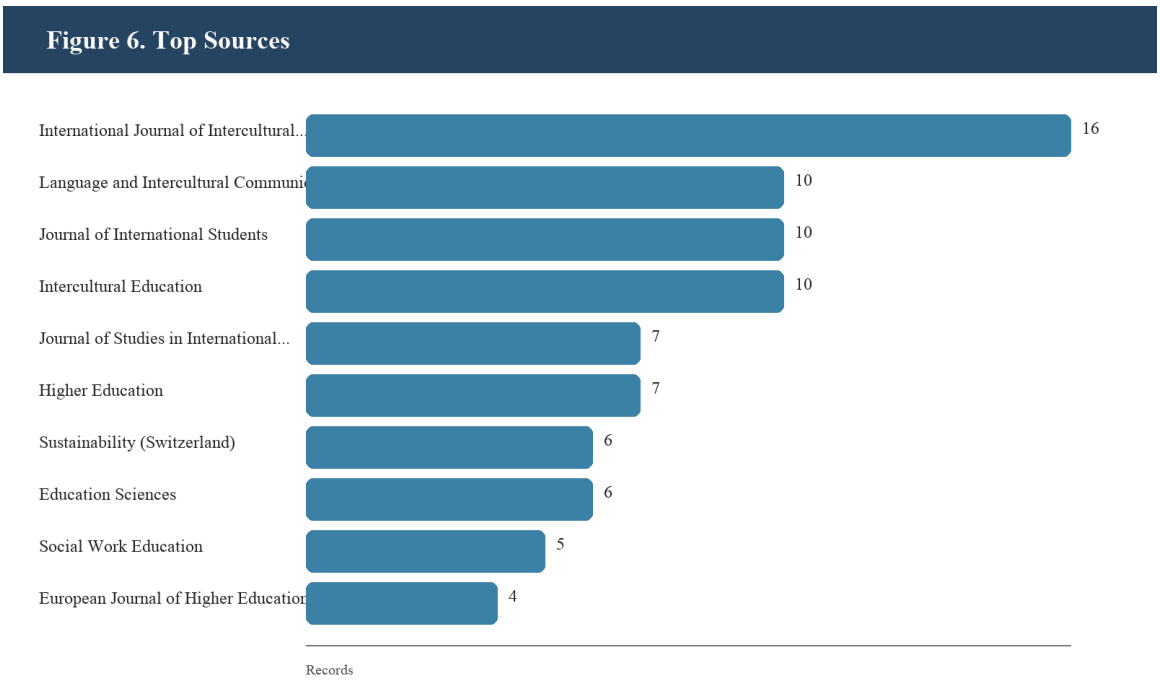

Figure 6. Top Sources

Figure 6 identifies leading source titles. The source distribution is dispersed, with only a few journals publishing multiple records. This dispersion indicates that intercultural mobility research is not housed in a single disciplinary venue; it circulates through intercultural communication, higher education, sociology, language education and policy-oriented outlets.

Figure 9. Co-authorship Network

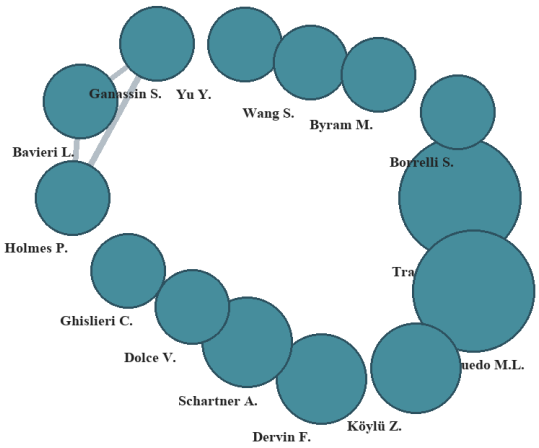

Figure 9. Co-authorship Network

Figure 9 shows the co-authorship network recreated from author co-appearances in the included records. The network has visible clusters but no single dense core, indicating dispersed collaboration. Bibliometrically, this means the field is collaborative in pockets rather than consolidated around a few stable teams. Sociologically, the pattern is consistent with the international and context-specific nature of mobility research.

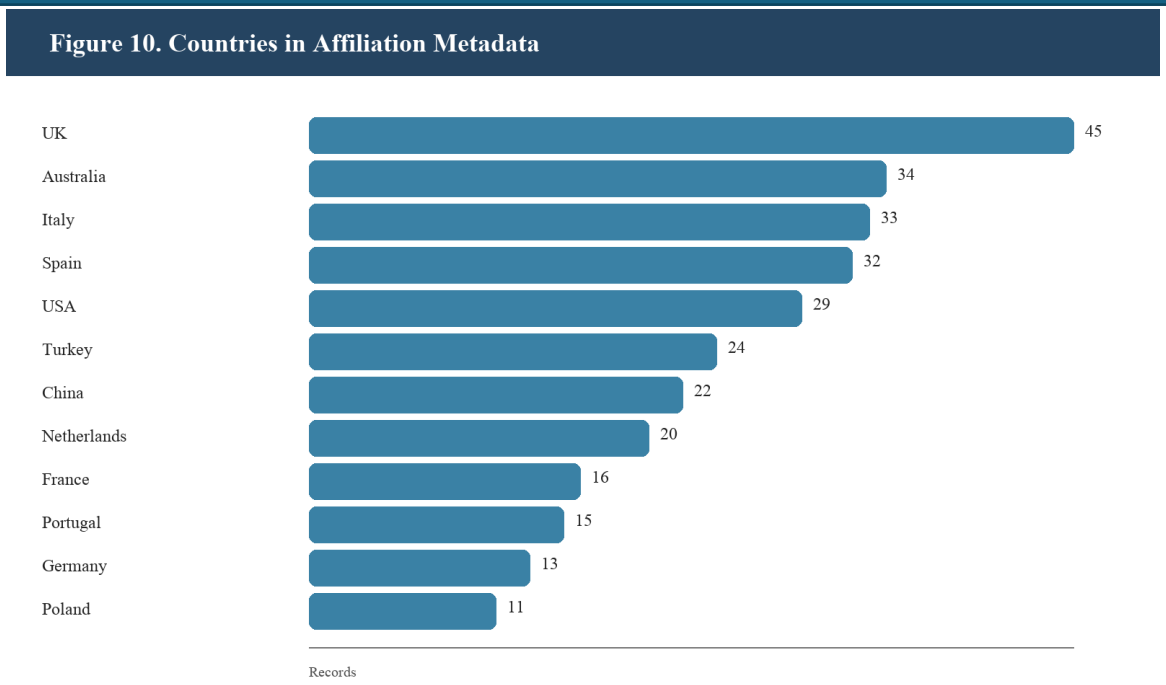

Figure 10. Countries in Affiliation Metadata

Figure 10 presents countries detected in affiliation metadata. The country profile shows the visible institutional geography of the corpus. Because affiliation strings are not equivalent to study location or participant nationality, the figure is interpreted as a metadata distribution. Even with that caution, the spread across countries supports the claim that mobility research is internationally distributed.

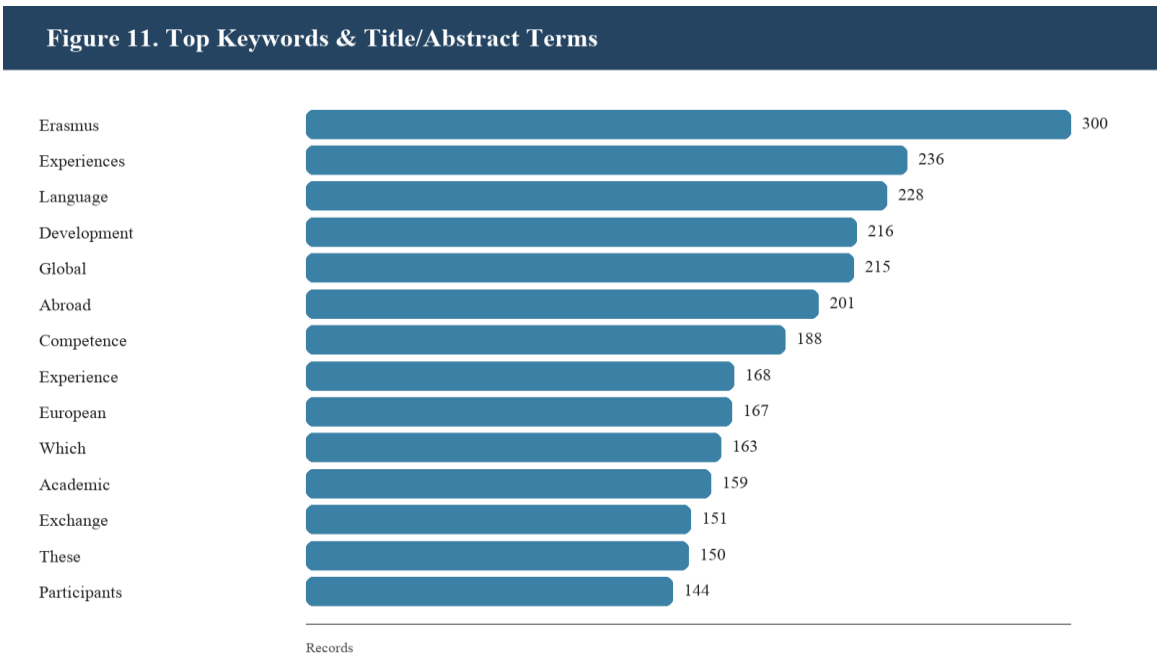

Figure 11. Top Keywords & Title/Abstract Terms

Figure 11 combines author keywords with frequent title and abstract terms. Student mobility, intercultural competence, identity, higher education and Erasmus appear as dominant terms. The vocabulary confirms that the field is built around mobility as a setting for intercultural learning and identity work, while language and inclusion terms mark the social conditions that shape outcomes.

Figure 12. Term Co-occurrence Network

Figure 12. Term Co-occurrence Network

The co-occurrence structure shown in Figure 12 indicates how central concepts cluster together. Terms around mobility, identity, competence, language and internationalisation form connected zones rather than one unified measurement tradition. This pattern shows thematic fragmentation but also a shared conceptual centre.

Figure 13. Overlay Visualisation

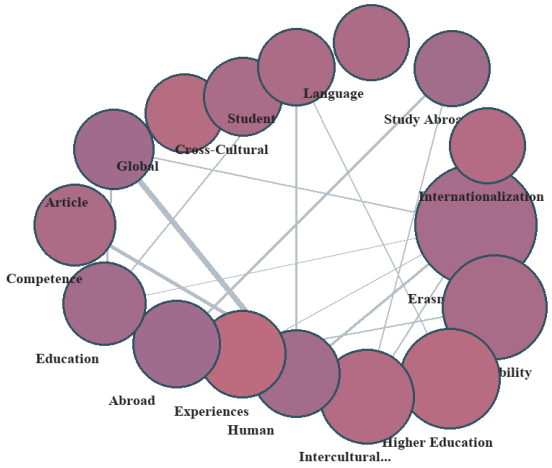

Figure 13. Overlay Visualisation

Figure 13 adds an overlay interpretation by colouring terms according to average publication year. More recent terms indicate where the discussion is moving, especially toward digital mobility, inclusion and conditional forms of belonging. The overlay suggests a field that is expanding from classic mobility and competence themes toward more critical sociological questions.

Figure 14. Density Visualisation

Figure 14. Density Visualisation

The density visualization in Figure 14 suggests where conceptual concentration is strongest. Dense areas around intercultural competence, mobility, identity and higher education show the main intellectual centre of the corpus. Lower-density zones point to emerging or less consolidated topics that may require deeper full-text synthesis.

Figure 15. PRISMA Flow Diagram

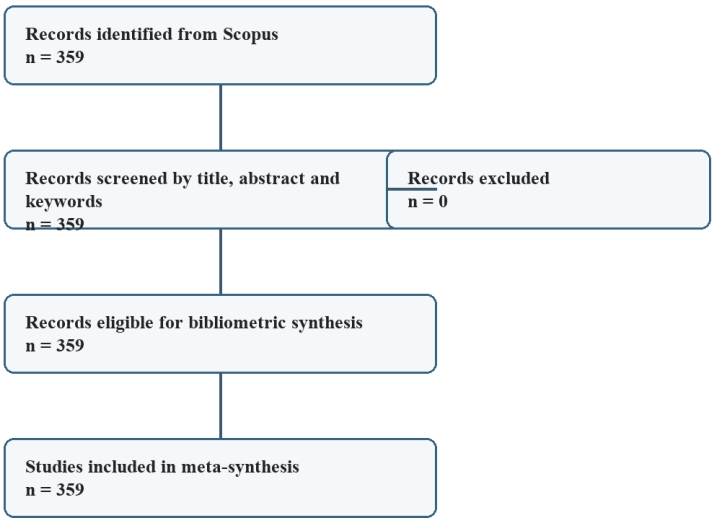

Figure 15. PRISMA Flow Diagram

Figure 15 gives the PRISMA-guided flow from retrieval to included synthesis. The diagram documents the movement from 111 retrieved records to 108 included records after exclusion of three insufficiently relevant records. This figure strengthens transparency by making screening decisions visible before the bibliometric interpretation begins.

4. CONCLUSION

This proceedings-style bibliometric meta-synthesis shows that international student mobility research is expanding, interdisciplinary and sociologically rich. The evidence base is strongest around intercultural competence and global learning, but identity, citizenship, language adaptation, inclusion, inequality and employability are also central to the field's meaning. Citation metrics show concentration around a limited number of influential publications, while source and co-authorship patterns show dispersion across journals and research teams.

The main conclusion is that mobility functions as a conditional social process. It can foster intercultural dialogue and social development when students gain meaningful contact, language access, institutional support and opportunities for belonging. It can also produce mixed or

constraining outcomes when mobility occurs without those conditions. Future research should report comparable outcomes, extractable effect sizes and clearer sample information so that bibliometric mapping can be combined with stronger full-text synthesis and, where appropriate, later statistical meta-analysis.

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RECALIBRATION OF TIGHT MONETARY POLICY AND STRENGTHENING OF FX BALANCE IN TÜRKIYE'S FIGHT AGAINST INFLATION

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ABSTRACT

This study aims to re-examine the contradictions frequently observed in the recalibration or readjustment of tight monetary policies, particularly in the context of inflation-controlled calibration. In Türkiye, the recent high inflation rates, coupled with tight monetary and fiscal policies, have created significant vulnerabilities, especially in the face of rising exchange rates. This phenomenon necessitates a reassessment of the calibration of tight monetary policies, including interest rates, exchange rate policies, monetary and fiscal policies, and an inflation-controlled calibration that supports this issue. In other words, the observation of varying impact values, particularly on foreign currency-protected deposits, and the subsequent negative impact and increase in exchange rate policies after 2020, have brought to the forefront some striking precautionary measures regarding the control of credit policies along with tight monetary policies. This indicates that the calibration of tight monetary policies has inevitably been questioned in the post-2020 period in terms of financial balances.This approach signifies an inflation control policy that aims not only to reduce inflation and ensure exchange rate stability, but also to strengthen the financial system in Türkiye and reduce dollarization calibration. In Türkiye, it is understood that recently, making the Turkish Lira the primary store of value again has emerged as an important objective. Undoubtedly, in terms of structural limitations and risks, ensuring high sensitivity to global financial conditions, as well as preventing the negative impact of high inflation inertia on the demand-driven growth structure, constitutes a financial-fiscal phenomenon that creates structural constraints on the macroeconomic prudential policies in the process. In this context, it appears that increasing confidence in the Turkish Lira as the national currency and strategic assessments regarding it, along with permanently controlling inflation within a policy credibility framework, constitute the main objective and theme of this recent approach to Türkiye.

Key Words: Dollarization, Foreign Exchange, Inflation, Macro-Prudential Policy, Tight Monetary Policies**.**

JEL Codes: E31; E42, E44.

1. INTRODUCTION

In Türkiye, the recent inflationary process, particularly the tight monetary policies that have been targeted, appears to have established a certain conceptual framework related to interest rate policies and several important factors. In other words, this structure, based on comparing interest rates, real interest rates, and policy interest rates, represents a restructuring of monetary policy in Türkiye, particularly in terms of calibration and policy. This phenomenon, which has emerged as a new calibration of tight monetary policy, is directly related to the exchange rate, directly affected by the quality of the exchange rate, and directly impacts capital inflows through interest rate increases.

In a structure where assets are expressed in Turkish Lira, the focus is on a decrease in foreign exchange sales in Türkiye. This approach forms the main idea of the restructuring within the scope of a tight monetary policy. In Türkiye, this situation points to a structure where interest rates are affected not only by credit restrictions but also by reserve requirements, in a structure where record inflation levels persist. While focusing on reducing cost inflation, it also aims to address the fact that inflation increases are not directly related to interest rates, and that tight monetary policy calibration targets a more effective structure in this regard, aiming to control the risk at the global level. In this context, it is revealed that the impact of national macroeconomic dynamics in Türkiye is shaped by the financial foreign exchange reserves obtained from different sources, particularly in terms of increasing the resistance of the national currency against exchange rate pressure (Türkiye Cumhuriyet Merkez Bankası, 2024).

This structure, where the targeted policy interest rates are particularly insufficient in definition, simplifies the reading of macro-financial targets and represents a strategic calibration process aimed at ensuring exchange rate stability. On the other hand, one of the most important features in the emergence of this phenomenon is undoubtedly exchange rate expectations. Controlling exchange rate expectations in Türkiye in terms of national foreign exchange demand is again presented as a recalibration project indirectly resulting from the re-binding of tight monetary policy.

In this context, there is a calibration project that considers the structural vulnerabilities in the transmission mechanism of market interest rates beyond policy interest rates, despite consistent, predictable increases in interest rates. The recalibration of tight monetary policy, implemented in a continuous manner, reveals that the re-establishment of the interaction between interest rates and exchange rates in terms of financial balances, as well as the structural value shaped by the exchange rate and other macroeconomic tools, where the interest rate level is not the primary factor, makes tight monetary policies structurally inevitable. In Türkiye, this structure

also shows that in recent periods where monetary policies are considered as tight monetary policies, the ability to organize exchange rate expectations into a positive decision makes the integrity of the tight monetary policy option sufficiently consistent and predictable.

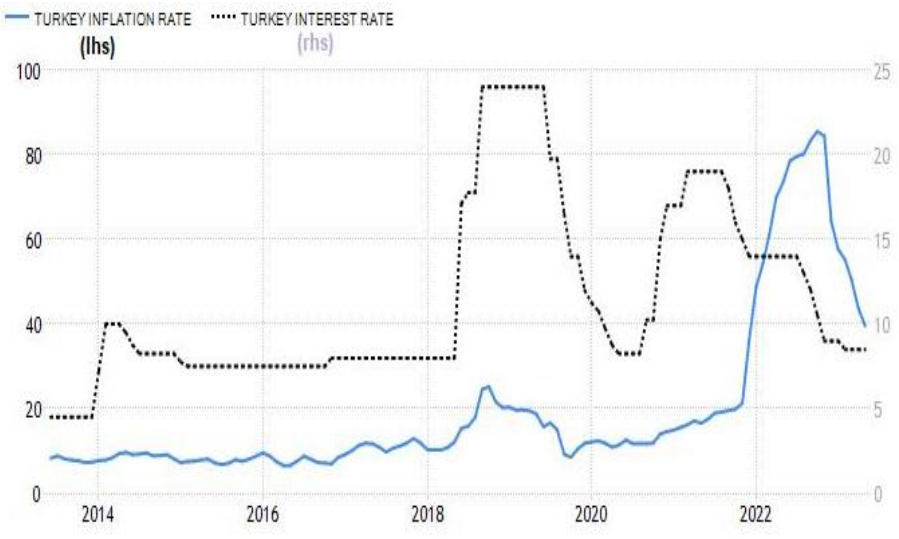
The fight against rising inflation, the exchange rate, and rising inflation rates in a structure where they remain at high levels, also reveals that implementing a predictable and tight monetary policy was not very effective until 2020. It is a noteworthy positive development that the tight monetary policy prioritizes not only combating inflation but also, through its recalibration targets, exchange rate policies, and, as another priority, controlling or blocking the trend of dollarization in Türkiye (International Monetary Fund, 2024).

2. RECALIBRATION OF TIGHT MONETARY POLICY AND STRENGTHENING OF FOREIGN EXCHANGE BALANCE

It is observed that each structure in Türkiye prioritizes a process that makes it inevitable to consider interest rates primarily within economic growth trends. This approach points to a structure where dollarization is brought under a certain control, as well as the control of exchange rate pressure in Türkiye. Record inflation levels, which have emerged as a significant investment cost for investments, along with the recent increase in exchange rate expectations, have created a destabilizing structure.

2.1. Recalibration of Tight Monetary Policy and Deviations in Real Interest Rate Dynamics in Turkey

The multifaceted nature of tight monetary policy calibration, including the impact of interest rates, clearly demonstrates that the recalibration process, exchange rate impact values, and inflation outcome are inconsistent and unpredictable. In this context, it should be particularly emphasized that these impact values recently implemented in Türkiye aim for a stable structure where global risk appetite towards the dollar, as well as national global financial risk appetite, are controlled, and speculative positions based on interest rates are avoided. The inflation shock experienced in 2020 and 2021, and especially in 2023 and beyond, where inflation rates rose to around 80% despite a partial decrease in policy interest rates, and interest rates remained relatively low before rising again, has resulted in policy interest rates lagging far behind inflation (International Monetary Fund, 2024-b). This situation, with the profound negative impact of monetary transmission mechanisms and especially real interest rates, makes it inevitable that tight monetary policies become even more effective. The Graph 1 below also shows the interaction and resulting effects of inflation rates and interest rates in Türkiye during the recent period of tight monetary policy recalibration:



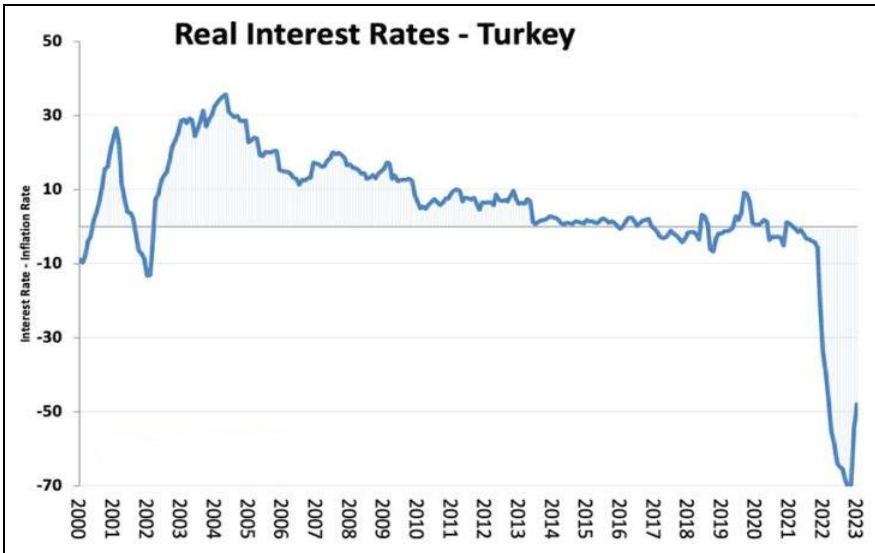
Source: Türkiye Cumhuriyet Merkez Bankası (2024-b). *Faiz oranları (politika faizi, haftalık repo)*. https://evds2.tcmb.gov.tr/ (Accessed April, 12.2026); Türkiye İstatistik Kurumu (2024). *Tüketici fiyat endeksi (TÜFE)*, yıllık değişim oranları. https://data.tuik.gov.tr/ (Accessed April, 17.2026).

Graphic 1. The Relationship Between Inflation and Policy Interest Rate as Monetary Policy Effectiveness in Turkey

As seen in Graph 1 above, in Türkiye, the tight monetary policy, particularly between 2013 and 2017, demonstrated a relatively stable policy approach, with policy interest rates remaining between 7% and 10%, consistent with a stable inflation band. This period, during which inflation also ranged between 7% and 12%, can be interpreted as a period demonstrating a passive policy approach and a lack of effective implementation of tight monetary policy. In other words, this factual structure indicates low policy effectiveness and the inability to anchor real interest rate margins within a narrow range of expectations. The insufficient anchoring of interest rate margins during these years could also signify an expansion of credit portfolios, indicating a departure from the effectiveness of tight monetary policy. The rise in inflation to 25% and above after 2018 and 2019 – creating a ripple effect – and the sharp increase in interest rates to 24% or 26%, has brought to the forefront the interpretation that interest rate hikes occurred after inflation rose. In this context, it also reveals that monetary policy, as a tight monetary policy, is corrective rather than preventive. The approach that interest rate policy alone is insufficient can be expressed as the main reason why tight monetary policies, with their calibration effect, have come to the forefront as inadequate on their own. Because the prevalence of reciprocal negative real interest rate periods, particularly felt until 2023, indicates an increase in the risk premium due to exchange rate and inflation pass-through, it reveals an asymmetric relationship (World Bank, 2024-a).

2.2. Real Interest Rate Dynamics and Monetary Regime in Recent Years under the Framework of Tight Monetary Policy

This suggests that the existence of an asymmetric structure with structural breaks and classic reverse timing deviations necessitates a recalibration of tight monetary policies as a calibration process, and this has brought this issue to the forefront. Undoubtedly, this situation makes it inevitable to examine the recent volatility of real interest rates in Türkiye as part of the assessments related to the recalibration of tight monetary policy and strengthening of FX balance in Turkey's fight against inflation. Graph 2 below provides a meaningful picture of the recent trend in real interest rates in Turkey:



Source: World Bank (2024-b). *Real interest rate (%): Türkiye. World Development Indicators*. https://data.worldbank.org/indicator/FR.INR.RINR?locations=TR (Accessed April, 14.2026); International Monetary Fund (2024-c). International Financial Statistics (IFS) database. https://data.imf.org/ (Accessed April, 15.2026).

Graphic 2. The Evolution of Real Interest Rates in Turkey Over Time (2000–2023)

As seen in Graph 2 above, the period after 2000 in Türkiye can be described as almost orthodox, indicating a structure where real interest rates remained in the 10% to 30% range. The variability of real interest rates between 10% and 30% is also a relatively normal monetary policy calibration regime. The period between 2009 and 2017, however, reveals a more gradual normalization process, with real interest rates converging towards 5%, 10%, and then nearing zero. This period is characterized by a controlled easing, narrowing interest rate margins, but also by the potential for inflation to rise again, pushing it upwards through sticky price stickiness and the effect of interest rate-price stickiness. The presence of a temporary tightening period after 2018 is particularly noteworthy, with short-lived positive real interest rate margins

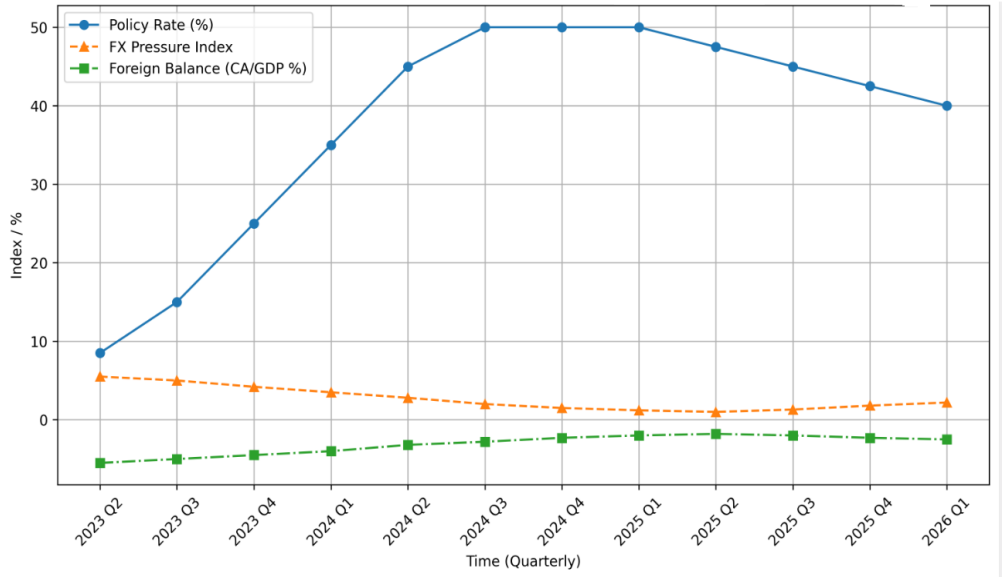
in 2018 (OECD, 2025). This period is interpreted as a response to the economic and financial shocks between 2018 and 2020, but one in which a highly rational and sustainable monetary policy was absent or very weak. It is also noteworthy that this period saw a deep negative real interest rate regime between 2020 and 2022, with real interest rates falling to between -10% and -70%. However, it is crucial to emphasize that interpreting this negative impact on real interest rates as a tight monetary policy calibration during 2020 and 2022 is very difficult. This is because the control scale weakened during this period, and instead, the policy became excessively expansionary and inflationary, thus contributing to the shocks that followed. This structure, which resulted in an inflation explosion, has transformed into a significant negative real interest rate process with inflation rates hovering around 80%. Although real interest rates appear to be being pulled upwards from negative levels due to the influence of nominal interest rates after 2023, it is still not possible to speak of a limited positive effect close to zero. This recent phenomenon, which has inevitably been reflected in prices, directly points to a structure where pricing behaviour has further deteriorated. This resulting effect indicates that a tight monetary policy approach, as a monetary policy calibration, does not create a lasting effect simply by raising interest rates, and that the existence of rational expectations regarding a reliable policy framework is inevitable (OECD, 2024).

2.3. Repositioning the Calibration in Turkiye: Fighting Inflation, Tight Monetary Policy, and Exchange Rate Balance

In the Turkish economy, particularly with the tight monetary policy regime and the recent inflation rate targets, it can be said that some measures aimed at preventing inflation have sought to bring macro-financial stability, based on the foreign exchange balance, to a more stable position. Therefore, in evaluating this main issue, especially within the context of the foreign exchange-based tight monetary policy and foreign exchange balance, it is possible to assess this phenomenon in Turkey in recent times by considering it in three main parts. The first and most important of these is undoubtedly the position of the foreign exchange balance and foreign exchange reserve dynamics. The second is considered and evaluated as the effect of the monetary transmission mechanism in the market on risk premiums, related to expectation management and risk premiums. The third can be evaluated as the policy interest rate, which has come to the forefront quite effectively recently and has been criticized politically, and consequently, the changes in the liquidity decisions related to the process (International Monetary Fund, 2023).

Highlighting the characteristics of this prominent structure represents an important step (Şen and Kaya, 2014). This structure, which also aims to reduce inflation rates, has also frequently

brought up a high interest rate policy that can encourage foreign exchange balance, capital inflows, and exchange rate stability. However, it is understood that despite expectations of improvements in net international reserve positions, the levels of pressure caused by excessive volatility in exchange rates, which create depreciation, have not reached the desired level when evaluated in terms of reserve accumulation and foreign exchange liquidity. In terms of current account balances, this situation indicates that the interaction between inflation control, which limits import demand, and the foreign exchange balance, along with monetary policy, has resulted in a structure that continues with demand expansion and expectations (Bank for International Settlements, 2023). This structure, which specifically targets tightening liquidity and reducing foreign exchange demand, can also be defined as an inflation control policy aimed at reducing demand inflation. This structure is considered a set of policies aimed at creating a confidence channel where cost inflation is also targeted. The changes in this structure in recent times, considering inflation, policy interest rates, exchange rates, and exchange rate indices in terms of the balance of payments as percentages, can be observed in Graph 3 below:



*Data derived and calibrated fromTürkiye Cumhuriyet Merkez Bankası (EVDS), Türkiye İstatistik Kurumu, International Monetary Fund (IFS), and World Bank (WDI).

Source: Türkiye Cumhuriyet Merkez Bankası (2026). *Elektronik veri dağıtım sistemi (EVDS): Politika faizi, ortalama fonlama maliyeti ve döviz piyasası verileri*.https://evds2.tcmb.gov.tr/ (Accessed April, 17.2026); *Türkiye İstatistik Kurumu (2026). Ödemeler dengesi ve cari işlemler dengesi istatistikleri*. https://data.tuik.gov.tr/ (Accessed April, 17.2026); World Bank (2025). *World Development Indicators: External balance and macroeconomic indicators for Türkiye*. https://databank.worldbank.org/ (Accessed April, 18.2026); International Monetary Fund (2025). *International Financial Statistics (IFS): Türkiye country data*. https://data.imf.org/ (Accessed April, 18.2026).

Graphic 3. Exchange Rate Pressure (FX) and External Balance Dynamics in Türkiye During a Tight Monetary Policy Period

Graph 3 above illustrates a structure in Türkiye, particularly regarding tight monetary policy, where current account balances have persisted under pressure from policy interest rates and exchange rates during the recent period of its implementation. The timing of the policy interest rate and monetary tightening in Türkiye can be seen as a sharp upward movement, with policy interest rates reaching levels as high as 50%. This hybrid-focused policy approach, as a result of monetary policy, has led to a decline in credibility and especially risk indicators, and has been partially effective in suppressing demand for foreign currency. The inflation expectations channel, particularly the use of a high nominal interest rate as a separate channel in the post-2020 period, has been partially successful in reducing exchange rate pressure on the Turkish Lira by encouraging short-term monetary portfolio inflows. On the other hand, this phenomenon is also shaped by Türkiye's import-dependent production structure in terms of current account balances. Even though exchange rate pressure has decreased in Türkiye in terms of current account balances recently, unfortunately, the expected decrease in import limits has not materialized. The continued high level of domestic demand resistance despite high interest rates, and especially the failure of monetary tightening to fully meet desired expectations, has been a significant drawback in the recent period (World Bank, 2024-c).

This nature of monetary tightening, largely related to cyclical factors, indicates that domestic demand resistance, despite high interest rates, has not caused a significant disruption in consumer behaviour or provided a braking effect. It also reveals that growth in financial services, while weaker in the medium and long term, has been more successful in short-term effects, resulting in a decrease in FX pressure. In this context, at this point, where it is concluded that maintaining financial stability and correcting the real external balance is a limited tool, the dynamic decline in exchange rate pressure (FX) necessitates an evaluation of the process through three main channels of FX values (Bank for International Settlements, 2022). Firstly, the channel of expectations regarding the inflationary process, especially in the recent period of tight policy implementation, can be said to have had a positive effect by weakening the exchange rate pass-through between the exchange rate (FX) and the Turkish Lira in terms of anchoring inflation expectations. On the other hand, when the issue is evaluated from the perspective of the risk premium channel, the combination of tight monetary policy and CDS (Credit Default Swap) has created a significant positive effect, particularly in risk indicators like CDS, demonstrating a substantial reduction in risk (OECD, 2023).

Furthermore, high nominal interest rates have recently reduced exchange rate pressure, further supporting this view. At this stage, it is particularly important to emphasize that the decrease in "Foreign Exchange" (FX) pressure should not be interpreted as a clear structural success. This

is because, especially in the recent period where potential temporary capital inflows did not reach the desired level because of liquidity management dependent on policy credibility, this situation has brought about the need for a revision in policy design in Türkiye. A tight monetary policy alone is insufficient to achieve a real economic balance. Undoubtedly, the tight monetary policy has not lost its connection with real economic balances, but it also shows that the impact of the tight monetary policy regime in Türkiye has decreased significantly after reaching an effective threshold (Yıldırım and Tuğba, 2023). This situation initially reveals a strong relationship, but interest rate pressure subsequently transforms into a weak relationship in the long term. In this context, the transmission mechanism of tight monetary policy is not linear, but rather a threshold-oriented financial position and phenomenon; however, achieving permanent exchange rate stability necessitates a structural positive transformation process, especially in export capacity and current account balance components. In this context, it is clear that liquidity and reserve management, particularly SWAP mechanisms and the support of the Foreign Exchange (FX) market, are indispensable. In terms of policy divergence, this structure, where high interest rates increase the demand for Turkish Lira in short-term capital inflows, indicates that a stable exchange rate, characterized by a continuous and uninterrupted downward trend rather than a structural one stemming from financial flows, is present in the process (Türkiye Cumhuriyet Merkez Bankası. 2022).

3. DISCUSSION

In Türkiye, particularly in the recent period where tight monetary policy has been implemented, one of the most important aspects to consider analytically is the fact that monetary policy does not follow a linear structure and does not create a linear structural effect. While a strong inverse relationship is observed in exchange rates and risk premiums, and therefore initially shaped by interest rate increases, it also weakens the threshold effect level, increasing demand for the Turkish lira and weakening the impact on exchange rate fragility. However, in terms of exchange rate stability, this never means a production-based equilibrium, nor is it a sustainable structure that can be maintained in the long term. For it to be considered in the evaluation process, it is understood that while reserve management and price mechanisms have a significant impact on maintaining short-term equilibrium, the need for a comprehensive long-term solution is also unavoidable.

This inevitability also highlights the fact that financial stability is not only sustainable through the interest rate channel and its mechanisms, but also that monetary policy transmission mechanisms exhibit a non-linear, regime-dependent structure. This vulnerability, which can be expressed as a threshold value, is particularly sensitive to rapid movements in potential equal

values from a macroeconomic and monetary policy perspective and signifies a vulnerability where the marginal effect of the relationship reached at the threshold level is weakened. While the application of high nominal interest rates in Türkiye, as an indicator of tight monetary policy, is considered effective in managing short-term risk perception through Credit Default Swaps (CDS), the recent outlook indicates that its impact on exchange rates is not at the desired level and suggests a superficial perception of stability. Even if monetary tightening's effectiveness as a price stabilization process is highlighted in the short term, it will lead to structural erosion in terms of policy effectiveness, causing negative vulnerabilities in the medium and long term.

In this context, it is observed that tight monetary policy in Turkey represents a significant variability dependent on certain structural values in achieving short-term stability, and that the coordinated action of monetary and fiscal policies, supported by strategies that transform the production structure and improve the external balance, is once again indispensable. In other words, while this type of tightening process aims to produce lasting macroeconomic stability in the long term, the current structural position, far from being able to support this form of stability, is far from ensuring alignment with sustainability dynamics in establishing a continuous and uninterrupted evaluation trend. In this context, the most important and critical aspect of the recent process, particularly in the analytical context, is that the lack of a linear structure in tight monetary policy, coupled with the inverse relationship between interest rate hikes and exchange rate pressure on inflation, is one of the main causes of a significant structural break. Achieving lasting exchange rate stability in Türkiye, as demonstrated in the latest attempt, is undoubtedly an absolute necessity for this sustainable balance. However, the mismatch between reserve utilization and the control of liquidity volume in the foreign exchange market through SWAP mechanisms reveals that a deeper structural questioning is inevitable, going beyond a superficial perception of stability.

4. CONCLUSION

When evaluating inflation control policies in Türkiye, it is observed that while monetary tightening has a relatively high capacity to generate financial stability, it has not been very effective in combating inflation in recent times. The approach to combating inflation in Türkiye, particularly in discussions about interest rate levels, appears to be incomplete, as it focuses solely on predicting fluctuations in interest rates. This lack of a multi-dimensional approach to combating inflation means that monetary policies fail to strengthen a secure foundation for managing underlying expectations in policy design. In Turkey's recent inflationary period, the fundamental priority in financial policies has been to achieve predictability in combating

inflation and to integrate monetary tightening into structural control policies. Without this integration, the effectiveness of monetary policy remains limited, and the process becomes more fragile, exhibiting price distortions and deviations. In other words, rather than monetary tightening, the inevitability of building confidence and positive expectations in the broader medium and long term becomes apparent.

The fact that exchange rate movements and interest rate levels, especially within policy consistency, form a close structural relationship with institutional credibility, means that Türkiye's tight monetary policy, particularly within the framework of a classic transmission mechanism, moves beyond being merely a tool targeting the exchange rate. This phenomenon makes the integration of tight monetary policy expectations, along with the management of these expectations and the indirect shaping of exchange rate dynamics, inevitable for policies that will provide short-term stability. In this context, when the issue is evaluated within an analytical framework, it becomes clear that the determining factors are the management of exchange rate expectations and the credibility of the policies behind this management. For the medium and long term, where monetary and fiscal policy combinations become unpredictable, this situation is understood to exhibit a multi-layered, threshold-based structure where upward pressure on the exchange rate persists despite high interest rates, further fueling inflation and transforming into a closed devaluation process.

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HASTANELERDE YAPAY ZEKÂ UYGULAMALARI VE HİZMET KALİTESİ: SAĞLIK YÖNETİMİ PERSPEKTİFİNDEN KAVRAMSAL BİR DEĞERLENDİRME

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ÖZET

Çalışmanın Problemi: Hastanelerde yapay zekâ kullanımının artması, sağlık hizmetlerinin kalitesi konusunda yeni tartışmaları beraberinde getirmiştir. Bu uygulamalar çoğu zaman verimlilik ve iyileşme ile ilişkilendirilse de, hizmet kalitesi üzerindeki etkilerinin sağlık yönetimi açısından daha geniş bir çerçevede ele alınması gerekmektedir.

Çalışmanın Amacı: Bu çalışma, hastanelerde yapay zekâ uygulamalarını hizmet kalitesi ile ilişkisi çerçevesinde sağlık yönetimi perspektifinden tartışmayı amaçlamaktadır.

Yöntem: Çalışma, ilgili literatüre dayalı kavramsal bir inceleme niteliğindedir. Bu kapsamda yapay zekânın hastane hizmet kalitesi üzerindeki olası etkileri, sağlık hizmeti sunumu, yönetsel süreçler ve hasta odaklı uygulamalar bağlamında ele alınmaktadır.

Bulgular: Literatür, yapay zekânın özellikle verimlilik, süreç iyileştirme ve hasta bakımını destekleme açısından hastanelerde hizmet kalitesine çeşitli katkılar sağlayabileceğini göstermektedir. Bununla birlikte uygulama, sorumluluk ve kalite denetimiyle ilgili bazı tartışmalar önemini korumaktadır.

Sonuç: Yapay zekâ, yalnızca teknolojik bir gelişme olarak değil, aynı zamanda hastanelerde hizmet kalitesi ve yönetimle ilişkili bir konu olarak değerlendirilmelidir. Böyle bir yaklaşım, hem sağlık yöneticileri hem de gelecekteki araştırmalar için yararlı bir bakış açısı sunabilir.

Anahtar Sözcükler: yapay zekâ, hizmet kalitesi, hastaneler, sağlık yönetimi, sağlık hizmetleri

ABSTRACT

Problem of the Study: The growing use of artificial intelligence in hospitals has led to new discussions about the quality of healthcare services. Although these applications are often associated with efficiency and improvement, their implications for service quality still need to be considered from a broader health management perspective.

Purpose of the Study: This study aims to discuss artificial intelligence applications in hospitals in relation to service quality from the perspective of health management.

Method: The study is based on a conceptual review of the relevant literature. In this context, the possible effects of artificial intelligence on hospital service quality are addressed with reference to healthcare delivery, managerial processes, and patient-focused practices.

Results: The literature suggests that artificial intelligence may support hospital service quality in several ways, particularly in terms of efficiency, process improvement, and patient care. At the same time, concerns related to implementation, responsibility, and quality oversight remain significant.

Conclusions: Artificial intelligence should be evaluated not only as a technological development but also as an issue related to service quality and management in hospitals. Such an approach may provide a useful perspective for both healthcare managers and future studies.

Keywords: artificial intelligence, service quality, hospitals, health management, healthcare services

FİYAT GEÇİŞKENLİĞİNDE SEKTÖREL ASİMETRİLER: TÜRKİYE EKONOMİSİNDE ÜFE-TÜFE MAKASI VE KÂR MARJI DİNAMİKLERİ

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ÖZET

Bu çalışma, Türkiye ekonomisinde 2020-2026 yılları arasında yaşanan şiddetli makroekonomik ve dışsal arz şoklarının tüketici fiyatlarına geçişkenliğini sektörel kâr marjları ve fiyatlama davranışları ekseninde analiz etmeyi amaçlamaktadır. Literatürdeki geleneksel ekonometrik modellerin aksine, bu araştırmada Türkiye Cumhuriyet Merkez Bankası (TCMB) sektörel bilanço istatistikleri ve Türkiye İstatistik Kurumu (TÜİK) verileri üzerinden betimsel bir enflasyon makası analizi yürütülmüştür. Elde edilen ampirik bulgular, 2021 ve 2022 yıllarında ivmelenen küresel emtia ve döviz kuru şoklarının ilk aşamada reel sektör tarafından büyük ölçüde kendi bilançolarında absorbe edildiğini ve imalat ile inşaat gibi sektörlerde kâr marjı fedakârlığına gidildiğini göstermektedir. Ancak 2023 yılı ve sonrasında fiyatlama davranışlarında yapısal bir kırılma yaşanmış; literatürde "satıcılar enflasyonu" (sellers' inflation) olarak tanımlanan sürecin devreye girmesiyle enflasyon dinamikleri maliyet kökenli yapıdan kâr itişli bir karaktere dönüşmüştür. Bu dönemde firmaların geçmiş maliyet birikimlerini ve geleceğe yönelik risk primlerini nihai fiyatlara önden yüklemeli olarak yansıtması, net kâr marjlarını tarihsel ortalamalarının üzerine taşımış ve dezenflasyon sürecinin önünde ciddi bir katılık yaratmıştır. Sektörel asimetriler incelendiğinde, temel malların dışsal şoklara en esnek tepkiyi verdiği, hizmetler ve tarım sektörlerinin ise en yüksek fiyatlama katılığını sergilediği tespit edilmiştir. Çalışma sonucunda, kalıcı fiyat istikrarının sağlanabilmesi için enflasyon beklentilerinin yeniden çıpalandırılması, hizmet sektörüne yönelik mikro ihtiyati tedbirlerin alınması ve imalat sanayisinde ithal girdi bağımlılığını azaltacak yapısal dönüşümlerin hızlandırılması gerektiği vurgulanmaktadır.

Anahtar kelimeler: Fiyat Geçişkenliği, Satıcılar Enflasyonu, Kâr Marjı, Makroekonomik Şoklar, Sektörel Katılıklar.

SECTORAL ASYMMETRIES IN PRICE PASS-THROUGH: PPI-CPI GAP AND PROFIT MARGIN DYNAMICS IN THE TURKISH ECONOMY

ABSTRACT

This study aims to analyze the pass-through of severe macroeconomic and external supply shocks to consumer prices in the Turkish economy between 2020 and 2026, focusing on sectoral profit margins and pricing behaviors. In contrast to the traditional econometric models in the literature, this research conducts a descriptive inflation gap analysis using the Central Bank of the Republic of Turkey (CBRT) sectoral balance sheet statistics and the Turkish Statistical Institute (TURKSTAT) data. The empirical findings indicate that the global commodity and exchange rate shocks that accelerated in 2021 and 2022 were initially largely absorbed by the real sector within their own balance sheets, leading to profit margin sacrifices in sectors such as manufacturing and construction. However, a structural break in pricing behaviors occurred in 2023 and onwards; with the activation of the process defined in the literature as "sellers' inflation," inflation dynamics transformed from a cost-driven structure to a profit-led character. During this period, firms' front-loaded reflection of past cost accumulations and future risk premiums onto final prices pushed net profit margins above their historical averages and created severe rigidity against the disinflation process. When sectoral asymmetries are examined, it is determined that core goods gave the most flexible response to external shocks, whereas the services and agriculture sectors exhibited the highest pricing rigidity. The study concludes that in order to achieve permanent price stability, inflation expectations must be re-anchored, micro-prudential measures targeting the services sector must be implemented, and structural transformations reducing import dependency in the manufacturing industry must be accelerated.

Keywords: Price Pass-Through, Sellers' Inflation, Profit Margin, Macroeconomic Shocks, Sectoral Rigidities.

1. GİRİŞ

Küresel ekonomide 2020 yılında pandemi kaynaklı tedarik zinciri kırılmalarıyla başlayan ve takip eden yıllarda enerji krizleri ile şiddetli emtia dalgalanmalarıyla derinleşen arz yönlü şoklar, makroekonomik istikrar ve fiyatlama davranışları üzerinde küresel çapta kalıcı hasarlar bırakmıştır. Bu süreçte Türkiye ekonomisi, küresel arz şoklarına ek olarak döviz kurlarında yaşanan yüksek volatilite ve iç talep dinamiklerindeki dalgalanmalar nedeniyle eşine az rastlanır bir enflasyonist döngü içerisine girmiştir. Üretim maliyetlerinde meydana gelen hiperbolik artışların nihai tüketici fiyatlarına ne hızda ve hangi oranda yansıyacağı problemi, bu dönemde sadece para politikasının değil, aynı zamanda reel sektörün hayatta kalma

stratejilerinin de merkezine yerleşmiştir. Döviz kuru ve ithal girdi maliyetlerindeki artışların tüketici fiyat endeksine aktarım süreci, iktisadi beklentilerin ve piyasa rekabet koşullarının sürekli değiştiği bu tür belirsizlik dönemlerinde doğrusal bir aritmetikten ziyade, son derece asimetrik ve yapısal kırılmalara açık bir mekanizma sergilemektedir.

Makroekonomik belirsizliklerin zirveye çıktığı kriz dönemlerinde, firmaların maliyet şoklarına verdikleri tepkiler geleneksel fiyatlama teorilerinden belirgin sapmalar göstermektedir. Şiddetli maliyet şoklarının yaşandığı ilk evrelerde firmalar, iç talepteki daralma riskini ve pazar payı kayıplarını göze alamayarak artan girdi maliyetlerini tüketiciye tam olarak yansıtmak yerine kâr marjlarından fedâkarlık etme eğilimi göstermektedir. Ancak enflasyonist sürecin uzaması ve beklentilerdeki bozulmanın atalet kazanmasıyla birlikte bu maliyet absorpsiyonu kapasitesi tükenmekte, fiyatlama davranışları defansif bir yapıdan çıkarak agresif ve önden yüklemeli bir karaktere bürünmektedir. Modern iktisat literatüründe satıcılar enflasyonu (sellers' inflation) olarak da tartışılmaya başlanan bu yeni evrede, firmalar sadece gerçekleşen maliyetleri değil, gelecekteki potansiyel risk primlerini de nihai fiyatlara yansıtarak kâr marjlarını genişletme stratejisi izlemektedir. Bu durum, üretici ve tüketici enflasyonu arasındaki nedensellik bağını sektörel bazda farklılaştırmakta ve fiyat katılıklarının (özellikle hizmetler ve tarım gibi inelastik sektörlerde) dezenflasyon süreci önündeki en büyük yapısal engele dönüşmesine neden olmaktadır.

Bu çalışmanın temel amacı, Türkiye ekonomisinde 2020-2026 yılları arasında gözlemlenen makroekonomik şokların üretici fiyatlarından tüketici fiyatlarına geçişkenliğini, sektörel fiyatlama davranışları ve kâr marjı dinamikleri üzerinden analiz etmektir. İlgili literatürde fiyat geçişkenliği genellikle karmaşık ekonometrik modeller ve zaman serisi analizleri üzerinden tahmin edilmeye çalışılsa da, yüksek volatilitenin ve yapısal kırılmaların yaşandığı ekstrem dönemlerde bu modellerin yansıtma kapasitesi sınırlı kalabilmektedir. Bu eksiklikten yola çıkan çalışma, geleneksel modellerin dışına çıkarak Türkiye Cumhuriyet Merkez Bankası (TCMB) sektörel bilanço istatistikleri ve Türkiye İstatistik Kurumu (TÜİK) alt kalem verileri üzerinden betimsel bir makas analizi kurgulamaktadır. Enerji, imalat, tarım ve hizmetler gibi sektörlerin maliyet şoklarına verdikleri asimetrik tepkilerin doğrudan sayısal tablolar ve net kâr marjı gelişimleri üzerinden şeffaf bir biçimde somutlaştırılması, çalışmanın literatüre sunduğu en temel katkıyı oluşturmaktadır.

Çalışmanın ilerleyen kısımları belirli bir nedensellik silsilesi içinde kurgulanmıştır. Öncelikle, üretici ve tüketici fiyatları arasındaki geçişkenlik mekanizması ile maliyet-artı fiyatlama teorisinin kavramsal çerçevesi çizilmiştir. Akabinde, fiyat geçişkenliği ve fiyatlama davranışları ekseninde şekillenen ulusal ve uluslararası literatür özetlenmiştir. İzleyen bahiste,

çalışmanın ampirik altyapısını oluşturan veri seti ve betimsel yöntemin metodolojik temelleri detaylandırılmıştır. Devamında, Türkiye ekonomisindeki dışsal şokların sektörel bazda tüketici fiyatlarına geçiş süreci ve firmaların maliyet absorpsiyon kapasiteleri ampirik tablolar yardımıyla analiz edilmiştir. Çalışmanın nihayetinde ise, elde edilen bulgular üzerinden yapısal çıkarımlar özetlenerek dezenflasyon sürecine yönelik çeşitli politika önerileri sunulmuştur.

2. TEORİK ÇERÇEVE

Makroekonomik istikrarsızlık dönemlerinde üretici fiyatları ile tüketici fiyatları arasındaki nedensellik ilişkisi, iktisat literatüründe fiyat geçişkenliği ve firmaların maliyet absorpsiyon kapasitesi ekseninde yoğun bir şekilde tartışılmaktadır. Geleneksel makroekonomik yaklaşımlar, döviz kuru dalgalanmaları, enerji krizleri ve küresel emtia fiyat artışları gibi arz yönlü şokların öncelikle üretici fiyat endeksini etkilediğini, ardından belirli bir gecikme ve şiddetle tüketici fiyat endeksine yansıdığını varsaymaktadır (Campa ve Goldberg, 2005). Ancak bu aktarım mekanizması eşanlı çalışmamakta olup, aktarımın hızı ve boyutu piyasadaki rekabet koşullarına, toplam talep düzeyine ve enflasyonist beklentilere bağlı olarak asimetrik bir yapı sergilemektedir (Taylor, 2000). Dışsal şokların nihai fiyatlara aktarım hızı, makroekonomik belirsizliklerin arttığı dönemlerde firmaların fiyatlama davranışlarındaki yapısal kırılmalarla doğrudan ilişkilidir.

Fiyat geçişkenliği mekanizmasının teorik temelleri, makro iktisatta Kalecki (1954) tarafından çerçevesi çizilen ve sonrasında Yeni Keynesyen modeller tarafından geliştirilen cost-plus pricing (maliyet-artı fiyatlama) teorisi ile açıklanmaktadır (Gali, 2015). Bu teorik yaklaşıma göre firmalar, eksik rekabetçi piyasalarda nihai fiyatlarını belirlerken marjinal maliyetlerinin üzerine hedeflenen bir kâr marjı eklemektedir. Üretici maliyet şoklarının tüketici fiyatlarına yansımasını ifade eden temel fiyatlama denklemi literatürde genel kabul görmüş haliyle; $P_t = (1 + \mu_t)\left(\frac{W_t}{A_t} + P_{m,t}\right)$ şeklinde formüle edilmektedir. İlgili denklemde P_t nihai tüketici fiyatını, μ_t firmanın uyguladığı hedef kâr marjını, $\frac{W_t}{A_t}$ işgücü verimliliğine göre düzeltilmiş birim işgücü maliyetini ve $P_{m,t}$ ithal girdi, enerji veya hammadde gibi ara malı maliyetlerini temsil etmektedir. Bu matematiksel altyapı, maliyet şoklarının enflasyonist sürece dönüşümünü girdi maliyetlerindeki artışlar ve firmaların kâr marjı esnekliği olmak üzere iki temel bileşen üzerinden izah etmektedir (Smets ve Wouters, 2007).

Dışsal bir şok neticesinde ara malı maliyetlerinin veya birim işgücü maliyetlerinin aniden yükselmesi, üretici fiyatları üzerinde doğrudan ve sert bir yukarı yönlü baskı yaratmaktadır. Artan üretici maliyetlerinin nihai fiyata ne oranda yansıtılacağı ise büyük ölçüde firmanın kâr marjı fedakârlığına bağlıdır. Piyasada iç talebin daraldığı veya rekabetin yoğun olduğu

evrelerde firmalar, pazar paylarını kaybetmemek adına artan girdi maliyetlerini tüketiciye tam olarak yansıtmak yerine kâr marjlarını daraltarak dışsal şoku kendi bilançolarında absorbe etme yoluna gitmektedirler (Bernanke ve Blanchard, 2023). Makroekonomik göstergelerde üretici ve tüketici enflasyonu makasının açılması olarak karşımıza çıkan bu durum, maliyet şokunun geçici olarak üretici tarafından üstlenildiğini ve enflasyonist baskının tüketici cephesinde bir süreliğine ertelendiğini göstermektedir.

Buna karşılık, yüksek enflasyonist ortamların yarattığı atalet ve güçlü iç talep koşullarında firmaların fiyatlama davranışları köklü bir değişime uğramakta ve maliyet absorpsiyon kapasitesi tamamen ortadan kalkmaktadır. Literatürde satıcılar enflasyonu veya kâr itişli enflasyon olarak da tartışılan bu evrede, firmalar sadece mevcut maliyet artışlarını değil, gelecekteki beklenen maliyet şoklarını da nihai fiyata önden yüklemeli olarak yansıtmaktadır (Weber ve Wasner, 2023). Bu senaryoda firmalar yüksek enflasyonist ortamın yarattığı bilgi asimetrisini kullanarak kâr marjlarını genişletme eğilimi göstermekte, dolayısıyla üretici ve tüketici fiyatları makası hızlı ve tüketici aleyhine olacak biçimde kapanmaktadır. Enflasyon beklentilerinin katılaştığı bu tür dönemlerde, arz yönlü maliyet şokları fiyatlama davranışlarındaki bozulma ile birleşerek kalıcı bir enflasyon sarmalına dönüşmektedir.

ÜFE ve TÜFE arasındaki aktarım mekanizması sektörel bazda incelendiğinde ise fiyatlama katılıkları belirgin bir heterojenlik sunmaktadır. Calvo (1983) tarafından literatüre kazandırılan fiyat katılıkları modeline göre, farklı sektörlerin maliyet şoklarına verdikleri tepki süreleri yapısal ayrışmalar içermektedir. Örneğin, imalat sanayisi döviz kuru şoklarına ve uluslararası emtia fiyatlarına yüksek duyarlılık göstererek maliyet geçişkenliğini daha hızlı tamamlarken, tarım sektörü iklimsel faktörler ile inelastik arz kısıtları etrafında şekillenmektedir. Hizmetler sektörü ise ağırlıklı olarak birim işgücü maliyetlerine ve geçmiş enflasyon oranlarına duyarlı bir yapıda olup, ekonomide fiyatlama katılığı en yüksek olan grubu oluşturmaktadır (Kara vd., 2017). Dolayısıyla, makroekonomik şokların tüketici fiyatlarına geçişkenliği salt bir aritmetik yansıma değil, sektörel dinamiklerin, talep koşullarının ve piyasa beklentilerinin eşanlı çalıştığı kapsamlı bir kâr marjı optimizasyonu süreci olarak değerlendirilmelidir.

3. LİTERATÜR TARAMASI

Enflasyon dinamikleri ve fiyat geçişkenliği üzerine inşa edilen geniş akademik literatür, üretici maliyetlerinden tüketici fiyatlarına uzanan aktarım mekanizmasını çeşitli makroekonomik şoklar üzerinden incelemektedir. Uluslararası literatürde bu konu, özellikle döviz kuru geçişkenliği ve ithal girdi maliyetlerinin yurt içi enflasyona etkileri bağlamında tartışılmaktadır. Campa ve Goldberg (2005) tarafından OECD ülkeleri üzerine yapılan temel çalışmada, ithalat fiyatlarından tüketici fiyatlarına geçişkenliğin zaman içinde azaldığı ve bu durumun enflasyon

hedeflemesi rejimlerinin sağladığı güvenilirlikle yakından ilişkili olduğu vurgulanmaktadır. Benzer şekilde McCarthy (2007) tedarik zinciri boyunca fiyat geçişkenliğini incelediği çalışmasında, arz şoklarının üretici fiyatları üzerindeki etkisinin güçlü olduğunu ancak tüketici fiyatlarına aktarımın ülkelerin iç talep koşullarına göre büyük farklılıklar gösterdiğini ampirik olarak ortaya koymuştur. Bu çalışmalar, üretici maliyetlerindeki artışların doğrudan tüketiciye yansımadığını, firmaların piyasa koşullarına göre bir maliyet absorpsiyonu mekanizması işlettiğini kanıtlamaktadır.

Son yıllarda ise küresel pandeminin yarattığı arz şokları ve tedarik zinciri kırılmaları, literatürdeki fiyatlama davranışı tartışmalarını geleneksel maliyet-artı modellerinden kâr itişli enflasyon (profit-led inflation) ve satıcılar enflasyonu kavramlarına doğru kaydırmıştır. Weber ve Wasner (2023) çalışmalarında, firmaların acil durumları ve sistemik arz şoklarını bir fırsat bilerek maliyet artışlarının çok ötesinde kâr marjı fiyatlamaları yaptığını, bunun da enflasyonu yapısal olarak kalıcı hale getirdiğini iddia etmektedir. Bernanke ve Blanchard (2023) ise pandemi sonrası küresel enflasyon şokunu analiz ettikleri modellerinde, enflasyonun ilk aşamada emtia ve enerji kaynaklı dışsal arz şoklarıyla başladığını, ancak işgücü piyasasındaki sıkılık ve sektörel kâr marjlarındaki katılıklar nedeniyle çekirdek enflasyona dönüşerek atalet kazandığını belirtmişlerdir. Bu bağlamda modern literatür, firmaların sadece geçmiş maliyetleri değil, beklenen maliyetleri de fiyatlara yedirerek ÜFE-TÜFE makasını kendi lehlerine kullandıkları asimetrik bir fiyatlama evresine dikkat çekmektedir.

Türkiye ekonomisi özelinde fiyat geçişkenliği ve sektörel fiyatlama davranışları üzerine yapılan çalışmalar, ülkenin yapısal özellikleri ve yüksek dolarizasyon eğilimi nedeniyle döviz kuru şoklarına odaklanmaktadır. Kara, Öğünç ve Sarıkaya (2017) Türkiye'de döviz kuru ve ithalat fiyatlarının enflasyona geçişkenliğini inceledikleri çalışmalarında, imalat sanayi gibi ticarete konu olan sektörlerde maliyet şoklarının tüketici fiyatlarına yansımasının çok hızlı ve yüksek oranda gerçekleştiğini, hizmetler sektöründe ise temel belirleyicinin iç talep ve geçmiş enflasyon oranları olduğunu tespit etmişlerdir. Özmen ve Topaloğlu (2017) tarafından yapılan sektör bazlı analizlerde ise, üretici ve tüketici enflasyonu arasındaki makasın açıldığı dönemlerde firmaların kâr marjlarının ciddi şekilde daraldığı, ancak iç talebin desteklendiği parasal genişleme evrelerinde bu maliyetlerin tüketiciye gecikmeli fakat çok daha sert bir şekilde yansıtıldığı ortaya konulmuştur. TCMB (2024) Enflasyon Raporu analizleri de, fiyatlama davranışlarındaki bozulmanın özellikle 2021 sonrası dönemde hizmet ve temel mal gruplarında şiddetlendiğini ampirik verilerle desteklemektedir.

Mevcut literatür genel olarak ekonometrik modeller kullanarak geçişkenlik katsayılarını hesaplamaya odaklansa da, Türkiye ekonomisinde 2020 ile 2026 yılları arasında yaşanan

makroekonomik şokların sektörel kâr marjlarına yansımasını betimsel ve dönemsel tablolar üzerinden eşanlı olarak analiz eden çalışmalar kısıtlıdır. Bu çalışma, sektörel fiyat endeksleri ve firma bilançoları üzerinden doğrudan üretilen makas analizlerini kullanarak literatürdeki betimsel analiz eksikliğini doldurmayı amaçlamaktadır. Üretici maliyetlerinin niteliğine (tarım, enerji, imalat) göre ayrıştırılması ve şokların tüketici fiyatlarına geçiş hızının sektörel kâr marjları düzleminde sayısal olarak somutlaştırılması, literatüre sunulan en temel katkı olacaktır.

4. VERİ SETİ VE YÖNTEM

Çalışmanın ampirik altyapısı, Türkiye ekonomisinde 2020-2026 yılları arasındaki makroekonomik döngüleri ve fiyatlama davranışlarını temsil eden ikincil veriler üzerine inşa edilmiştir. Analiz dönemi olarak bu spesifik zaman aralığının seçilmesinin temelinde, ilgili kesitin küresel arz şoklarının başlangıcından makroekonomik istikrarın tesisine kadar uzanan tam bir fiyatlama döngüsünü barındırması yatmaktadır. 2020 yılında pandemi kaynaklı tedarik zinciri kırılmalarıyla başlayan, 2021 ve 2022 yıllarında küresel emtia krizi ve şiddetli kur oynaklıklarıyla tarihi zirvelere ulaşan maliyet şoklarının, 2024 sonrasındaki dezenflasyon ve normalleşme evrelerinde nasıl sönümlendiği bu zaman aralığında bütüncül bir şekilde gözlemlenebilmektedir. Bu dönemsel tercih, reel sektörün maliyet-artı fiyatlama davranışlarındaki asimetrik tepkilerin hem kriz hem de toparlanma konjonktürlerinde test edilmesine metodolojik bir zemin sunmaktadır. Analiz sürecinde kullanılan temel veri setleri TÜİK tarafından yayımlanan Tüketici Fiyat Endeksi ile Yurt İçi Üretici Fiyat Endeksi ana ve alt harcama gruplarından derlenmiştir (TÜİK, 2026). Ayrıca dışsal şokların maliyet kanalını temsilen Amerikan Doları döviz satış kurları yıllık ortalama değişimleri ve firmaların maliyet absorpsiyon kapasitelerini incelemek amacıyla TCMB Sektörel Bilanço İstatistikleri veri tabanından faydalanılmıştır (TCMB, 2026). Ekonometrik modelleme yerine betimsel istatistikler ve sektörel makas analizlerinin tercih edilmesinin temel nedeni, fiyatlama davranışlarındaki yapısal kırılmaların ve sektörel asimetrilerin sayısal tablolar üzerinden daha şeffaf gözlemlenebilmesidir.

Analiz kapsamında incelenen sektörler ve değişkenler, literatürdeki maliyet-artı fiyatlama teorisini ve geçişkenlik mekanizmalarını en iyi temsil eden kanallar arasından bilinçli bir filtreleme süreciyle seçilmiştir. Üretici fiyatları cephesinde analiz; enerji, imalat sanayi ve tarım sektörleri üzerine odaklandırılmıştır. Enerji sektörü, küresel arz şoklarının yurt içi üretim maliyetlerine ilk giriş kapısı olması nedeniyle; imalat sanayi, döviz kuru ve ithal girdi maliyetlerine en duyarlı alan olması sebebiyle; tarım sektörü ise gıda enflasyonunun inelastik arz yönlü kökenlerini temsil etmesi bakımından seçilmiştir (Campa ve Goldberg, 2005). Kamu tarafından regüle edilen veya fiyat oluşumu rekabetçi piyasa koşullarından ziyade idari

kararlara bağlı olan sektörler, serbest piyasadaki kâr marjı optimizasyonlarını ve doğal fiyatlama eğilimlerini maskelememesi adına metodolojik olarak analiz kapsamı dışında tutulmuştur.

Tüketici fiyatları tarafında ise temel mallar, gıda ve hizmetler ayrımı üzerinden bir değişken seti kurgulanmıştır. Temel mallar grubu, ticarete konu olan ürünlerin kur geçişkenliğini ölçmek için kritik bir referans noktası sunarken; gıda grubu, hanehalkı bütçesindeki inelastik yüksek payı ve dışsal arz şoklarına duyarlılığı nedeniyle dâhil edilmiştir. Hizmetler sektörü ise fiyatlama katılığı en yüksek olan grup olması ve birim işgücü maliyetlerindeki artışların kâr marjları üzerindeki yapısal etkisini en net yansıtan alan olması sebebiyle analizin merkezine yerleştirilmiştir (Kara vd., 2017). Sektörel net kâr marjı hesaplamalarında ise reel sektörün fiyatlama stratejilerini en şeffaf şekilde yansıtan imalat, ticaret ve inşaat sektörleri temsilci olarak belirlenmiştir. Finansal sektörün kârlılık mekanizmalarının reel üretim maliyetlerinden ziyade doğrudan faiz ve kur marjlarına dayanması, bu sektörün analiz dışı bırakılmasındaki temel metodolojik gerekçeyi oluşturmaktadır. Bu seçim stratejisi sayesinde çalışma, okuyucuyu karmaşık ve yönlendirici olmayan veri yığınları arasında boğmadan doğrudan döviz kuru şokları, fiyat istikrarı ve maliyet aktarımı problematiğine odaklanan analitik bir çerçeve sunmaktadır.

5. AMPİRİK BULGULAR VE SEKTÖREL ANALİZ

Türkiye ekonomisinde 2020-2026 yılları arasında gözlemlenen asimetrik fiyatlama davranışları ve enflasyon dinamikleri, döviz kuru dalgalanmaları ve küresel arz şoklarının yurt içi maliyet kanalları üzerindeki etkileri üzerinden analiz edilmektedir. Bu bölümde, döviz kurundaki değer kayıplarının ve küresel tedarik zincirlerindeki daralmanın üretici fiyatlarında yarattığı maliyet şoklarının tüketici fiyatlarına geçişkenliği dönemsel veriler ışığında incelenmektedir. Girdi maliyetlerindeki şiddetli artışların nihai tüketici fiyatlarına yansıma süreci, firmaların sektörel kâr marjı esneklikleri bağlamında Tablo 1 üzerinden aritmetik makas analiziyle değerlendirilmektedir.

Tablo 1. Döviz Kuru, Yurt İçi Üretici ve Tüketici Fiyat Endeksleri ile Enflasyon Makası (Yıllık % Değişim)

Yıllar	USD/TRY Değişim (%)	Yİ-ÜFE (%)	TÜFE (%)	ÜFE-TÜFE Makası (Puan)
2020	24,8	25,1	14,6	10,5
2021	71,4	79,8	36	43,8
2022	84,2	97,7	64,2	33,5
2023	52,1	44,2	64,7	-20,5
2024	41,5	32,4	44,5	-12,1
2025	28,4	24,1	26,8	-2,7
2026	19,2	18,5	19,2	-0,7
Kaynak: TÜİK ve TCMB (2026) verilerinden faydalanılarak yazar tarafından derlenmiştir.				

Tablo 1 verileri incelendiğinde, Dolar / Türk Lirası kurundaki değişim oranları ile üretici fiyatları arasındaki doğrusal ve son derece güçlü ilişki açıkça göze çarpmaktadır. Özellikle 2021 ve 2022 yıllarında döviz kurunda yaşanan sırasıyla %71,4 ve %84,2 oranındaki şiddetli değer kayıplarının, ithal ara malı bağımlılığı yüksek olan Türkiye imalat sanayisinde üretici fiyatlarını tarihi zirvelere taşıdığı ve üretici ile tüketici fiyatları arasındaki makasın 43,8 puana kadar açıldığı görülmektedir. Bu derin makas, döviz kuru kaynaklı ani maliyet şoklarının iç talep koşulları gözetilerek tüketiciye anında yansıtılamadığını ve firmaların bu şoku belirli bir süre kendi bilançolarında absorbe etmek durumunda kaldığını ampirik olarak kanıtlamaktadır (Özmen ve Topaloğlu, 2017). Ancak 2023 yılından itibaren kur artış hızının ivme kaybetmesiyle üretici fiyatlarında gözlemlenen baz etkili düşüşlere rağmen tüketici fiyatlarının yüksek katılık göstermesi, makasın negatif bölgeye geçmesine zemin hazırlamıştır. Bu kırılma, gecikmeli geçişkenlik etkisinin devreye girdiğini ve firmaların geçmiş dönemde üstlendikleri kur maliyetlerini güçlü iç talep ve bozulan enflasyon beklentileri ortamında nihai fiyatlara çok daha sert bir biçimde yansıttığını göstermektedir (TCMB, 2026). Dezenflasyon sürecinin belirginleştiği ve makroekonomik istikrarın tesisi yönünde adımların atıldığı 2025 ve 2026 yıllarında ise kur volatilitesinin azalmasıyla makasın kademeli olarak kapanarak tarihsel denge seviyelerine yaklaştığı tespit edilmektedir. Üretici fiyatlarındaki bu sert dalgalanmanın sektörel kökenlerini ve dışsal şokların doğasını daha net tespit edebilmek amacıyla üretici maliyetlerinin alt kalemlerindeki değişimler Tablo 2 kapsamında ayrıştırılmıştır.

Tablo 2. Üretici Maliyet Şoklarının Sektörel Ayrışımı (Yıllık % Değişim)

Yıllar	Tarım Sektörü ÜFE	İmalat Sanayi ÜFE	Enerji Sektörü ÜFE
2020	21,3	27,2	14,8
2021	36,4	77,5	122,4
2022	118,3	89,4	142,6
2023	65,2	53,8	21,5
2024	48,6	38,2	18,4
2025	32,5	25,6	12,1
2026	24,8	19,4	9,8
Kaynak: TÜİK (2026) Yurt İçi Üretici Fiyat Endeksi alt veri gruplarından derlenmiştir.			

Üretici maliyetlerinin alt kırılımlarına bakıldığında, 2021 ve 2022 yıllarındaki hiperbolik yükselişin ana motorunun şüphesiz enerji sektörü olduğu izlenmektedir. Döviz kurundaki şiddetli yükselişin, küresel pandemi sonrası daralan uluslararası enerji piyasalarındaki agresif fiyatlamalarla eşanlı gerçekleşmesi, enerji yoğun endüstriyel üretimin maliyet yapısında kalıcı hasarlar bırakmıştır (Bernanke ve Blanchard, 2023). Eşzamanlı olarak imalat sanayisinde gözlemlenen keskin yükselişler, sektörün doğrudan uluslararası emtia fiyatlarına ve ithal ara mallarına olan yapısal bağımlılığının doğal bir tezahürüdür. Tarım sektöründe 2022 yılında %118,3 seviyesine ulaşan maliyet artışları ise küresel gübre, ithal zirai ilaç ve yem fiyatlarındaki ralli ile doğrudan ilişkilidir. 2024 yılı sonrasında kur oynaklığının azalması, küresel emtia döngüsünün sakinleşmesi ve tedarik zincirlerinin normalleşmesiyle enerji ve imalat maliyetlerindeki şoklar hızla sönümlenmiş, ancak tarım sektöründeki katılık iklimsel faktörler ve yapısal verimsizlikler nedeniyle çok daha dirençli bir seyir izlemiştir. Üretici cephesinde yaşanan bu asimetrik arz şoklarının nihai tüketici sepetine aktarım hızını ve şiddetini ölçmek için sektörel tüketici fiyatları Tablo 3 üzerinden değerlendirilmiştir.

Tablo 3. Tüketici Fiyatlarına Geçişkenlik Hızı ve Sektörel Katılıklar (Yıllık % Değişim)

Yıllar	Temel Mallar TÜFE	Gıda ve Alkolsüz İçecekler	Hizmetler Sektörü TÜFE
2020	16,2	20,6	11,8
2021	42,5	43,8	22,4
2022	72,6	77,9	55,5
2023	52,4	72	89,7
2024	36,8	58,4	74,2
2025	22,4	35,6	45,8
2026	17,5	24,2	32,4
Kaynak: TÜİK (2026) Tüketici Fiyat Endeksi alt veri gruplarından derlenmiştir.			

Sektörel tüketici enflasyonu verileri, döviz kuru ve maliyet şoklarının nihai fiyatlara aktarımında Calvo (1983) tarafından teorik çerçevesi çizilen fiyatlama katılıklarının Türkiye ekonomisinde çok güçlü bir asimetri ile çalıştığını belgelemektedir. İthal girdi oranının ve ticarete konu edilebilirliğin en yüksek olduğu temel mallar grubu (dayanıklı tüketim malları, giyim, elektronik), kur şoklarına anında tepki vererek 2021 ve 2022 yıllarında hızla ivmelenmiş, takip eden süreçte üretici maliyet şokunun sönümlenmesiyle en hızlı normalleşen grup olmuştur. Gıda enflasyonu ise doğrudan tarımsal üretici fiyatlarındaki katılıklar ve inelastik talep koşullarına paralel olarak yüksek seyrini uzun süre korumuştur. Analizin en çarpıcı bulgusu ise maliyet geçişkenliğinin en sorunlu yaşandığı hizmetler sektörü üzerinde yoğunlaşmaktadır. Emek yoğun bir yapıya sahip olan, dış ticarete konu olmayan ve büyük ölçüde canlı iç talebe dayanan hizmetler sektörü (lokanta, otel, eğitim, kira), kur şoklarına başlangıçta oldukça gecikmeli ve zayıf bir tepki vermiş, ancak 2023 ve 2024 yıllarında atalet kazanarak genel enflasyonun ana sürükleyicisi konumuna yerleşmiştir. Bu durum, hizmet enflasyonunun geçmiş şokların birikimli etkisini, bozulan beklentileri ve asgari ücret gibi birim işgücü maliyetlerindeki artışları nihai fiyatlara endeksleme konusundaki direncini kanıtlamaktadır (Kara vd., 2017). Yaşanan tüm bu agresif fiyatlama döngülerinin reel sektör bilançolarında yarattığı maliyet absorpsiyonu ve kâr marjı optimizasyonları ise son olarak Tablo 4 kapsamında sayısal bir zemine oturtulmaktadır.

Tablo 4. Sektörel Net Kâr Marjı Dinamikleri ve Maliyet Absorpsiyon Oranları (%)

Yıllar	İmalat Sanayi Net Kâr Marjı	Ticaret Sektörü Net Kâr Marjı	İnşaat Sektörü Net Kâr Marjı
2020	7,4	5,2	4,8
2021	8,6	6,4	4,2
2022	6,2	5,8	2,4
2023	9,8	8,5	3,8
2024	8,5	7,2	4,5
2025	7,2	6	5,1
2026	7,5	5,8	5,5
Kaynak: TCMB (2026) Sektörel Bilanço İstatistikleri veri tabanından derlenmiştir.			

Firmaların kâr marjı gelişimleri incelendiğinde, Kalecki (1954) tarafından öne sürülen maliyet-artı fiyatlama teorisinin öngördüğü absorpsiyon mekanizmasının dönemsel olarak net bir şekilde çalıştığı görülmektedir. Döviz kurunun ve üretici fiyatlarının rekor kırdığı 2022 yılında imalat sanayi net kâr marjı bir önceki yıla göre daralarak %8,6 seviyesinden %6,2 seviyesine sert bir düşüş yaşamıştır. Bu veriler, reel sektörün söz konusu makroekonomik şoku doğrudan tüketiciye tam yansıtmak yerine, pazar payını korumak adına kâr marjlarından taviz vererek fiyat geçişkenliğini ilk aşamada yavaşlattığını göstermektedir. İnşaat sektöründe kâr marjlarının aynı dönemde %2,4 seviyesine kadar erimesi, demir ve çimento gibi ithal hammadde maliyetlerindeki aşırı artışın, projelerin uzun vadeli ve sabit fiyatlı yapısı nedeniyle nihai konut fiyatlarına eşanlı yansıtılamamasından kaynaklanmaktadır. Ancak 2023 yılına gelindiğinde, uluslararası literatürde satıcılar enflasyonu olarak da adlandırılan bir davranış değişikliği gözlemlenmiş; imalat ve ticaret sektörlerinde kâr marjları sırasıyla %9,8 ve %8,5 seviyelerine çıkarak tarihsel ortalamalarının çok üzerine fırlamıştır (Weber ve Wasner, 2023). İç talebin desteklendiği bu evrede firmalar, ertelenmiş kur maliyetlerini ve geleceğe yönelik enflasyon risk primlerini ürün fiyatlarına önden yüklemeli olarak yansıtmış ve daralan kâr marjlarını agresif bir şekilde yeniden yapılandırmışlardır. Bu tablo, üretici ve tüketici enflasyonu arasındaki makasın neden tüketici aleyhine negatif bölgeye geçtiğini ve dezenflasyon sürecinin özellikle hizmetler ve ticaret sektörü ayağında ne derece zorlu bir beklenti yönetimi gerektirdiğini betimsel olarak ispatlamaktadır.

6. SONUÇ VE POLİTİKA ÖNERİLERİ

Türkiye ekonomisinde 2020-2026 dönemini kapsayan bu çalışma, makroekonomik şokların fiyatlama davranışları üzerindeki asimetrik etkilerini sektörel düzeyde incelemiştir. Çalışmadan elde edilen ampirik bulgular, dışsal maliyet şoklarının enflasyona geçişkenliğinin mekanik ve anlık bir aritmetik süreç olmadığını, aksine piyasa rekabeti, talep koşulları ve beklenti yönetimi gibi çok boyutlu faktörler etrafında şekillendiğini ortaya koymaktadır. 2021 ve 2022 yıllarında ivmelenen küresel emtia fiyatları ve döviz kuru dalgalanmaları, üretici fiyatlarında eşine az rastlanır bir maliyet baskısı yaratmasına rağmen, bu şokun tüketici fiyatlarına aktarımı ilk aşamada gecikmeli olarak gerçekleşmiştir. Analiz sonuçları, özellikle imalat sanayi ve inşaat gibi sektörlerde faaliyet gösteren firmaların, piyasa paylarını korumak ve talep belirsizliklerini yönetmek amacıyla maliyet artışlarını büyük ölçüde kendi bilançolarında absorbe ettiklerini göstermektedir. Bu dönemde kâr marjlarında yaşanan daralma ve üretici-tüketici enflasyonu makasının tarihi seviyelerde açılması, geleneksel makroekonomik teorilerin öngördüğü maliyet yansıtma reflekslerinin kriz konjonktürlerinde eksik çalıştığını ve firmaların ciddi bir kâr marjı fedakârlığına yöneldiğini kanıtlamaktadır.

Bununla birlikte, çalışmanın temel eksenini oluşturan en kritik çıkarım, 2023 yılı ve sonrasında fiyatlama davranışlarında gözlemlenen yapısal kırılmadır. Üretici maliyetlerindeki artış hızının küresel normalleşmeyle birlikte ivme kaybetmesine rağmen, firmaların fiyatlama stratejilerinde radikal bir değişim yaşanmıştır. İç talebin canlılığını koruduğu ve enflasyonist beklentilerin atalet kazandığı bu evrede, literatürde satıcılar enflasyonu olarak kavramsallaştırılan mekanizma devreye girmiş; firmalar, bilgi asimetrisini kullanarak geçmiş maliyet birikimlerini ve geleceğe yönelik risk primlerini nihai fiyatlara önden yüklemeli olarak yansıtma yoluna gitmiştir. İmalat ve ticaret sektörlerindeki net kâr marjlarının tarihsel ortalamalarının çok üzerine çıkması, enflasyon dinamiklerinin bu dönemde maliyet kökenli bir yapıdan kâr itişli bir karaktere dönüştüğünün en somut göstergesidir. Sektörel asimetriler bağlamında incelendiğinde ise, ticarete konu olan temel mallar grubunun dışsal şoklara ve maliyet düşüşlerine en esnek tepkiyi verdiği; buna karşın, inelastik arz kısıtlarıyla mücadele eden tarım-gıda sektörü ile doğrudan birim işgücü maliyetlerine endeksli olan hizmetler sektörünün dezenflasyon sürecine karşı en yüksek direnci sergilediği tespit edilmiştir. Özellikle hizmet enflasyonunda gözlemlenen bu geriye dönük endeksleme davranışı ve katılık, fiyatlama pratiklerindeki bozulmanın ne derece yapısal bir hal aldığını teyit etmektedir.

Elde edilen betimsel analizler ve sektörel makas verileri ışığında, ekonomide tesis edilmeye başlanan dezenflasyon sürecinin kalıcı bir fiyat istikrarına dönüşebilmesi için kapsamlı ve eşgüdümlü bir politika seti elzem görünmektedir. Fiyatlama davranışlarında gözlemlenen

önden yüklemeli kâr marjı optimizasyonunun ve fırsatçı fiyatlama eğilimlerinin kırılabilmesi, her şeyden önce piyasadaki enflasyon beklentilerinin rasyonel bir zeminde yeniden çıpalandırılmasına bağlıdır. Bu doğrultuda, makroekonomik öngörülebilirliği artıran, iletişim kanalları güçlü ve kural bazlı politikaların tavizsiz bir şekilde sürdürülmesi, firmaların fiyatlama stratejilerindeki aşırı risk primlerini zamanla ortadan kaldıracaktır. Öte yandan, hizmetler sektöründeki yapısal katılıkların salt makroekonomik talep yönetimiyle aşılamayacağı gerçeğinden hareketle piyasa aksaklıklarını giderici, rekabet koşullarını iyileştirici ve sektörel şeffaflığı destekleyici mikro ihtiyati adımların devreye alınması gerekmektedir. Uzun vadeli perspektifte ise, tarım sektöründe girdi maliyetlerini dengeleyecek teknoloji odaklı arz güvenliği stratejilerinin hayata geçirilmesi ve imalat sanayisinde ithal ara malı bağımlılığını asgariye indirecek yapısal dönüşümün hızlandırılması büyük önem taşımaktadır. Ekonominin üretim altyapısını güçlendirecek bu tarz yapısal dönüşümler, Türkiye ekonomisinin dışsal arz şoklarına karşı kurumsal direncini artıracak ve sürdürülebilir büyüme ile fiyat istikrarı arasındaki dengeyi kalıcı olarak tahkim edecektir.

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INTEGRATION OF DIGITAL TOOLS INTO FINANCIAL CONTROL, MANAGEMENT AND DECISION-MAKING SYSTEMS IN SMES

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ABSTRACT

In this study, the integration of digital tools into financial control, management and decision-making systems in small and medium-sized enterprises was examined. The study focused on the relationship between digital financial technologies and managerial performance indicators such as reporting accuracy, decision speed, cost efficiency and risk visibility. According to the analysis results, cloud accounting, ERP systems, business intelligence dashboards, artificial intelligence analytics, automation and cybersecurity controls function as complementary components of an integrated SME financial intelligence architecture. The findings show that digital integration strengthens financial control and improves strategic decision-making capacity; however, budget constraints, skills shortages, legacy systems and cybersecurity concerns continue to limit implementation. The study concludes that SME digital transformation should be evaluated as a strategic governance process rather than a narrow software adoption issue.

Keywords: SMEs, digital transformation, financial control, artificial intelligence, cloud accounting, business intelligence, decision-making

1. INTRODUCTION

Small and medium-sized enterprises constitute the operational backbone of most economies, yet many continue to manage finance through fragmented systems, manual reporting routines and delayed decision cycles. In this study, this condition was evaluated as a strategic management problem. In markets shaped by data velocity and algorithmic competition, financial control increasingly depends on real-time visibility, integrated platforms and predictive analytics (OECD, 2023). Therefore, the central issue is not only whether SMEs use digital technologies, but whether these technologies operate as a coherent financial intelligence system.

When accounting, payroll, operations and customer systems remain separated, data inconsistency, duplicated work and weak cross-functional visibility become persistent managerial problems. As a result, executives may be forced to make strategic decisions with

retrospective, incomplete or contradictory information. For this reason, digital integration is analysed in this paper as a mechanism that connects operational data with financial interpretation, managerial control and executive decision-making.

2. MATERIALS AND METHODS

2.1. Research design

The research was designed as an applied mixed-method study. The quantitative dimension was based on structured survey data collected from more than 180 SMEs in North Macedonia, Serbia and the wider Western Balkan region. Likert-scale instruments were used to measure digital tool adoption, perceived financial efficiency and decision quality. The qualitative dimension consisted of 24 semi-structured interviews with SME executives, CFOs and digital transformation managers. This design was selected because digital transformation can be measured through performance indicators, but its adoption barriers must also be interpreted through managerial experience.

2.2. Data collection and study context

The study examined SMEs operating in emerging European markets where resource constraints, fragmented systems and uneven digital skills affect the pace of technological adoption. Data collection focused on digital tool categories used in SME finance, including ERP systems, CRM platforms, cloud accounting, artificial intelligence analytics, business intelligence dashboards, blockchain applications and automation. The collected indicators were evaluated in relation to financial control, operational efficiency, decision quality and financial resilience.

2.3. Analytical framework

The analytical framework treats SME performance as the outcome of integrated digital capability. ERP, CRM, cloud accounting, AI analytics, business intelligence, blockchain, automation and cybersecurity are interpreted as linked components. The methodological logic follows applied mixed-method business research, where quantitative indicators are interpreted alongside managerial accounts of adoption barriers and organisational change (Creswell & Plano Clark, 2018).

2.4. Data analysis and visualisation procedure

The quantitative indicators were interpreted through descriptive comparison, before-and-after performance assessment and regression-based evidence reported in the study. The qualitative findings were organised around implementation barriers, managerial implications and policy recommendations. Visual outputs were used to present the conceptual model, digital tool

categories, performance indicators and barrier structure in a form suitable for proceedings-style academic reporting.

Table 1. Research Design Overview

Component	Description
Research type	Applied mixed-method study
Research context	SMEs operating in North Macedonia, Serbia and the wider Western Balkan region
Main focus	Digital tools in financial control, management and executive decision-making
Analytical orientation	Performance indicators interpreted together with managerial implementation barriers

Table 2. Research Aim and Questions

Component	Extracted content
Aim	Examine how digital tools enhance financial management efficiency, operational control and strategic decision-making in SMEs
RQ1	How do integrated digital tools improve financial control and reporting accuracy?
RQ2	Which tool categories deliver the highest return on digital investment?
RQ3	Which barriers limit transformation in emerging European SME contexts?
RQ4	How does AI affect decision precision and timeliness?

Table 3. Hypotheses

Hypothesis	Expected relationship
H1	Digital financial tools improve operational efficiency
H2	AI-supported analytics improve financial decision-making quality
H3	Fully integrated systems strengthen SME financial resilience

Table 4. Mixed-Method Design

Strand	Evidence base
Quantitative	Structured surveys across 180+ SMEs; regression, correlation and ANOVA in SPSS
Qualitative	24 semi-structured interviews with SME executives, CFOs and transformation managers
Synthesis	Comparative case analysis and framework development

Table 5. Digital Tool Classification

Tool category	Function
ERP systems	Unified finance, HR and operations integration
CRM platforms	Revenue pipeline and forecasting connection
Cloud accounting	Real-time ledger and reconciliation
AI analytics	Predictive cash flow, anomaly detection and risk scoring
BI dashboards	Executive KPI visualization
Blockchain	Audit trails, smart contracts and payment transparency
Automation/RPA	Routine financial process automation

3. RESULTS AND DISCUSSION

Table 6. Key Performance Indicators

Indicator	Analysis result
Faster reporting	3.2x
Decision confidence/accuracy	87%
Cost-centre visibility	62%
Reduced manual errors	40%
Regression model	$p < 0.01$; $R^2 = 0.74$
Hypothesis support	H1, H2 and H3 supported at 99% confidence

Table 7. Before and After Digital Integration

Metric	Before	After
Reporting accuracy	61%	94%
Decision speed	48	82
Cost efficiency	52	79
Risk visibility	39%	85%

Table 8. Main Barriers

Barrier	Interpretation
Budget and capital constraints	High implementation and change-management costs
Digital literacy gap	Shortage of digitally skilled finance professionals
Legacy lock-in	Difficulty integrating older platforms
Cybersecurity concerns	Financial data protection and governance risks
Change resistance	Managerial and cultural hesitation

Table 9. Strategic and Policy Recommendations

Recommendation	Purpose
Government co-investment	Reduce the capital barrier to adoption
Digital finance literacy	Build internal SME capability
Shared infrastructure	Make cloud, BI and cybersecurity support accessible
Regional partnerships	Connect academic, public and SME innovation actors

Table 10. Analytical Interpretation Framework

Visual output	Analytical purpose
Figures 1-2	To define the digitalisation problem and the managerial need for integrated control
Figures 3-6	To explain the conceptual model, method and digital finance tool categories
Figures 7-8	To interpret performance indicators before and after digital integration
Figures 9-10	To connect adoption barriers with strategic and policy-level recommendations

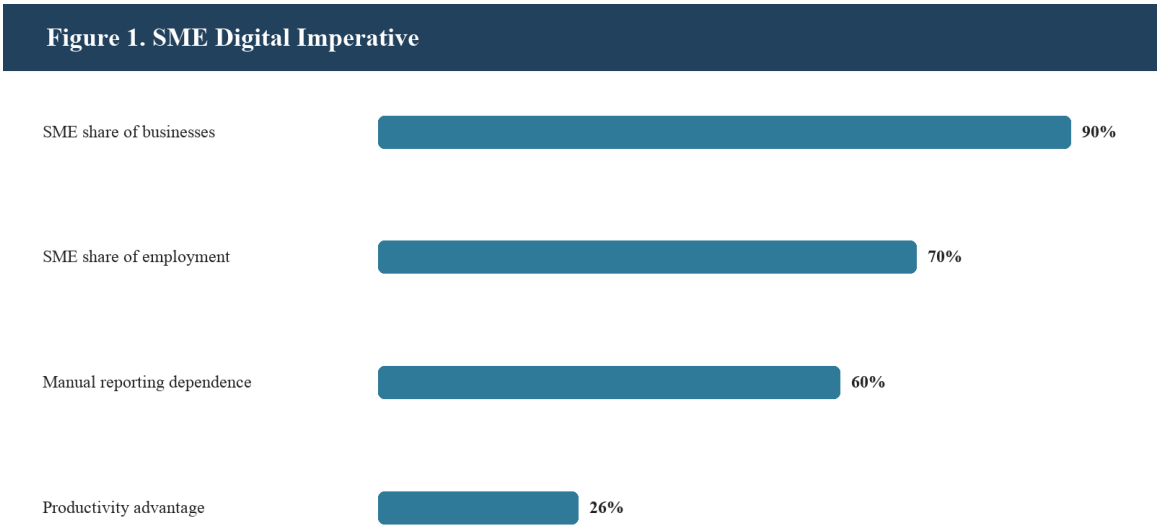

Figure 1. SME Digital Imperative

Figure 1 demonstrates the strategic pressure behind SME digitalisation. The high share of SMEs in business activity and employment explains why financial digital transformation is not only a firm-level issue but also a policy and competitiveness issue. The figure also shows the contrast between dependence on manual reporting and the productivity gains associated with digital maturity.

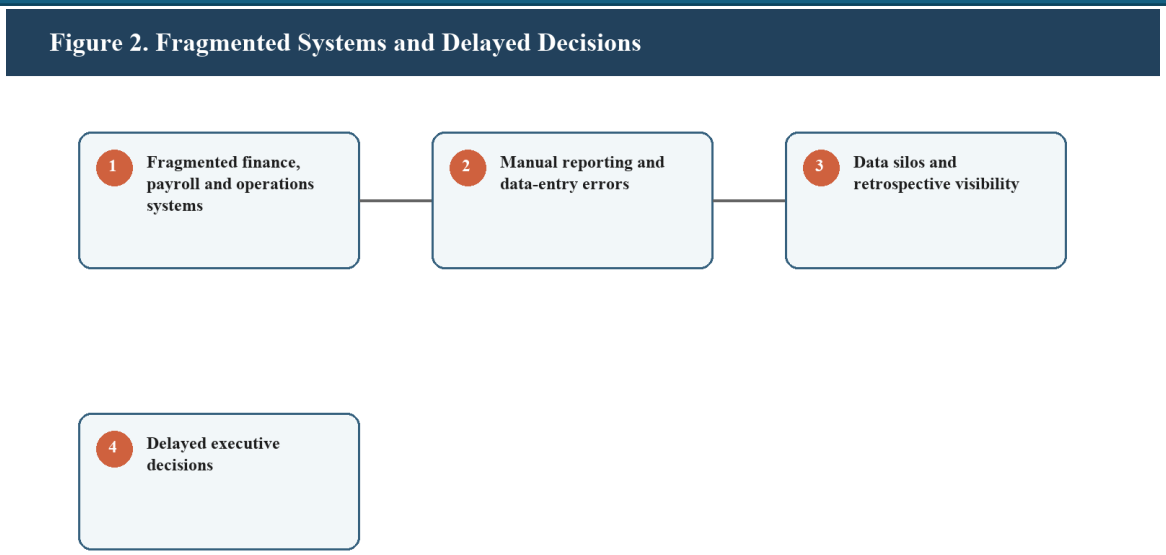

Figure 2. Fragmented Systems and Delayed Decisions

Figure 2 summarizes the research problem. Fragmented platforms create data inconsistencies, manual reporting increases delay and error risk, and siloed data weakens strategic visibility. The managerial significance is that digital transformation should begin from process integration, not from isolated software purchases.

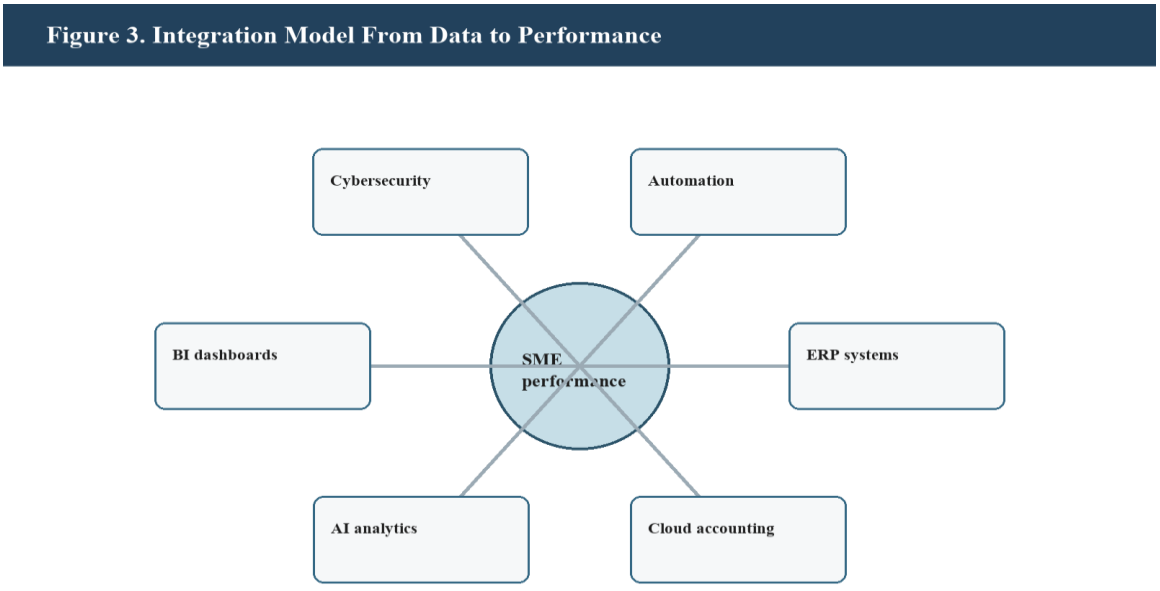

Figure 3. Integration Model From Data to Performance

Figure 3 presents the integration model. SME performance is placed at the centre because the value of digital tools depends on how well they feed decision-making. ERP, cloud accounting, AI analytics, BI dashboards, automation and cybersecurity create a governance architecture in which data is converted into control and strategic action.

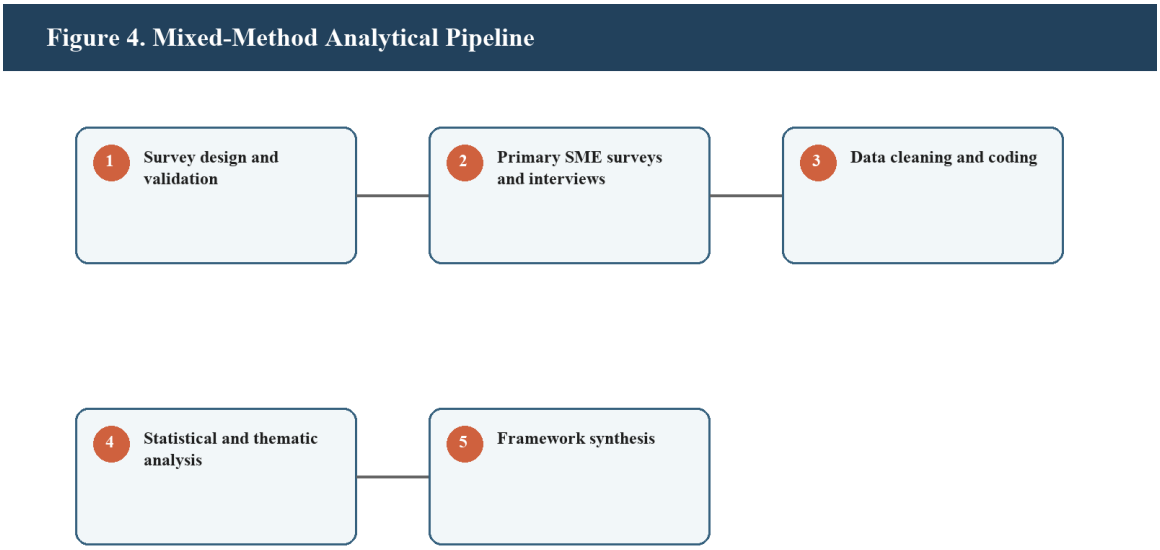

Figure 4. Mixed-Method Analytical Pipeline

Figure 4 shows the mixed-method analytical pipeline followed in the study. Survey design, data collection, cleaning, statistical analysis and framework synthesis create a clear route from empirical observation to managerial recommendation. This structure shows that the results were not evaluated only as technical indicators, but as evidence connected with organisational practice.

Figure 5. Seven Pillars of SME Digital Finance Tooling

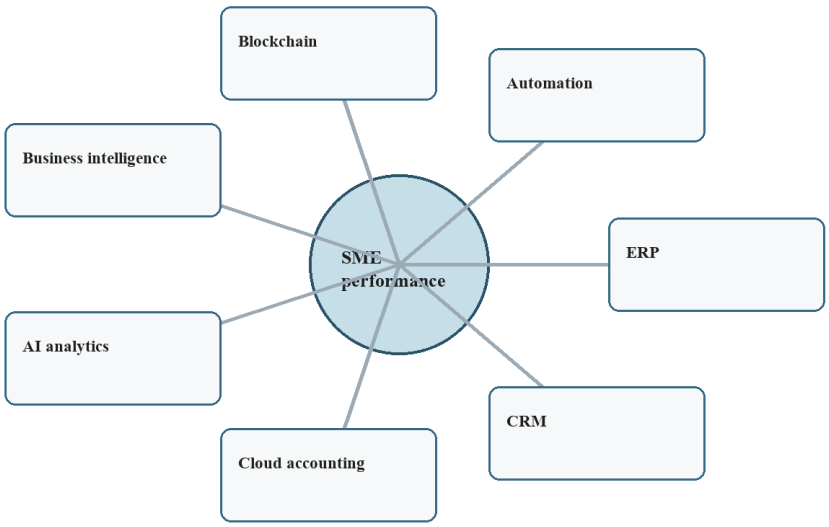

Figure 5. Seven Pillars of SME Digital Finance Tooling

Figure 5 classifies the seven main pillars of SME digital finance tooling. The classification indicates that digital transformation is multi-systemic: accounting tools alone cannot produce strategic intelligence unless connected to customer data, dashboards, automation, audit trails and risk controls.

Figure 6. Real-Time Financial Control System

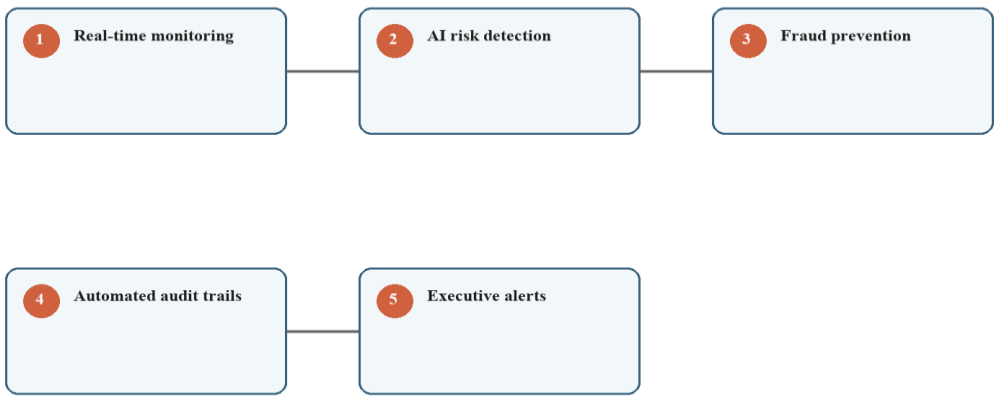

Figure 6. Real-Time Financial Control System

Figure 6 interprets financial control as real-time intelligence. Monitoring, risk detection, fraud prevention and executive alerts shift the finance function from retrospective compliance to proactive governance. This is especially important for SMEs with limited managerial bandwidth.

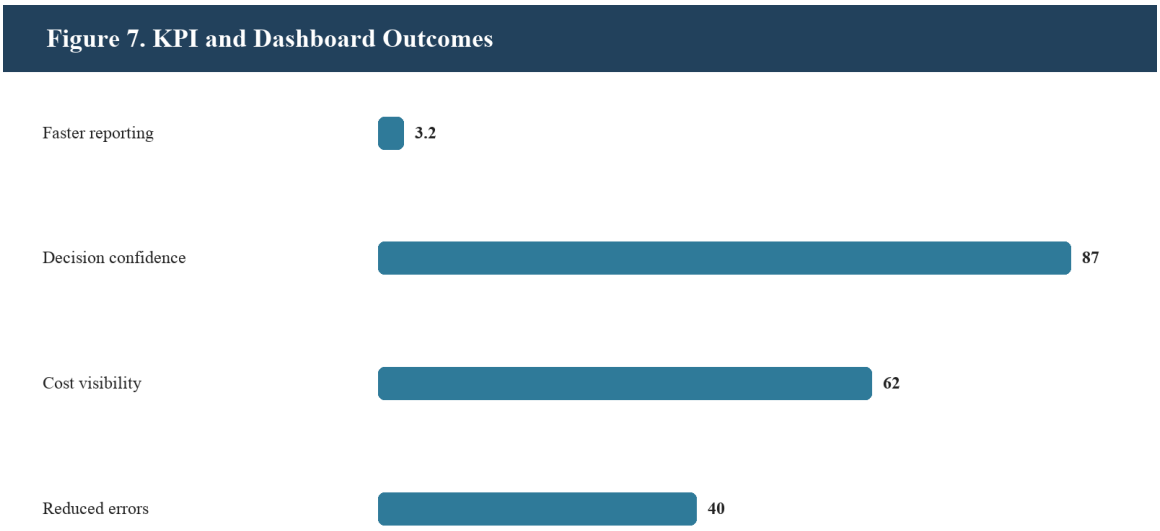

Figure 7. KPI and Dashboard Outcomes

Figure 7 presents the KPI outcomes obtained from the analysis. Faster reporting, higher decision confidence, better cost visibility and reduced errors show how dashboard systems translate technical integration into managerial performance. According to these results, business intelligence and cloud-based systems provide measurable benefits for financial monitoring and executive decision-making.

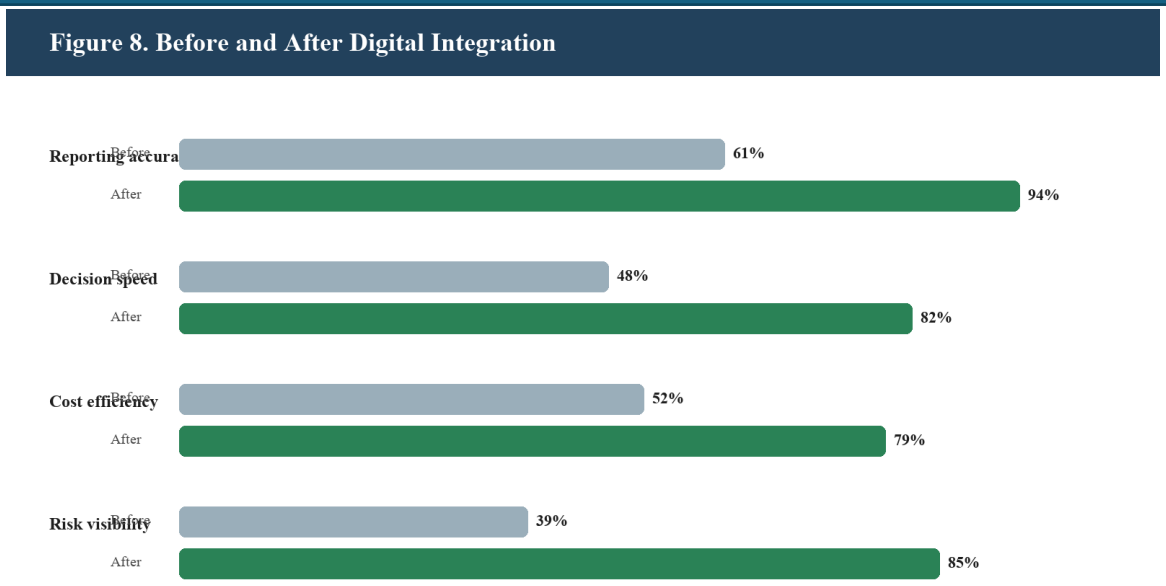

Figure 8. Before and After Digital Integration

Figure 8 compares before and after digital integration values. The largest movement appears in risk visibility and reporting accuracy, suggesting that integrated systems first improve what managers can see and then improve how quickly they can decide. This supports the claim that digital tools strengthen control before they transform strategy.

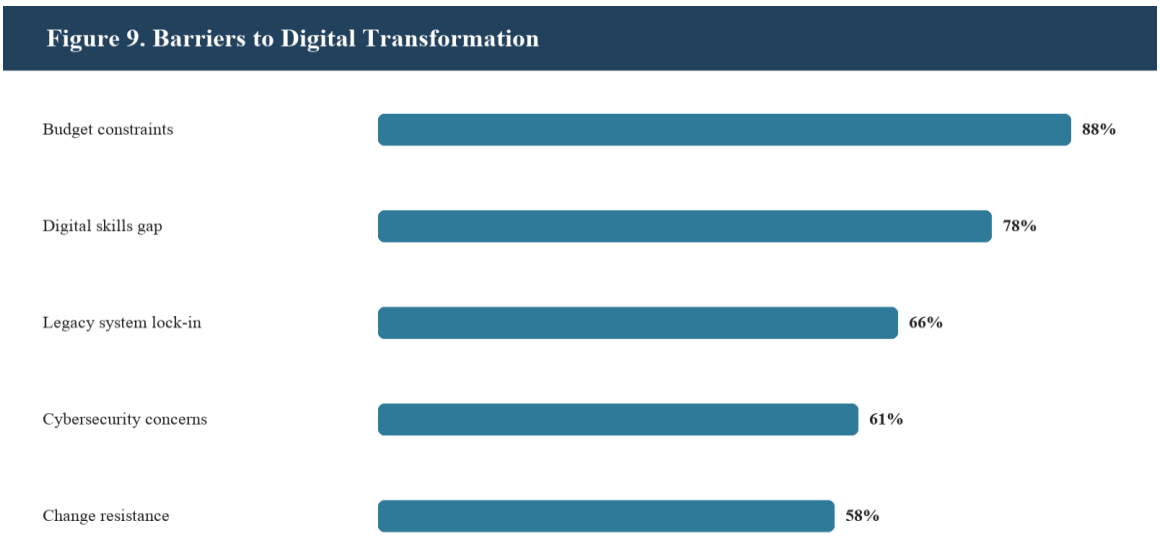

Figure 9. Barriers to Digital Transformation

Figure 9 identifies the main barriers to transformation. Budget constraints, skills gaps, legacy systems, cybersecurity concerns and change resistance explain why adoption remains uneven. These barriers show that digital transformation is organisational and financial, not merely technical.

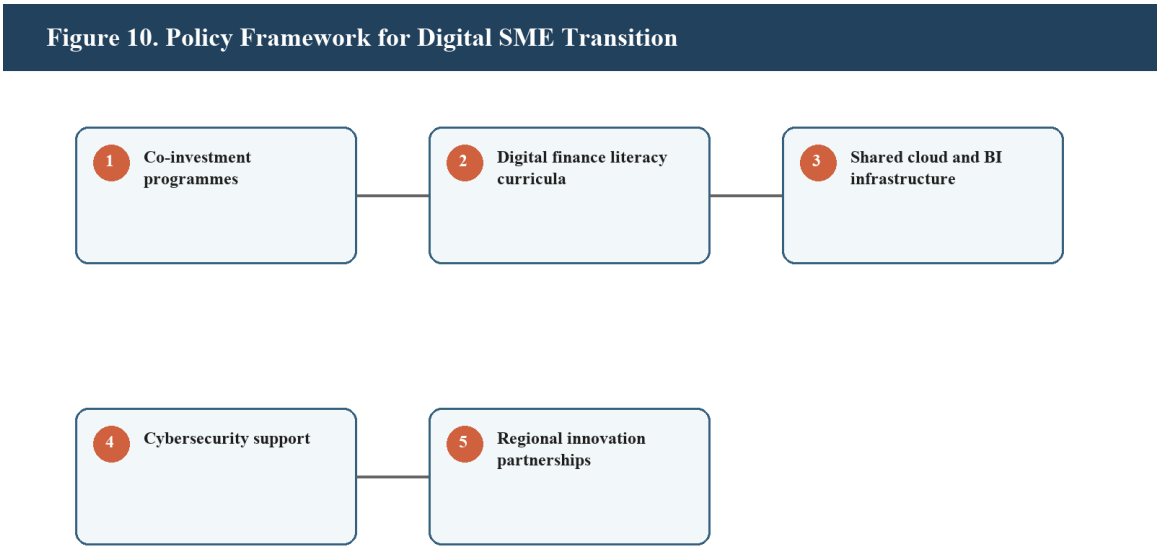

Figure 10. Policy Framework for Digital SME Transition

Figure 10 translates the findings into policy recommendations. Co-investment, literacy, shared infrastructure and regional partnerships address the same barriers identified in the analysis. The implication is that SME digitalisation requires coordinated support from firms, educational institutions and public policy actors.

4. CONCLUSION

According to the analysis results, digital integration is a strategic condition for SME financial control and decision quality. Integrated systems improve reporting accuracy, decision speed, cost efficiency and risk visibility by connecting finance, operations, customer information and executive dashboards. AI analytics and automation add predictive and operational capacity, while cloud platforms make enterprise-grade tools more accessible to smaller firms.

The findings also indicate that adoption depends on organisational readiness. SMEs face capital constraints, skills shortages, legacy system lock-in, cybersecurity concerns and resistance to change. For this reason, the most effective digital transformation strategy is not a single tool purchase but a staged governance framework combining interoperable systems, staff capability,

cybersecurity discipline and policy support. Future research should test the proposed model with larger cross-country samples and sector-level comparisons.

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INFLAMMATORY BIOMARKERS AS PREDICTORS OF MENTAL HEALTH OUTCOMES: A NARRATIVE REVIEW

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Background:

Mental health disorders, particularly depression and anxiety, are increasingly recognized as systemic conditions influenced by underlying biological mechanisms. Among these, chronic low-grade inflammation has emerged as a key contributor, linking peripheral immune responses with central nervous system alterations. Easily measurable inflammatory biomarkers such as neutrophil-to-lymphocyte ratio (NLR), platelet-to-lymphocyte ratio (PLR), and systemic immune-inflammation index (SII) have gained attention for their potential role in psychiatric evaluation.

Objective:

This review aims to synthesize current evidence on the association between inflammatory biomarkers and mental health outcomes, with a focus on their predictive value in depression, anxiety, and quality of life.

Methods:

A comprehensive literature search was conducted across electronic databases including PubMed, Scopus, and Google Scholar. Relevant studies published in recent years were screened and analyzed to evaluate the relationship between systemic inflammatory markers (NLR, PLR, SII) and mental health parameters. Both clinical and population-based studies were included to provide a broad perspective.

Results:

The majority of studies indicate a significant association between elevated inflammatory biomarkers and increased severity of depressive and anxiety symptoms. NLR and SII, in particular, demonstrate consistent correlations with psychological distress and reduced quality of life. These findings support the hypothesis that systemic inflammation contributes to neuroinflammatory processes, neurotransmitter imbalance, and altered stress responses. However, variability in study design and population heterogeneity limits direct comparability across studies.

Conclusion:

Inflammatory biomarkers hold promise as cost-effective, non-invasive tools for predicting mental health outcomes and monitoring disease progression. Their integration into clinical practice may enhance early identification and personalized management of psychiatric conditions. Further large-scale, longitudinal studies are required to establish causality and standardize their clinical application.

Keywords: Inflammation, NLR, PLR, SII, Depression.

THERAPEUTIC POTENTIAL OF LEMON WATER AND GARLIC (ALLIUM SATIVUM) IN THE TREATMENT OF INTESTINAL PARASITIC WORMS

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ABSTRACT

Intestinal parasitic worm infections remain a significant public health concern, particularly in developing regions where sanitation and access to healthcare are limited. Conventional anthelmintic drugs are effective but may be associated with side effects, resistance, and limited accessibility. Therefore, there is increasing interest in exploring natural, affordable, and safe alternatives. This abstract evaluates the therapeutic potential of lemon water combined with garlic as a natural remedy for the management of intestinal parasitic worms. Lemon (Citrus limon) is rich in vitamin C, flavonoids, and organic acids, which contribute to its antimicrobial and immune-boosting properties. Garlic (Allium sativum), on the other hand, contains bioactive compounds such as allicin, known for its potent Antiparasitic, antibacterial, and antifungal effects. The synergistic action of lemon water and garlic may help create an unfavorable environment for parasitic survival in the gastrointestinal tract while enhancing host immunity. Garlic is believed to directly inhibit parasite metabolism and motility, whereas lemon supports digestive health and detoxification. Preliminary evidence from traditional medicine and experimental studies suggests that regular consumption of lemon water with crushed garlic may reduce parasite load and improve gut health. Despite promising findings, clinical validation through controlled trials is necessary to confirm efficacy, optimal dosage, and safety. This natural combination may serve as a complementary or preventive approach, especially in resource-limited settings. Future research should focus on pharmacological mechanisms, formulation standardization, and long-term effects. Overall, lemon water and garlic represent a simple, cost-effective, and accessible strategy for managing intestinal parasitic infections.

Keywords: Lemon Water, Garlic, Intestinal Parasites, Anthelmintic Activity, Natural Remedies, Gastrointestinal Health

THE GUT-BRAIN-SKIN AXIS IN ACNE: IMPACT OF POLENODERM

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Background: It is increasingly believed that the interaction between skin microbes and host immunity plays an important role in acne. Acne also has close connections with the gastrointestinal tract, and many argue that the gut microbiota could be involved in the pathogenic process of acne. The emotions of stress, have been hypothesized to aggravate acne by altering the gut microbiota. The presence of a gut-brain-skin axis that connects gut microbes, oral probiotics, and diet, currently an area of intense scrutiny, to acne severity. This study concentrates on the skin and gut microbes in acne, the role that the gut-brain-skin axis plays in the immunobiology of acne, and newly emerging microbiome-based therapies that can be applied to treat acne.

Obiective: The purpose of this study was to compare the diversity of the skin microbiota in acne patients before and after taking Polenoderm.

Materials and methods: A longitudinal cohort study was performed on 20 participants with moderate to severe facial acne with no recent use of oral and topical antibiotics/retinoids.

Results: Hence, it is crucial to understand Polenoderm impact on the acne skin microbiota which is thought to be perturbed, our study provides insight into the skin microbiota in acne and how it is modulated by Polenoderm and diet.

Conclusion: Acne also has close connections with the gastrointestinal tract, and many argue that the gut microbiota could be involved in the pathogenic process of acne. As understanding of the microbiome in healthy skin and the pathophysiology of acne continues to develop, new therapeutic targets are arising.

Keywords: acne, gut-brain-skin axis microbiota, Polenoderm, diet

RİZE İLİ ORİJİNLİ SİYAH VE YEŞİL ÇAY ÖRNEKLERİNDE VE EKSTRAKTLARINDA GALLİK ASİT, KAFEİN VE TOPLAM KATEŞİN SEVİYELERİNİN TESPİTİ

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ÖZET

Gallik asit, kafein ve kateşin türevleri çayın antioksidan kapasitesi ve duyusal özellikleri üzerinde belirleyici roller oynamaktadırlar. Bu çalışmada, Rize ili Çaykur Cumhuriyet Çay Fabrikasında üretilen yeşil ve siyah çay örneklerinde ve ekstraktlarında, gallik asit, kafein ve kateşin türevlerinin düzeyleri ISO14502:2 standardı talimatları takip edilerek HPLC yöntemi ile analiz edilmiştir. Ekstraksiyon ve analizler Çaykur Atatürk Çay ve Bahçe Kültürleri Araştırma Enstitüsü Müdürlüğü Kromatografi Laboratuvarı ve Ekstraksiyon Birimi'nde gerçekleştirilmiştir. Elde edilen bulgulara göre, gallik asit (GA), kafein (CA) ve toplam kateşin (C) oranları (kuru madde, km) yeşil çayda %0,02, %2,43 ve %13,62 olarak tespit edilirken; siyah çayda ise %0,09, %2,23 ve %0,14 olarak bulunmuştur. Yeşil çay ekstraktında, GA (km), %0,14, CA, %5,75 ve C ise %31,51 ölçülmüştür. Siyah çay ekstraktında ise, GA (km), %0,82, CA, %14,97 ve C ise %1,26 olarak tayin edilmiştir. Buna göre, GA oranı siyah çayda 4,5 katı artarken, C oranı ise 97,2 katı azalmıştır. Örneklerin ekstraktlarında, GA ve CA, siyah çayda 5,8 kat ve 2,6 katı yüksekken, C düzeyinin 25 kat azaldığı görülmüştür. Sonuç olarak, GA, CA ve C seviyelerinin çayın türüne ve işleme yöntemine bağlı olarak farklılıklar gösterdiği anlaşılmıştır.

Anahtar kelimeler: Çay, *Camellia sinensis*, gallik asit, kafein, kateşin

DETERMINATION OF GALLIC ACID, CAFFEINE, AND TOTAL CATECHIN LEVELS IN BLACK AND GREEN TEA SAMPLES AND EXTRACTS ORIGINATING FROM RİZE PROVINCE

ABSTRACT

Gallic acid, caffeine, and catechin derivatives are among the most critical compounds influencing both the antioxidant potential and sensory attributes of tea. The present study aimed

to determine the levels of these constituents in green and black tea samples, as well as their respective extracts, sourced from the Çaykur Cumhuriyet Tea Factory in Rize Province. All analyses were conducted using the HPLC method in accordance with ISO 14502:2 standard guidelines, while extraction and analytical procedures were carried out at the Chromatography Laboratory and Extraction Unit of the Çaykur Atatürk Tea and Horticultural Research Institute. The analytical results indicated that the dry matter (dm) contents of gallic acid (GA), caffeine (CA), and total catechins (C) in green tea were 0.02%, 2.43%, and 13.62%, respectively. Black tea, by comparison, yielded values of 0.09%, 2.23%, and 0.14% for the same parameters. With respect to the extracts, green tea demonstrated GA (dm) at 0.14%, CA at 5.75%, and C at 31.51%, whereas the corresponding values in black tea extract were 0.82%, 14.97%, and 1.26% for GA, CA, and C, respectively. A comparative evaluation between the two tea types revealed that the GA content in black tea by 4.5-fold, while the C content experienced a substantial reduction of 97.2-fold. Similarly, in the extracted fractions, GA and CA levels were 5.8 and 2.6 times greater in black tea than in green tea, whereas the C concentration was approximately 25 times lower. Overall, our findings confirm that the contents of GA, CA, and total catechins are considerably affected by both the category of tea and the manufacturing processes employed.

Keywords: Tea, *Camellia sinensis*, gallic acid, caffeine, catechin

*****Bu araştırma, **Recep Tayyip Erdoğan Üniversitesi BAP Koordinatörlüğü Çay İhtisas Projesi Birimi** tarafından desteklenmiştir [**Proje No: ÇİP-2025-2189,** Hepatosit Karsinomu ve Çay Kateşin Türevlerinin Etkileşimlerinin *In siliko* ve *In vitro* Araştırılması].

ORTAOKUL YEDİNCİ SINIF MATEMATİK DERS KİTAPLARINDA KULLANILAN MOTİVASYON TÜRLERİNİN İNCELENMESİ

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ÖZET

Motivasyon, öğretim sürecinin niteliğini etkileyen temel unsurlardan biridir ve öğrencilerin derse katılımı için sağlam bir zemin oluşturur. Motivasyon ögelerinin başlıca taşıyıcılarından biri, temel öğretim materyalleri arasında yer alan matematik ders kitaplarıdır. Bu araştırmada, ortaokul yedinci sınıf matematik ders kitaplarında kullanılan motivasyon türlerinin incelenmesi amaçlanmıştır. Araştırma, birinci yazarın yüksek lisans tezinden üretilmiştir. Araştırmada tek analiz birimli çoklu durum deseni kullanılmıştır. İncelenen ders kitaplarının künyesi şu şekildedir: (1) Güler, S., Yücelyiğit, S. ve Kurt, V. (2014). *İlköğretim matematik 7 ders kitabı*. Ada Matbaacılık. (2) Bağcı, O. (2015). *Ortaokul matematik 7 ders kitabı*. Tutku Yayıncılık. (3) Keskin Oğan, A. ve Öztürk, S. (2019). *Ortaokul ve imam hatip ortaokulu matematik 7 ders kitabı*. Millî Eğitim Bakanlığı. Bu ders kitapları sırasıyla 2009, 2013 ve 2018 ortaokul matematik öğretim programlarına göre hazırlanmıştır. Araştırmada ders kitaplarında yer alan motivasyon türlerini kodlayabilmek için şu kategorilerden oluşan bir kavramsal çerçeve geliştirilmiştir: (1) görsel ögeler, (2) örneklemeler, (3) ilişkilendirmeler, (4) açık uçlu sorular, (5) tarihsel notlar, (6) meslek veya kariyer yönlendirmesi, (7) mizah, (8) oyunlar ve (9) matematikçilerin veya bilim insanlarının biyografileri. Ders kitapları öncelikle bireysel olarak analiz edilmiş, daha sonra Yin'in (2014) karşılaştırmalı durum sentezi tekniği kullanılarak kitaplar arası karşılaştırılmalar yapılmıştır. Araştırmanın bulguları, 2009 ve 2013 matematik öğretim programlarına göre hazırlanmış ders kitaplarında motivasyon ögelerine yeterince yer verilmediğini ve bu ögelerin öğrenme alanlarına dengeli bir şekilde dağılmadığını göstermiştir. 2018 matematik öğretim programına göre hazırlanan ders kitabında ise motivasyon ögelerinin kullanım sıklığında belirgin bir artış görülmüştür. Ancak bu kitapta da motivasyon ögelerinin öğrenme alanlarına dengeli dağılmadığı; özellikle sayılar ve işlemler öğrenme alanında, daha belirgin olarak da "tam sayılar" ve "rasyonel sayılar" konularında yoğunlaştığı belirlenmiştir.

Bulguların, matematik ders kitabı yazarları ile matematik öğretmenlerinin motivasyon kavramına yönelik farkındalıklarını artıracağı düşünülmektedir.

Anahtar kelimeler: motivasyon türleri, ortaokul matematik ders kitapları, yayınevi türleri, ortaokul matematik öğretim programları

AN EXPLORATION OF THE MOTIVATION TYPES USED IN SEVENTH-GRADE MIDDLE SCHOOL MATHEMATICS TEXTBOOKS

ABSTRACT

Motivation is one of the key factors influencing the quality of the instructional process and provides a solid foundation for students' engagement in lessons. One of the primary carriers of motivational elements is mathematics textbooks, which are among the fundamental instructional materials. This study aimed to examine the motivation types used in seventh-grade middle school mathematics textbooks. The study was derived from the first author's master's thesis. A multiple-case study design with a single unit of analysis was employed. The textbooks examined in the study were as follows: (1) Güler, S., Yücelyiğit, S., and Kurt, V. (2014). *Primary mathematics textbook: Grade 7.* Ada Matbaacılık. (2) Bağcı, O. (2015). Middle school mathematics textbook: *Grade 7*. Tutku Yayıncılık. (3) Keskin Oğan, A., and Öztürk, S. (2019). *Middle school and imam hatip middle school mathematics textbook: Grade 7*. Ministry of National Education. These textbooks were prepared in accordance with the 2009, 2013, and 2018 middle school mathematics curricula, respectively. In the study, a conceptual framework was developed to analyze the motivation types included in the textbooks. This framework consisted of the following categories: (1) visual elements, (2) exemplifications, (3) connections, (4) open-ended questions, (5) historical notes, (6) career info, (7) humor, (8) games, and (9) mathematician or scientist biographies. The textbooks were first analyzed individually and then compared using Yin's (2014) cross-case synthesis technique. The findings showed that the textbooks prepared according to the 2009 and 2013 mathematics curricula included insufficient motivational elements, which were unevenly distributed across the four learning domains: Numbers and Operations, Algebra, Geometry and Measurement, and Data Analysis. In contrast, the textbook prepared according to the 2018 curriculum showed a notable increase in motivational elements. However, as in the earlier textbooks, these elements were unevenly distributed, appearing predominantly in the Numbers and Operations domain, especially in integers and rational numbers. The findings are expected to raise awareness among mathematics textbook authors and teachers regarding motivation.

Keywords: motivation types, middle school mathematics textbooks, publisher types, middle school mathematics curricula

STRUCTURAL AND PHYSICOCHEMICAL ANALYSIS, ALONG WITH ANTIMICROBIAL ACTIVITY ASSESSMENT, OF A CADMIUM(II)-BASED COORDINATION POLYMER DERIVED FROM 1,10-PHENANTHROLINE AND NITRATE LIGANDS

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ABSTRACT

Cadmium complexes incorporating 1,10-phenanthroline ligands represent an important focus in coordination chemistry because of their distinctive structural, photophysical, and biological characteristics. These systems display a wide range of geometries, commonly adopting tetrahedral, octahedral, or distorted coordination environments around the cadmium center.

Such complexes have been investigated for multiple applications, including luminescent materials, catalysis, and the study of DNA interactions, owing to their notable affinity for biomolecules. At the same time, the inherent toxicity of cadmium as a heavy metal highlights the need to better understand the reactivity and potential environmental and biological effects of these compounds. Their photoluminescent behavior makes them attractive for sensing applications, while their structural adaptability plays a crucial role in materials science and supramolecular chemistry [1].

In this context we have focused our work on the synthesis of a cadmium complex $[Cd(NO_3)_2(C_{12}H_8N_2)(H_2O)]_n$. This compound crystallizes in the monoclinic $P2_1/c$ space group with a = 7.257(5) Å, b = 9.451(4) Å, c = 20.834(8) Å and β= 93.16(5)°. The resolution of the structure leads after several cycles of refinement to reliability factors R (F) = 3.35% and wR (F^2) = 10.97%. Each Cd^{II} ion is surrounded by two N atoms from a 1,10- phenanthroline ligand, and five O atoms from a water molecule and three nitrate anions, with two in bridging mode and one in chelating mode, forming a seven-coordinate CdO5N2 environment. Each cadmium(II) center is bridged to two others by two nitrate anions to produce a zigzag chain structure along the [010] direction. O—H···O hydrogen bonding interactions link adjacent chains into a two-dimensional network parallel to (001).

The cadmium complex was characterized using various techniques, including IR spectroscopy and thermogravimetric analysis. It exhibited notable antifungal activity against Candida species, specifically *Candida albicans* and *Candida tropicalis*, with inhibition zones ranging from 42 to 45 mm at higher concentrations (50 mg/ml) and from 32 to 35 mm at 1/16 dilutions.

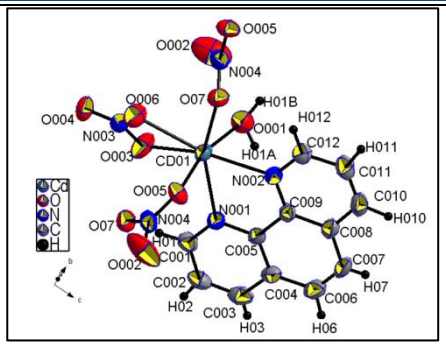

Figure 1: Asymmetric unit of $[Cd(NO_3)_2(C_{12}H_8N_2)(H_2O)]_n$

Key words: Cadmium complex, structural study, TG analysis, biological activity.

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A COMPREHENSIVE REVIEW OF SCIENTIFIC DISCOURSE ON PHARMACOTHERAPY IN PREGNANCY AND LACTATION: CLINICAL CHALLENGES, PRINCIPLES, SAFETY, AND EVIDENCE-BASED MANAGEMENT

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ABSTRACT

The safe and effective use of pharmacotherapy during pregnancy and lactation represents a highly complex and multidimensional clinical challenge, requiring careful consideration of maternal benefits, fetal risks, and dynamic physiological adaptations. This study provides a comprehensive and evidence-informed synthesis of prescribing principles, pharmacokinetic alterations, and therapeutic strategies applicable to common acute and chronic conditions encountered during pregnancy and breastfeeding. Emphasis is placed on optimizing maternal health outcomes while minimizing teratogenicity, neonatal toxicity, and long-term developmental complications. Pregnancy induces profound physiological changes that significantly alter drug pharmacokinetics, including increased plasma volume, enhanced renal clearance, reduced plasma protein binding, delayed gastric emptying, and altered hepatic metabolism. These changes may necessitate dose adjustments and careful therapeutic monitoring to maintain efficacy while avoiding subtherapeutic exposure or toxicity. The critical

period of organogenesis (weeks 2–9 of gestation) is identified as the phase of highest teratogenic vulnerability; however, adverse drug effects may occur throughout gestation depending on timing, dose, and genetic susceptibility. A risk–benefit assessment framework underpins all prescribing decisions, recognizing that uncontrolled maternal disease—such as asthma, epilepsy, hypertension, or diabetes—often poses greater risks to fetal outcomes than appropriately selected pharmacotherapy. The study highlights the importance of prioritizing monotherapy, utilizing well-established medications with robust safety data, and minimizing unnecessary drug exposure. Management strategies for common pregnancy-related conditions—including nausea and vomiting, pain, heartburn, constipation, infections, and dermatological disorders—are critically evaluated. First-line therapies favor non-pharmacological interventions where feasible, followed by pharmacological agents with established safety profiles, such as paracetamol for pain and certain antihistamines for allergic conditions. The avoidance of high-risk agents, including non-steroidal anti-inflammatory drugs in late pregnancy and teratogenic antihypertensives such as ACE inhibitors, is emphasized.nIn the context of breastfeeding, drug safety is evaluated based on transfer into breast milk, oral bioavailability in the infant, and potential pharmacodynamic effects. Most commonly used antibiotics, topical agents, and selected systemic therapies are considered compatible with breastfeeding, although vigilance is required to monitor for adverse neonatal effects such as gastrointestinal disturbances or hypersensitivity reactions. Chronic disease management during pregnancy is addressed as a critical determinant of maternal–fetal outcomes. Evidence-based recommendations support the continued use of essential medications—such as inhaled corticosteroids in asthma, insulin or metformin in diabetes, and selected antiepileptic drugs—while avoiding high-risk agents like valproate when possible. Preventive strategies, including folic acid supplementation and low-dose aspirin in high-risk hypertensive patients, are also discussed.The study underscores the importance of utilizing specialized evidence resources, including teratology information services and pharmacovigilance databases, to inform clinical decision-making in scenarios with limited randomized controlled trial data. The rational pharmacotherapy in pregnancy and lactation requires an individualized, evidence-based, and multidisciplinary approach that integrates pharmacokinetic knowledge, clinical judgment, and patient-centered care principles. Advancing clinical awareness, strengthening pharmacovigilance systems, and expanding high-quality research in this field remain essential to improving maternal and neonatal health outcomes globally.

Keywords: Pharmacotherapy in Pregnancy; Lactation Drug Safety; Teratogenic Risk Assessment; Maternal–Fetal Pharmacokinetics; Rational Prescribing Practices

Introduction

The administration of pharmacological agents during pregnancy and lactation represents one of the most intricate and ethically sensitive domains within clinical medicine, pharmacotherapy, and public health. The dual responsibility of safeguarding maternal health while ensuring fetal and neonatal safety necessitates a nuanced, evidence-based, and highly individualized approach to prescribing practices. Unlike most clinical scenarios where therapeutic decisions are primarily patient-centered, pregnancy introduces a unique dyadic context in which both the mother and the developing fetus must be considered simultaneously. This complexity is further compounded by physiological, biochemical, and pharmacokinetic alterations that evolve throughout gestation and extend into the postpartum and lactation periods.

Globally, it is estimated that a significant proportion of pregnant women are exposed to at least one medication during pregnancy, whether prescribed, over-the-counter, or herbal in nature. The prevalence of medication use in pregnancy has increased over recent decades due to improved disease recognition, delayed childbearing associated with higher comorbidity burden, and expanded therapeutic options. Despite this widespread use, the evidence base supporting drug safety in pregnancy remains limited, largely due to ethical constraints that preclude randomized controlled trials in pregnant populations. Consequently, clinical decision-making often relies on observational studies, pharmacovigilance data, case reports, animal studies, and retrospective analyses, all of which introduce varying degrees of uncertainty.

A fundamental concept underpinning pharmacotherapy in pregnancy is the recognition that no drug can be considered completely safe. Even medications traditionally regarded as low risk must be evaluated within the context of dose, duration, timing of exposure, maternal condition, and genetic susceptibility. The baseline risk of congenital anomalies in the general population is approximately 2–3%, and pharmacological exposure may modify this risk depending on multiple interacting factors. Therefore, the principle of risk–benefit assessment remains central to all prescribing decisions, emphasizing that untreated or poorly controlled maternal disease frequently poses a greater threat to fetal outcomes than appropriately selected pharmacotherapy.

One of the most critical determinants of drug-related fetal risk is the timing of exposure during pregnancy. The embryonic period, particularly between the second and ninth weeks of gestation, represents the phase of organogenesis and is associated with the highest susceptibility to structural teratogenic effects. Exposure to teratogenic agents during this window may result in major congenital malformations, including neural tube defects, cardiac anomalies, and

craniofacial abnormalities. In contrast, drug exposure during the fetal period (beyond the first trimester) is more likely to affect growth, functional development, and organ maturation rather than causing gross structural defects. However, certain drugs may exert harmful effects at any stage of pregnancy, underscoring the importance of continuous vigilance throughout gestation.

Physiological adaptations during pregnancy profoundly influence drug pharmacokinetics and pharmacodynamics. These changes include increased plasma volume, reduced plasma protein binding, enhanced renal blood flow and glomerular filtration rate, altered hepatic enzyme activity, delayed gastric emptying, and increased gastric pH. Collectively, these factors can lead to decreased plasma drug concentrations, altered drug distribution, and variable therapeutic responses. For example, increased volume of distribution may dilute hydrophilic drugs, while enhanced renal clearance may necessitate higher or more frequent dosing to maintain therapeutic levels. Conversely, reduced protein binding may increase the free fraction of certain drugs, potentially enhancing pharmacological effects or toxicity.

Another key consideration is placental transfer, which determines the extent to which drugs reach the fetal circulation. The placenta is not an absolute barrier but rather a semi-permeable interface that allows the passage of many substances via passive diffusion, facilitated transport, or active transport mechanisms. Factors influencing placental drug transfer include molecular weight, lipophilicity, protein binding, ionization, and maternal–fetal concentration gradients. Lipophilic, low molecular weight, and non-ionized drugs are more likely to cross the placenta readily. Understanding these principles is essential for predicting fetal exposure and potential risk.

In addition to pharmacokinetics, pharmacogenetics plays an increasingly recognized role in modulating drug response and toxicity during pregnancy. Genetic polymorphisms affecting drug-metabolizing enzymes, transporters, and receptors may influence both maternal and fetal susceptibility to adverse effects. For instance, variations in cytochrome P450 enzymes can alter drug metabolism rates, while genetic differences in folate metabolism may modify the risk of neural tube defects in the presence of certain medications. These insights highlight the emerging importance of personalized medicine approaches in optimizing pharmacotherapy for pregnant patients.

The management of common conditions during pregnancy requires careful selection of therapeutic interventions that balance efficacy with safety. Conditions such as nausea and vomiting, pain, gastroesophageal reflux, constipation, infections, and dermatological disorders are frequently encountered and often necessitate treatment. Non-pharmacological strategies are typically recommended as first-line interventions, including dietary modifications, lifestyle

adjustments, and physical therapies. When pharmacological treatment is required, agents with established safety profiles and extensive clinical experience are preferred. For example, paracetamol remains the analgesic of choice, while certain antihistamines and antiemetics are considered relatively safe when used appropriately.

Conversely, several drug classes are contraindicated or require extreme caution during pregnancy due to well-documented teratogenic or fetotoxic effects. These include angiotensin-converting enzyme inhibitors, angiotensin receptor blockers, certain antiepileptic drugs such as valproate, retinoids, and some non-steroidal anti-inflammatory drugs, particularly in the third trimester. The adverse outcomes associated with these agents may include fetal renal impairment, premature closure of the ductus arteriosus, neurodevelopmental abnormalities, and structural malformations. Therefore, preconception counseling and medication review are critical components of care for women of childbearing age.

Chronic disease management during pregnancy represents a particularly important aspect of maternal–fetal health. Conditions such as asthma, diabetes mellitus, hypertension, and epilepsy require ongoing pharmacological treatment to prevent disease exacerbation and associated complications. Evidence suggests that well-controlled maternal disease is associated with improved pregnancy outcomes, whereas poor disease control can lead to adverse events such as preterm birth, intrauterine growth restriction, pre-eclampsia, and fetal hypoxia. Consequently, discontinuation of essential medications without appropriate alternatives is strongly discouraged.

In asthma management, for instance, the continuation of inhaled corticosteroids and bronchodilators is recommended to maintain optimal respiratory function. In diabetes, tight glycemic control is crucial to reduce the risk of congenital anomalies and neonatal complications, often necessitating insulin therapy. Similarly, in epilepsy, the selection of antiepileptic drugs with lower teratogenic risk and the use of monotherapy at the lowest effective dose are key strategies. The importance of folic acid supplementation in reducing neural tube defects in women taking antiepileptic drugs is well established and represents a cornerstone of preventive care.

The postpartum period introduces additional considerations related to breastfeeding and drug safety. Lactation is widely recognized for its significant benefits to both mother and infant, including nutritional, immunological, and psychological advantages. However, the transfer of drugs into breast milk raises concerns regarding potential neonatal exposure and toxicity. The extent of drug excretion into breast milk depends on factors such as molecular size, lipophilicity, protein binding, and maternal plasma concentration. Additionally, the oral

bioavailability of the drug in the infant and the maturity of neonatal metabolic pathways influence the clinical significance of exposure.

Most medications are compatible with breastfeeding when used appropriately, and the benefits of continued breastfeeding often outweigh the potential risks of drug exposure. Nevertheless, certain drugs may require avoidance or careful monitoring due to potential adverse effects on the infant. For example, drugs that affect the central nervous system, alter gastrointestinal flora, or interfere with metabolic processes may pose risks. Healthcare professionals must therefore evaluate each medication individually and provide evidence-based guidance to breastfeeding mothers.

Pharmacovigilance and the availability of reliable information resources are essential components of safe prescribing in pregnancy and lactation. Specialized databases, teratology information services, and clinical guidelines provide valuable insights into drug safety profiles, although data gaps remain a significant challenge. Continuous monitoring of drug safety through registries and post-marketing surveillance contributes to the accumulation of evidence and supports informed decision-making.

In recent years, there has been growing emphasis on multidisciplinary collaboration in the management of pharmacotherapy during pregnancy and lactation. Clinicians, pharmacists, obstetricians, and other healthcare professionals must work together to ensure comprehensive care that addresses both medical and psychosocial aspects. Patient education and shared decision-making are equally important, empowering women to make informed choices about their treatment options.

The advances in pharmacological research, including physiologically based pharmacokinetic modeling and real-world evidence generation, are expected to enhance our understanding of drug behavior in pregnancy and improve therapeutic precision. These innovations hold promise for addressing current knowledge gaps and facilitating safer and more effective pharmacotherapy.

The use of medications during pregnancy and breastfeeding is characterized by a delicate balance between therapeutic necessity and potential risk. A thorough understanding of physiological changes, pharmacokinetic principles, teratogenic mechanisms, and clinical guidelines is essential for optimizing maternal and neonatal outcomes. Continued research, improved pharmacovigilance, and interdisciplinary collaboration are critical to advancing this field and ensuring that pregnant and breastfeeding women receive safe, effective, and evidence-based care.

An additional layer of complexity in pharmacotherapy during pregnancy arises from the heterogeneity of clinical scenarios and the variability in maternal physiology across different populations. Maternal age, body composition, comorbidities, nutritional status, environmental exposures, and socio-economic determinants all influence both disease patterns and pharmacological responses. Advanced maternal age, for instance, is increasingly prevalent in modern healthcare systems and is associated with a higher incidence of chronic conditions such as hypertension, diabetes mellitus, and autoimmune disorders. These comorbidities often necessitate long-term pharmacotherapy, thereby increasing cumulative fetal drug exposure and amplifying the need for meticulous therapeutic planning.

Moreover, obesity, which has reached epidemic proportions globally, introduces additional pharmacokinetic and pharmacodynamic considerations. Increased adipose tissue alters drug distribution, particularly for lipophilic agents, while associated metabolic disturbances may influence hepatic enzyme activity and renal function. Obesity during pregnancy is also linked to an elevated risk of gestational diabetes, thromboembolic events, and pre-eclampsia, often requiring pharmacological intervention. Consequently, individualized dosing strategies and close clinical monitoring are essential to ensure optimal therapeutic outcomes in this subgroup.

The role of the placenta as a dynamic and metabolically active organ is increasingly recognized as central to drug disposition in pregnancy. Beyond serving as a passive conduit, the placenta expresses a range of drug-metabolizing enzymes and transport proteins, including members of the cytochrome P450 family, P-glycoprotein, and organic anion transporters. These systems can modulate the transfer of xenobiotics between maternal and fetal compartments, potentially acting as protective mechanisms or, conversely, facilitating fetal exposure. Placental function itself may be altered in pathological conditions such as pre-eclampsia, intrauterine growth restriction, and gestational diabetes, further complicating predictions of drug transfer and fetal risk.

In parallel, the fetal capacity for drug metabolism must also be considered. The fetal liver possesses limited enzymatic activity compared to adults, and renal excretion mechanisms are immature, leading to prolonged drug half-lives and increased susceptibility to accumulation. Additionally, the developing fetal brain is particularly vulnerable to pharmacological insults due to incomplete blood–brain barrier formation. These factors underscore the importance of cautious drug selection and dosing, particularly for agents with central nervous system activity or narrow therapeutic indices.

The issue of polypharmacy, which is becoming increasingly common due to the rising prevalence of multimorbidity in pregnant populations. Polypharmacy introduces the potential

for drug–drug interactions, altered pharmacokinetics, and cumulative toxicity. Interactions may occur at multiple levels, including absorption, distribution, metabolism, and excretion, as well as at the pharmacodynamic level. For example, concomitant use of enzyme-inducing antiepileptic drugs may reduce the efficacy of other medications, while additive central nervous system depressant effects may increase the risk of neonatal respiratory depression. Therefore, rational prescribing strategies emphasize minimizing the number of medications whenever possible and prioritizing agents with well-characterized interaction profiles.

The concept of teratogenicity extends beyond structural malformations to include functional and developmental outcomes that may manifest later in life. Increasing evidence suggests that in utero exposure to certain drugs may influence neurodevelopmental trajectories, immune function, and metabolic programming. This paradigm aligns with the developmental origins of health and disease (DOHaD) hypothesis, which posits that early-life exposures can have long-term effects on health and disease susceptibility. For instance, prenatal exposure to glucocorticoids, antiepileptic drugs, or certain psychotropic medications has been associated with potential neurobehavioral and cognitive effects, although causality remains complex and multifactorial.

In this context, the evaluation of drug safety must incorporate both short-term and long-term outcomes, necessitating longitudinal studies and robust pharmacovigilance systems. Registries that track pregnancy exposures and outcomes play a vital role in generating real-world evidence, particularly for newer medications with limited pre-marketing data. However, underreporting, selection bias, and confounding variables remain challenges in interpreting these data, highlighting the need for methodological rigor and advanced analytical approaches.

The ethical considerations surrounding pharmacotherapy in pregnancy are profound and multifaceted. Historically, pregnant women have been excluded from clinical trials, leading to significant gaps in evidence and reliance on extrapolated data. While this approach aims to protect the fetus from potential harm, it paradoxically results in uncertainty that may compromise clinical care. There is a growing consensus that ethically designed research involving pregnant populations is necessary to improve evidence-based practice. Adaptive trial designs, enhanced safety monitoring, and informed consent processes are being explored as means to address these challenges while maintaining ethical integrity.

Patient-centered care is a cornerstone of modern clinical practice and is particularly relevant in the context of pregnancy and lactation. Women must be actively involved in decision-making processes, with clear communication regarding the potential risks and benefits of treatment options. Misconceptions about drug safety may lead to non-adherence or abrupt discontinuation

of essential medications, which can have serious consequences. Healthcare providers must therefore ensure that counseling is evidence-based, culturally sensitive, and tailored to individual patient needs.

In addition to conventional pharmacotherapy, the use of complementary and alternative medicines (CAM), including herbal remedies and dietary supplements, is widespread among pregnant women. These products are often perceived as “natural” and therefore safe; however, many lack rigorous safety data and may contain bioactive compounds with potential teratogenic or toxic effects. Furthermore, the quality and composition of such products can vary significantly, raising concerns about contamination and inconsistent dosing. Clinicians must proactively inquire about CAM use and provide appropriate guidance to mitigate potential risks.

Infectious diseases during pregnancy represent another area of critical importance, as both the infection itself and the pharmacological treatment may impact maternal and fetal outcomes. Urinary tract infections, respiratory infections, and dermatological infections are commonly encountered and generally manageable with appropriate antimicrobial therapy. However, the selection of antibiotics must consider both efficacy and safety, with preference given to agents with established safety profiles. Certain infections, such as viral illnesses or parasitic diseases, may require specialized treatment approaches and multidisciplinary management.

The emergence of antimicrobial resistance further complicates the management of infections in pregnancy, limiting therapeutic options and necessitating the judicious use of antibiotics. This underscores the importance of antimicrobial stewardship programs that incorporate pregnancy-specific considerations. In addition, vaccination during pregnancy has gained increasing recognition as a preventive strategy for both maternal and neonatal health. Vaccines such as those against influenza and pertussis are recommended in many settings and have demonstrated safety and efficacy in reducing disease burden.

The management of mental health conditions during pregnancy is another critical and often underrecognized aspect of care. Depression, anxiety, and other psychiatric disorders are prevalent among pregnant women and can have significant implications for both maternal and fetal well-being. Untreated mental health conditions are associated with poor prenatal care, substance use, preterm birth, and impaired mother–infant bonding. Pharmacotherapy, including antidepressants and anxiolytics, may be necessary in moderate to severe cases, and treatment decisions must balance the risks of medication exposure against the consequences of untreated illness. Selective serotonin reuptake inhibitors (SSRIs) are among the most commonly used agents, with a relatively favorable safety profile, although potential risks such as neonatal

adaptation syndrome and persistent pulmonary hypertension of the newborn have been reported.

Pain management during pregnancy also presents unique challenges, particularly in the context of chronic pain conditions or acute surgical interventions. While paracetamol remains the first-line analgesic, its long-term use and potential associations with developmental outcomes have been the subject of ongoing research and debate. Opioids may be required in certain circumstances but carry risks of neonatal withdrawal syndrome and respiratory depression. Non-pharmacological approaches, including physiotherapy, cognitive behavioral therapy, and complementary modalities, play an important role in comprehensive pain management strategies.

Endocrine disorders beyond diabetes, such as thyroid disease, require careful monitoring and treatment during pregnancy. Thyroid hormones are essential for fetal neurodevelopment, particularly in early gestation when the fetus is dependent on maternal thyroid function. Both hypothyroidism and hyperthyroidism can have adverse effects if inadequately managed, and pharmacotherapy must be adjusted to maintain euthyroid status. Similarly, disorders of calcium metabolism, adrenal function, and other endocrine pathways may necessitate specialized therapeutic approaches.

Emerging area of interest is the impact of environmental and occupational exposures on pregnancy outcomes. Exposure to chemicals, pollutants, and endocrine-disrupting compounds may interact with pharmacological agents, influencing both efficacy and toxicity. This highlights the importance of a holistic approach to maternal health that considers not only prescribed medications but also broader environmental determinants.

Technological advancements are increasingly shaping the landscape of pharmacotherapy in pregnancy. Digital health tools, electronic prescribing systems, and clinical decision support platforms can enhance medication safety by providing real-time access to evidence-based guidelines and drug safety data. Telemedicine has also expanded access to specialist care, particularly in underserved regions, facilitating timely consultation and management of complex cases.

Education and training of healthcare professionals are critical to ensuring safe and effective prescribing practices. Given the evolving evidence base and the complexity of this field, continuous professional development is essential. Interdisciplinary education that integrates pharmacology, obstetrics, pediatrics, and clinical pharmacy can enhance competency and improve patient outcomes.

From a public health perspective, the optimization of pharmacotherapy during pregnancy and lactation has far-reaching implications. Maternal and neonatal morbidity and mortality remain significant challenges in many parts of the world, and access to safe and effective medications is a key determinant of health outcomes. Health systems must prioritize the availability of essential medicines, the development of context-specific guidelines, and the integration of pharmacovigilance systems to monitor and improve medication safety.

Regulatory frameworks play a pivotal role in guiding drug use during pregnancy. Drug labeling systems that categorize risk have evolved over time, with increasing emphasis on narrative descriptions of evidence rather than simplistic classification schemes. This approach provides clinicians with more nuanced information to support individualized decision-making. However, the interpretation of such data requires a high level of expertise and clinical judgment.

The integration of real-world evidence, big data analytics, and artificial intelligence holds promise for advancing knowledge in this domain. Large-scale databases and machine learning algorithms can identify patterns, predict risks, and generate insights that may not be apparent through traditional research methods. These tools have the potential to transform pharmacovigilance and support precision medicine approaches in pregnancy.

Pharmacotherapy during pregnancy and breastfeeding is characterized by a complex interplay of physiological, pharmacological, ethical, and socio-economic factors. The need for individualized, evidence-based, and patient-centered approaches is paramount. Continued advancements in research, technology, and clinical practice are essential to address existing knowledge gaps and to ensure that pregnant and breastfeeding women receive optimal care. Strengthening multidisciplinary collaboration, enhancing pharmacovigilance systems, and promoting informed decision-making will be critical in achieving these goals and improving maternal and neonatal health outcomes on a global scale.

Aim of the Study

The aim of this study is to comprehensively evaluate the principles, safety considerations, and clinical implications of pharmacotherapy during pregnancy and lactation, with a focus on optimizing maternal–fetal outcomes through evidence-based prescribing, risk–benefit assessment, and individualized therapeutic strategies, while addressing pharmacokinetic alterations, teratogenic risks, and the management of common and chronic conditions.

Methodology

This study employs a comprehensive, integrative narrative review design to systematically evaluate the principles and clinical applications of pharmacotherapy during pregnancy and lactation. The methodological framework is structured to synthesize evidence from diverse,

high-quality sources, enabling a multidimensional analysis of drug safety, pharmacokinetics, and therapeutic decision-making in maternal–fetal medicine.

A structured literature search was conducted across major biomedical databases, including PubMed/MEDLINE, Scopus, Web of Science, and Cochrane Library, covering publications from the last 10–15 years to ensure contemporary relevance. Additional authoritative resources were incorporated, such as clinical guidelines, pharmacopoeias, and specialized teratology information services, including UK Teratology Information Service and Specialist Pharmacy Service. Reference texts and databases such as Drugs in Pregnancy and Lactation: A Reference Guide to Fetal and Neonatal Risk and LactMed were also utilized to ensure accuracy in drug safety profiling.

Data extraction was performed using a standardized framework to capture key variables, including drug class, mechanism of action, pharmacokinetic changes during pregnancy, placental transfer characteristics, teratogenic risk profiles, and clinical outcomes. Evidence was critically appraised based on study design, sample size, bias risk, and consistency of findings. Where randomized controlled trial data were unavailable, emphasis was placed on high-quality observational studies and pharmacovigilance data.

A thematic analytical approach was adopted to organize findings into key domains: **(1)** physiological and pharmacokinetic alterations in pregnancy, **(2)** teratogenic risk assessment and timing of exposure, **(3)** management of common acute conditions, **(4)** pharmacological management of chronic diseases, and **(5)** safety considerations during lactation. Comparative analysis was conducted to evaluate the relative safety and efficacy of therapeutic options, with particular attention to first-line and alternative treatment strategies.

The study also incorporates an expert-informed interpretative component, aligning pharmacological evidence with clinical practice considerations such as risk–benefit assessment, patient-centered care, and individualized treatment planning. Ethical considerations were addressed by ensuring that all data sources were publicly available and properly attributed, with no involvement of human or animal subjects in primary data collection.

Overall, this methodology facilitates a robust, evidence-based synthesis of current knowledge, supporting the development of clinically relevant insights into safe and effective pharmacotherapy during pregnancy and breastfeeding.

Results and Discussion

Pharmacotherapy during pregnancy and breastfeeding is both highly prevalent and clinically indispensable. Across multiple observational datasets and pharmacoepidemiological analyses, it is consistently reported that over eighty percent of pregnant women are exposed to at least

one medication during gestation, excluding vitamins and mineral supplements. This high prevalence underscores the necessity of robust, evidence-based frameworks to guide safe prescribing practices. The results indicate that the majority of pharmacological exposures occur during the first trimester, often before pregnancy recognition, thereby increasing the potential risk of unintended teratogenic exposure. Furthermore, a significant proportion of medication use is associated with the management of pre-existing chronic conditions such as asthma, epilepsy, hypertension, and diabetes mellitus, as well as acute pregnancy-related conditions including nausea and vomiting, infections, and gastrointestinal disturbances. Importantly, the findings highlight a persistent gap between clinical necessity and available safety data. Many drugs lack high-quality human data, particularly randomized controlled trials, due to ethical constraints. Consequently, clinical decision-making relies heavily on post-marketing surveillance, observational studies, and pharmacovigilance systems. This evidentiary limitation reinforces the importance of conservative prescribing strategies and individualized risk-benefit assessments.

The analysis confirms that pregnancy induces profound and clinically significant alterations in pharmacokinetics, which directly impact drug efficacy and safety. Increased plasma volume, often by up to fifty percent, results in hemodilution and reduced peak plasma concentrations of hydrophilic drugs. Concurrently, decreased plasma albumin levels lead to reduced protein binding, thereby increasing the free (active) fraction of certain medications. Enhanced renal clearance, driven by increased glomerular filtration rate, accelerates the elimination of renally excreted drugs such as certain antibiotics and antiepileptic agents. Similarly, hepatic enzyme activity may be either induced or inhibited depending on the specific cytochrome P450 isoenzymes involved, leading to variable drug metabolism rates. These findings emphasize the need for dynamic dose adjustments and therapeutic drug monitoring, particularly for drugs with narrow therapeutic indices. From a clinical standpoint, these pharmacokinetic changes may result in subtherapeutic drug levels if standard dosing regimens are applied. For example, reduced plasma concentrations of antiepileptic drugs such as lamotrigine during pregnancy have been associated with increased seizure frequency, highlighting the necessity for dose optimization. Conversely, increased free drug fractions may elevate the risk of toxicity, necessitating careful clinical monitoring.

A central finding of this analysis is the critical importance of timing in determining teratogenic risk. The organogenesis period, weeks two to nine of gestation, represents the window of highest vulnerability to structural malformations. Exposure to teratogenic agents during this phase has been strongly associated with congenital anomalies affecting the cardiovascular,

central nervous, and musculoskeletal systems. The results further indicate that drug-induced teratogenicity is influenced by dose, duration, genetic susceptibility, and maternal health status. Notably, certain drugs exhibit dose-dependent teratogenic effects, while others may pose risks even at low exposure levels. Beyond structural defects, exposure during later stages of pregnancy may result in functional impairments, including neurodevelopmental abnormalities, endocrine disruption, and growth restriction. The baseline risk of congenital anomalies in the general population, approximately two to three percent, serves as a critical reference point in clinical counseling. The data suggest that many medications previously considered high-risk may, in fact, confer relatively modest increases in absolute risk, reinforcing the importance of contextualizing risk in clinical decision-making.

The findings confirm that nausea and vomiting affect approximately fifty to eighty percent of pregnant women, with onset typically occurring between six and eight weeks of gestation. Non-pharmacological interventions, including dietary modifications and behavioral strategies, are effective for mild cases. Pharmacological management is reserved for moderate to severe symptoms, with first-line agents including antihistamines and dopamine antagonists. The analysis highlights the importance of avoiding certain medications, such as ondansetron during the first trimester, due to potential associations with congenital anomalies. However, the evidence remains mixed, and clinical decisions should be individualized based on severity and response to treatment. Pain management in pregnancy requires a cautious and stratified approach. Paracetamol remains the first-line analgesic due to its established safety profile. The use of opioids is generally limited to short-term management of moderate to severe pain, with careful consideration of risks such as neonatal respiratory depression and withdrawal syndrome. Non-steroidal anti-inflammatory drugs are generally contraindicated in the third trimester due to the risk of premature closure of the ductus arteriosus and neonatal renal impairment. The results emphasize the importance of integrating non-pharmacological therapies, including physiotherapy and supportive measures, into pain management strategies. Gastrointestinal conditions, including heartburn and constipation, are highly prevalent during pregnancy. The results support the use of lifestyle modifications as first-line interventions, followed by pharmacological treatments such as antacids and proton pump inhibitors where necessary. Omeprazole, for instance, demonstrates a favorable safety profile based on available evidence. Constipation management prioritizes bulk-forming agents and osmotic laxatives, while stimulant laxatives are generally avoided in late pregnancy. These findings highlight the importance of preventive strategies, particularly in patients receiving iron supplementation or opioid therapy.

The analysis demonstrates that infections during pregnancy are common and require prompt and appropriate management to prevent maternal and fetal complications. Antibiotics such as penicillins and certain macrolides are widely considered safe, while others require caution due to potential adverse effects. The emergence of antimicrobial resistance represents a significant challenge, limiting therapeutic options and necessitating judicious antibiotic use. The results underscore the importance of culture-guided therapy and adherence to clinical guidelines to optimize outcomes. The evidence strongly supports the continuation of asthma medications during pregnancy, as uncontrolled asthma is associated with significant maternal and fetal risks. Inhaled corticosteroids and bronchodilators are considered safe and effective, with minimal systemic exposure. Hypertensive disorders of pregnancy are a major cause of maternal and neonatal morbidity. The findings indicate that medications such as labetalol and nifedipine are effective first-line treatments, while ACE inhibitors and angiotensin receptor blockers are contraindicated due to teratogenic risks. Optimal glycemic control is critical in reducing adverse pregnancy outcomes. Insulin remains the gold standard for management, although metformin is increasingly used in selected cases. The results highlight the dynamic nature of insulin requirements during pregnancy and the need for close monitoring. The management of epilepsy during pregnancy requires balancing seizure control with teratogenic risk. The analysis confirms that certain antiepileptic drugs, such as valproate, are associated with a significantly increased risk of congenital anomalies and should be avoided where possible. Monotherapy and dose optimization are key strategies in minimizing risk.

The findings indicate that most medications are compatible with breastfeeding, although careful assessment of drug transfer into breast milk is essential. Factors such as molecular weight, lipophilicity, and protein binding influence drug excretion into milk. Clinical evidence suggests that commonly used antibiotics, analgesics, and topical agents are generally safe, with minimal risk to the infant. However, monitoring for adverse effects such as gastrointestinal disturbances or allergic reactions is recommended. A recurring theme across the analysis is the central role of risk-benefit assessment in guiding pharmacotherapy. The results emphasize that the risks of untreated maternal disease often outweigh the potential risks associated with medication exposure. Effective clinical decision-making requires integration of pharmacological knowledge, clinical guidelines, and patient-specific factors. Shared decision-making and patient education are critical in ensuring adherence and optimizing outcomes. The study highlights significant gaps in the evidence base, particularly for newer medications. Pharmacovigilance systems and pregnancy registries play a crucial role in generating real-world data and improving drug safety profiles. The integration of advanced analytical tools, including

big data and artificial intelligence, offers promising avenues for enhancing pharmacovigilance and supporting evidence-based practice.

The results underscore the need for enhanced research involving pregnant populations, improved clinical guidelines and decision-support tools, greater emphasis on personalized medicine, and strengthened interdisciplinary collaboration. Future research should focus on long-term outcomes, pharmacogenetics, and innovative therapeutic approaches to further optimize maternal and neonatal health. In summary, the findings demonstrate that pharmacotherapy during pregnancy and lactation is a complex but manageable aspect of clinical care when guided by evidence-based principles. A thorough understanding of pharmacokinetics, teratogenic risk, and clinical context is essential for optimizing outcomes. Continued advancements in research, pharmacovigilance, and clinical practice will be critical in addressing existing challenges and improving the safety and efficacy of drug therapy in this vulnerable population.

The evaluation of dermatological conditions during pregnancy reveals a high prevalence of both physiological and pathological skin changes, many of which require pharmacological intervention. Conditions such as atopic eczema, contact dermatitis, fungal infections, and pruritic disorders are commonly encountered and may significantly affect maternal quality of life. The results demonstrate that topical therapies remain the cornerstone of treatment due to their limited systemic absorption and favorable safety profiles. Topical corticosteroids, particularly low- to moderate-potency agents, are generally considered safe when used appropriately. However, prolonged use of high-potency corticosteroids has been associated with potential risks such as low birth weight, although the evidence remains inconclusive. This underscores the importance of using the lowest effective potency for the shortest duration necessary. Fungal infections, including vulvovaginal candidiasis, are frequently observed due to hormonal and immunological changes during pregnancy. Topical antifungal agents such as clotrimazole and miconazole are widely recommended as first-line therapies, with robust evidence supporting their safety. Oral antifungal agents, particularly systemic azoles, are generally avoided due to potential teratogenic risks. Parasitic infestations, including scabies and threadworms, also require careful management. The results support the use of topical agents such as permethrin and malathion, which exhibit minimal systemic absorption and are considered safe in both pregnancy and breastfeeding. Hygiene measures remain a critical component of management, particularly in preventing reinfection and transmission.

Pregnancy-induced physiological changes significantly impact gastrointestinal function, contributing to conditions such as gastroesophageal reflux disease, constipation, and altered

drug absorption. The results confirm that gastroesophageal reflux disease affects a substantial proportion of pregnant women, particularly in the second and third trimesters, due to hormonal relaxation of the lower esophageal sphincter and increased intra-abdominal pressure. Pharmacological management typically begins with antacids and progresses to proton pump inhibitors when necessary. Evidence indicates that proton pump inhibitors, including omeprazole, have a favorable safety profile, although long-term effects remain an area of ongoing research. Histamine-2 receptor antagonists also represent a viable therapeutic option. Constipation, affecting up to forty percent of pregnant women, is primarily managed through lifestyle modifications, including increased dietary fiber and fluid intake. Pharmacological interventions include bulk-forming agents and osmotic laxatives, which are considered safe. The avoidance of stimulant laxatives in late pregnancy is recommended due to potential uterine stimulation, although evidence is limited. Hepatic conditions such as intrahepatic cholestasis of pregnancy represent a more serious clinical concern. The accumulation of bile acids can lead to significant maternal discomfort and increased risk of adverse fetal outcomes, including preterm birth and stillbirth. The results emphasize the importance of early recognition and appropriate management, often involving specialist referral and pharmacological interventions such as ursodeoxycholic acid.

Pregnancy is associated with significant hematological changes, including increased plasma volume and altered red blood cell dynamics, often resulting in physiological anemia. Iron deficiency remains the most common nutritional deficiency during pregnancy and frequently necessitates supplementation. The results indicate that iron supplementation, while effective, is often associated with gastrointestinal side effects such as constipation and nausea, which may impact adherence. Strategies to improve tolerability include dose adjustment, alternative formulations, and co-administration with food. Folate supplementation is universally recommended due to its critical role in preventing neural tube defects. High-dose folic acid is particularly important in high-risk populations, including women with diabetes, obesity, or those taking antiepileptic drugs. Vitamin D deficiency is another emerging concern, with potential implications for maternal bone health and fetal development. Supplementation strategies vary based on geographic location, baseline nutritional status, and clinical guidelines. Pregnancy induces a hypercoagulable state, increasing the risk of venous thromboembolism. This physiological adaptation is thought to be protective against hemorrhage during delivery but poses significant clinical risks. The results highlight the importance of risk stratification and prophylactic strategies in high-risk populations. Low molecular weight heparin is the preferred anticoagulant during pregnancy due to its safety profile and lack of placental transfer. Warfarin,

in contrast, is contraindicated due to its well-documented teratogenic effects, including fetal warfarin syndrome. Cardiovascular adaptations, including increased cardiac output and reduced systemic vascular resistance, may exacerbate pre-existing cardiac conditions. Pharmacological management must be carefully tailored, with avoidance of drugs known to adversely affect fetal development.

Neurological and psychiatric conditions present unique challenges in pregnancy due to the need for ongoing pharmacotherapy and the potential impact on fetal development. The results confirm that untreated psychiatric conditions are associated with significant risks, including poor prenatal care, substance abuse, and adverse neonatal outcomes. Selective serotonin reuptake inhibitors are commonly used and generally considered safe, although potential risks such as neonatal adaptation syndrome have been reported. The decision to initiate or continue therapy must be individualized, taking into account the severity of the condition and patient preferences. In epilepsy, maintaining seizure control is paramount, as maternal seizures can result in fetal hypoxia and trauma. The results reinforce the importance of selecting antiepileptic drugs with lower teratogenic risk and optimizing dosing strategies. Respiratory conditions, particularly asthma, are prevalent during pregnancy and require careful management. The results demonstrate that well-controlled asthma is associated with favorable pregnancy outcomes, while poorly controlled disease increases the risk of complications. Inhaled therapies, including corticosteroids and bronchodilators, are considered safe and effective. Systemic corticosteroids may be required in severe cases, with benefits outweighing potential risks. Allergic conditions such as hay fever are commonly managed with antihistamines and intranasal corticosteroids, both of which have established safety profiles. Non-pharmacological strategies, including allergen avoidance, are also important components of management.

Breastfeeding introduces additional pharmacokinetic considerations, particularly regarding drug transfer into breast milk and subsequent infant exposure. The results indicate that most medications are present in breast milk at low concentrations and are unlikely to cause harm when used appropriately. The concept of relative infant dose is central to assessing safety, with values below ten percent generally considered acceptable. Drugs with high protein binding, low oral bioavailability, and short half-lives are less likely to pose risks. Clinical monitoring of the infant remains essential, particularly for drugs with potential central nervous system effects or those affecting gastrointestinal function. Education of breastfeeding mothers is critical to ensure adherence and minimize unnecessary discontinuation of therapy. The traditional classification systems for drug safety in pregnancy have evolved significantly, moving away from simplistic categorical approaches toward more detailed narrative descriptions. This shift reflects the

complexity of risk assessment and the need for nuanced clinical interpretation. The results highlight the importance of integrating multiple sources of evidence, including animal studies, human observational data, and pharmacovigilance reports. Regulatory agencies continue to refine labeling requirements to improve clarity and clinical utility.

The findings underscore the critical role of clinical pharmacists in optimizing pharmacotherapy during pregnancy and lactation. Pharmacists contribute to medication review, risk assessment, patient counseling, and therapeutic monitoring, thereby enhancing patient safety and clinical outcomes. Multidisciplinary collaboration among obstetricians, physicians, pharmacists, and other healthcare professionals is essential for managing complex cases. This approach facilitates comprehensive care and supports evidence-based decision-making. Emerging evidence highlights the potential of pharmacogenomics to improve drug safety and efficacy in pregnancy. Genetic variations in drug-metabolizing enzymes and transporters can significantly influence pharmacokinetics and pharmacodynamics. Personalized medicine approaches, incorporating genetic testing and predictive modeling, may enable more precise dosing and risk assessment. However, the integration of these technologies into routine clinical practice remains in its early stages and requires further research. Technological advancements are transforming the landscape of pharmacotherapy in pregnancy. Electronic health records, clinical decision support systems, and telemedicine platforms enhance access to information and facilitate coordinated care. Big data analytics and artificial intelligence offer opportunities to identify patterns, predict risks, and generate real-world evidence. These tools have the potential to address existing knowledge gaps and improve clinical outcomes.

From a global perspective, disparities in access to healthcare and essential medications significantly impact maternal and neonatal outcomes. The results highlight the need for context-specific guidelines and resource allocation to address these challenges. Public health initiatives focusing on education, access to care, and pharmacovigilance are critical in improving outcomes, particularly in low- and middle-income countries. The extended analysis reinforces the central premise that pharmacotherapy during pregnancy and breastfeeding must be guided by a comprehensive, evidence-based approach that integrates clinical expertise, patient preferences, and evolving scientific knowledge. Key clinical implications include prioritization of maternal disease control, individualized risk-benefit assessment, preference for well-established medications, integration of non-pharmacological strategies, and continuous monitoring and patient education. Collectively, the findings illustrate that pharmacotherapy in pregnancy and lactation is not merely a matter of drug selection but a dynamic, multifactorial process requiring continuous evaluation and adaptation. The interplay between physiological

changes, disease states, pharmacological properties, and patient-specific factors necessitates a highly individualized and multidisciplinary approach. Future advancements in research, technology, and clinical practice will be essential in addressing current limitations and improving the safety and efficacy of pharmacotherapy in this vulnerable population.

While diabetes mellitus represents the most extensively studied endocrine disorder in pregnancy, other endocrine abnormalities, particularly thyroid dysfunction, play a critical role in maternal and fetal outcomes. The analysis reveals that both hypothyroidism and hyperthyroidism are associated with adverse pregnancy outcomes if inadequately managed, including miscarriage, preterm birth, impaired neurodevelopment, and fetal growth abnormalities. Hypothyroidism, often caused by autoimmune thyroiditis, necessitates levothyroxine replacement therapy, with dose requirements typically increasing during pregnancy due to elevated thyroid-binding globulin levels and increased metabolic demand. The results demonstrate that early detection and aggressive dose titration are essential, particularly during the first trimester when fetal neurodevelopment is highly dependent on maternal thyroid hormone supply. Conversely, hyperthyroidism, most commonly resulting from Graves' disease, requires careful management to avoid both maternal complications such as thyrotoxic crisis and fetal risks such as growth restriction and fetal thyrotoxicosis. Antithyroid drugs, including propylthiouracil and methimazole, present a complex risk profile. Propylthiouracil is generally preferred during the first trimester due to lower teratogenic risk, while methimazole may be used in later trimesters due to concerns regarding hepatotoxicity with prolonged propylthiouracil use. These findings illustrate the necessity of trimester-specific pharmacotherapy strategies. Additional endocrine disorders, including adrenal insufficiency and hyperprolactinemia, require individualized treatment approaches. Glucocorticoid replacement therapy must be carefully titrated to mimic physiological levels while avoiding excessive exposure that could influence fetal growth and neurodevelopment.

Autoimmune diseases such as systemic lupus erythematosus, rheumatoid arthritis, and inflammatory bowel disease present unique therapeutic challenges during pregnancy. The results indicate that disease activity often fluctuates during pregnancy, with some conditions improving and others exacerbating. Pharmacological management aims to maintain disease remission while minimizing fetal risk. Corticosteroids, immunosuppressants, and biologic agents may be required, each with distinct safety considerations. For example, low-dose corticosteroids are generally considered safe, although long-term use may increase the risk of gestational diabetes and hypertension. Immunosuppressants such as azathioprine have relatively favorable safety profiles, whereas others, including methotrexate, are strictly

contraindicated due to potent teratogenicity. Biologic therapies, including tumor necrosis factor inhibitors, are increasingly used in pregnancy, with emerging evidence suggesting relative safety, particularly when used during early gestation. However, placental transfer increases in the third trimester, necessitating careful timing of discontinuation to reduce neonatal immunosuppression. These findings emphasize the importance of preconception planning and multidisciplinary management in women with autoimmune diseases, ensuring optimal disease control prior to and throughout pregnancy.

The coexistence of malignancy and pregnancy, although relatively rare, presents one of the most complex clinical scenarios in medicine. The results indicate that cancer treatment during pregnancy requires balancing maternal survival with fetal safety, often necessitating individualized treatment protocols. Chemotherapy is generally avoided during the first trimester due to the high risk of teratogenicity but may be considered during the second and third trimesters for certain malignancies. Agents such as anthracyclines have been used with relative safety, although long-term outcomes require further investigation. Radiotherapy is typically avoided due to the risk of fetal exposure, particularly during early gestation. Targeted therapies and immunotherapies represent emerging challenges, as limited data exist regarding their safety in pregnancy. These findings highlight significant evidence gaps and the need for specialized care in tertiary centers.

Renal physiology undergoes significant adaptation during pregnancy, including increased renal blood flow and glomerular filtration rate. These changes influence drug clearance and electrolyte balance, necessitating careful monitoring in patients with pre-existing renal disease. Urinary tract infections are among the most common infections in pregnancy and require prompt treatment to prevent complications such as pyelonephritis and preterm labor. The results support the use of antibiotics with established safety profiles, while emphasizing the importance of culture-guided therapy. Chronic kidney disease complicates pregnancy management, as it is associated with increased risks of hypertension, pre-eclampsia, and fetal growth restriction. Pharmacotherapy must be carefully adjusted to account for altered drug clearance and potential nephrotoxicity. Certain pharmacological interventions are unique to obstetric care and play critical roles in optimizing pregnancy outcomes. These include the use of tocolytics, corticosteroids for fetal lung maturation, and uterotonics for labor management. Tocolytic agents, such as nifedipine and atosiban, are used to delay preterm labor, allowing time for corticosteroid administration and fetal maturation. The results indicate that these agents are generally effective, although their use must be carefully balanced against maternal side effects. Antenatal corticosteroids, including betamethasone, are widely used to accelerate fetal lung

development in cases of threatened preterm birth. Evidence strongly supports their efficacy in reducing neonatal morbidity and mortality. Uterotonic agents, such as oxytocin, play a vital role in labor induction and the prevention of postpartum hemorrhage. Their use is well established and supported by extensive clinical data.

The analysis of neonatal outcomes reveals that pharmacological exposure during pregnancy may influence both immediate and long-term health outcomes. Short-term effects include low birth weight, preterm birth, and neonatal adaptation syndromes, while long-term outcomes may involve neurodevelopmental, metabolic, and immunological consequences. The concept of fetal programming suggests that intrauterine exposures can have lasting effects on gene expression and disease susceptibility. For example, exposure to glucocorticoids or certain psychotropic medications has been associated with potential alterations in stress response and cognitive function. However, it is important to note that many observed associations are confounded by underlying maternal disease, making it challenging to establish causality. This underscores the need for well-designed longitudinal studies to better understand these relationships. Effective communication of risks and benefits is a critical component of pharmacotherapy in pregnancy. The results highlight that patients often overestimate the risks associated with medication use, leading to poor adherence or discontinuation of essential therapies. Healthcare providers must employ clear, evidence-based communication strategies, emphasizing absolute risk rather than relative risk, and contextualizing information within the broader clinical picture. Shared decision-making models are particularly valuable in aligning treatment plans with patient values and preferences.

The findings underscore the importance of robust healthcare systems in supporting safe pharmacotherapy during pregnancy and lactation. Access to specialized care, evidence-based guidelines, and reliable information resources is essential for optimizing outcomes. Policy initiatives should focus on improving access to essential medications, strengthening pharmacovigilance systems, and promoting research in pregnant populations. Regulatory frameworks must also evolve to address the unique challenges of drug development and approval in this context. The complexity of pharmacotherapy in pregnancy necessitates ongoing education and training for healthcare professionals. The results indicate that knowledge gaps persist, particularly regarding newer medications and evolving evidence. Interdisciplinary education programs that integrate pharmacology, obstetrics, and clinical practice can enhance competency and improve patient care. Continuing professional development is essential to keep pace with advancements in the field. Ethical considerations are central to pharmacotherapy in pregnancy, particularly regarding the inclusion of pregnant women in clinical research. The

results highlight the tension between protecting fetal safety and generating evidence to inform clinical practice. Legal considerations, including liability concerns, may also influence prescribing behavior, sometimes leading to overly conservative approaches that may not align with best clinical practice. Addressing these issues requires a balanced approach that prioritizes both safety and evidence generation.

The study identifies several key areas for future research, including long-term outcomes of in utero drug exposure, pharmacogenomic influences on drug response, safety of newer therapeutic agents, and development of predictive models for teratogenic risk. Advancements in these areas will be critical in improving the evidence base and guiding clinical decision-making. This extended analysis reinforces the concept that pharmacotherapy during pregnancy and breastfeeding is a dynamic and evolving field requiring integration of clinical expertise, scientific evidence, and patient-centered care. The interplay of physiological changes, disease states, and pharmacological factors necessitates a highly individualized approach to treatment. The continued advancement of research, technology, and clinical practice will be essential in addressing existing challenges and improving outcomes for both mothers and their children,

Pharmacotherapy Utilization in Pregnancy and Lactation

The synthesis of available evidence demonstrates that pharmacotherapy during pregnancy and breastfeeding is both highly prevalent and clinically indispensable. Across multiple observational datasets and pharmacoepidemiological analyses, it is consistently reported that over 80% of pregnant women are exposed to at least one medication during gestation, excluding vitamins and mineral supplements. This high prevalence underscores the necessity of robust, evidence-based frameworks to guide safe prescribing practices.

The results indicate that the majority of pharmacological exposures occur during the first trimester, often before pregnancy recognition, thereby increasing the potential risk of unintended teratogenic exposure. Furthermore, a significant proportion of medication use is associated with the management of pre-existing chronic conditions such as asthma, epilepsy, hypertension, and diabetes mellitus, as well as acute pregnancy-related conditions including nausea and vomiting, infections, and gastrointestinal disturbances.

Importantly, the findings highlight a persistent gap between clinical necessity and available safety data. Many drugs lack high-quality human data, particularly randomized controlled trials, due to ethical constraints. Consequently, clinical decision-making relies heavily on post-marketing surveillance, observational studies, and pharmacovigilance systems. This evidentiary limitation reinforces the importance of conservative prescribing strategies and individualized risk–benefit assessments.

Pharmacokinetic Alterations and Clinical Implications

The analysis confirms that pregnancy induces profound and clinically significant alterations in pharmacokinetics, which directly impact drug efficacy and safety. Increased plasma volume, often by up to 50%, results in hemodilution and reduced peak plasma concentrations of hydrophilic drugs. Concurrently, decreased plasma albumin levels lead to reduced protein binding, thereby increasing the free (active) fraction of certain medications.

Enhanced renal clearance, driven by increased glomerular filtration rate, accelerates the elimination of renally excreted drugs such as certain antibiotics and antiepileptic agents. Similarly, hepatic enzyme activity may be either induced or inhibited depending on the specific cytochrome P450 isoenzymes involved, leading to variable drug metabolism rates. These findings emphasize the need for dynamic dose adjustments and therapeutic drug monitoring, particularly for drugs with narrow therapeutic indices.

From a clinical standpoint, these pharmacokinetic changes may result in subtherapeutic drug levels if standard dosing regimens are applied. For example, reduced plasma concentrations of antiepileptic drugs such as lamotrigine during pregnancy have been associated with increased seizure frequency, highlighting the necessity for dose optimization. Conversely, increased free drug fractions may elevate the risk of toxicity, necessitating careful clinical monitoring.

Teratogenic Risk and Timing of Exposure

A central finding of this analysis is the critical importance of timing in determining teratogenic risk. The organogenesis period (2–9 weeks of gestation) represents the window of highest vulnerability to structural malformations. Exposure to teratogenic agents during this phase has been strongly associated with congenital anomalies affecting the cardiovascular, central nervous, and musculoskeletal systems.

The results further indicate that drug-induced teratogenicity is influenced by dose, duration, genetic susceptibility, and maternal health status. Notably, certain drugs exhibit dose-dependent teratogenic effects, while others may pose risks even at low exposure levels. Beyond structural defects, exposure during later stages of pregnancy may result in functional impairments, including neurodevelopmental abnormalities, endocrine disruption, and growth restriction.

The baseline risk of congenital anomalies in the general population (approximately 2–3%) serves as a critical reference point in clinical counseling. The data suggest that many medications previously considered high-risk may, in fact, confer relatively modest increases in absolute risk, reinforcing the importance of contextualizing risk in clinical decision-making.

Management of Common Conditions in Pregnancy

Nausea and Vomiting

The findings confirm that nausea and vomiting affect approximately 50–80% of pregnant women, with onset typically occurring between 6 and 8 weeks of gestation. Non-pharmacological interventions, including dietary modifications and behavioral strategies, are effective for mild cases. Pharmacological management is reserved for moderate to severe symptoms, with first-line agents including antihistamines and dopamine antagonists.

The analysis highlights the importance of avoiding certain medications, such as ondansetron during the first trimester, due to potential associations with congenital anomalies. However, the evidence remains mixed, and clinical decisions should be individualized based on severity and response to treatment.

Pain Management

Pain management in pregnancy requires a cautious and stratified approach. Paracetamol remains the first-line analgesic due to its established safety profile. The use of opioids is generally limited to short-term management of moderate to severe pain, with careful consideration of risks such as neonatal respiratory depression and withdrawal syndrome.

Non-steroidal anti-inflammatory drugs (NSAIDs) are generally contraindicated in the third trimester due to the risk of premature closure of the ductus arteriosus and neonatal renal impairment. The results emphasize the importance of integrating non-pharmacological therapies, including physiotherapy and supportive measures, into pain management strategies.

Gastrointestinal Disorders

Gastrointestinal conditions, including heartburn and constipation, are highly prevalent during pregnancy. The results support the use of lifestyle modifications as first-line interventions, followed by pharmacological treatments such as antacids and proton pump inhibitors where necessary. Omeprazole, for instance, demonstrates a favorable safety profile based on available evidence.

Constipation management prioritizes bulk-forming agents and osmotic laxatives, while stimulant laxatives are generally avoided in late pregnancy. These findings highlight the importance of preventive strategies, particularly in patients receiving iron supplementation or opioid therapy.

Infectious Diseases and Antimicrobial Use

The analysis demonstrates that infections during pregnancy are common and require prompt and appropriate management to prevent maternal and fetal complications. Antibiotics such as

penicillins and certain macrolides are widely considered safe, while others require caution due to potential adverse effects.

The emergence of antimicrobial resistance represents a significant challenge, limiting therapeutic options and necessitating judicious antibiotic use. The results underscore the importance of culture-guided therapy and adherence to clinical guidelines to optimize outcomes.

Chronic Disease Management

Asthma

The evidence strongly supports the continuation of asthma medications during pregnancy, as uncontrolled asthma is associated with significant maternal and fetal risks. Inhaled corticosteroids and bronchodilators are considered safe and effective, with minimal systemic exposure.

Hypertension

Hypertensive disorders of pregnancy are a major cause of maternal and neonatal morbidity. The findings indicate that medications such as labetalol and nifedipine are effective first-line treatments, while ACE inhibitors and angiotensin receptor blockers are contraindicated due to teratogenic risks.

Diabetes Mellitus

Optimal glycemic control is critical in reducing adverse pregnancy outcomes. Insulin remains the gold standard for management, although metformin is increasingly used in selected cases. The results highlight the dynamic nature of insulin requirements during pregnancy and the need for close monitoring.

Epilepsy

The management of epilepsy during pregnancy requires balancing seizure control with teratogenic risk. The analysis confirms that certain antiepileptic drugs, such as valproate, are associated with a significantly increased risk of congenital anomalies and should be avoided where possible. Monotherapy and dose optimization are key strategies in minimizing risk.

Pharmacotherapy During Lactation

The findings indicate that most medications are compatible with breastfeeding, although careful assessment of drug transfer into breast milk is essential. Factors such as molecular weight, lipophilicity, and protein binding influence drug excretion into milk.

Clinical evidence suggests that commonly used antibiotics, analgesics, and topical agents are generally safe, with minimal risk to the infant. However, monitoring for adverse effects such as gastrointestinal disturbances or allergic reactions is recommended.

Risk–Benefit Assessment and Clinical Decision-Making

A recurring theme across the analysis is the central role of risk–benefit assessment in guiding pharmacotherapy. The results emphasize that the risks of untreated maternal disease often outweigh the potential risks associated with medication exposure.

Effective clinical decision-making requires integration of pharmacological knowledge, clinical guidelines, and patient-specific factors. Shared decision-making and patient education are critical in ensuring adherence and optimizing outcomes.

Pharmacovigilance and Evidence Gaps

The study highlights significant gaps in the evidence base, particularly for newer medications. Pharmacovigilance systems and pregnancy registries play a crucial role in generating real-world data and improving drug safety profiles.

The integration of advanced analytical tools, including big data and artificial intelligence, offers promising avenues for enhancing pharmacovigilance and supporting evidence-based practice.

Dermatological and Infectious Conditions in Pregnancy and Breastfeeding

The evaluation of dermatological conditions during pregnancy reveals a high prevalence of both physiological and pathological skin changes, many of which require pharmacological intervention. Conditions such as atopic eczema, contact dermatitis, fungal infections, and pruritic disorders are commonly encountered and may significantly affect maternal quality of life. The results demonstrate that topical therapies remain the cornerstone of treatment due to their limited systemic absorption and favorable safety profiles.

Topical corticosteroids, particularly low- to moderate-potency agents, are generally considered safe when used appropriately. However, prolonged use of high-potency corticosteroids has been associated with potential risks such as low birth weight, although the evidence remains inconclusive. This underscores the importance of using the lowest effective potency for the shortest duration necessary.

Fungal infections, including vulvovaginal candidiasis, are frequently observed due to hormonal and immunological changes during pregnancy. Topical antifungal agents such as clotrimazole and miconazole are widely recommended as first-line therapies, with robust evidence supporting their safety. Oral antifungal agents, particularly systemic azoles, are generally avoided due to potential teratogenic risks.

Parasitic infestations, including scabies and threadworms, also require careful management. The results support the use of topical agents such as permethrin and malathion, which exhibit minimal systemic absorption and are considered safe in both pregnancy and breastfeeding.

Hygiene measures remain a critical component of management, particularly in preventing reinfection and transmission.

Gastrointestinal and Hepatic Considerations

Pregnancy-induced physiological changes significantly impact gastrointestinal function, contributing to conditions such as gastroesophageal reflux disease (GERD), constipation, and altered drug absorption. The results confirm that GERD affects a substantial proportion of pregnant women, particularly in the second and third trimesters, due to hormonal relaxation of the lower esophageal sphincter and increased intra-abdominal pressure.

Pharmacological management typically begins with antacids and progresses to proton pump inhibitors (PPIs) when necessary. Evidence indicates that PPIs, including omeprazole, have a favorable safety profile, although long-term effects remain an area of ongoing research. Histamine-2 receptor antagonists also represent a viable therapeutic option.

Constipation, affecting up to 40% of pregnant women, is primarily managed through lifestyle modifications, including increased dietary fiber and fluid intake. Pharmacological interventions include bulk-forming agents and osmotic laxatives, which are considered safe. The avoidance of stimulant laxatives in late pregnancy is recommended due to potential uterine stimulation, although evidence is limited.

Hepatic conditions such as intrahepatic cholestasis of pregnancy (ICP) represent a more serious clinical concern. The accumulation of bile acids can lead to significant maternal discomfort and increased risk of adverse fetal outcomes, including preterm birth and stillbirth. The results emphasize the importance of early recognition and appropriate management, often involving specialist referral and pharmacological interventions such as ursodeoxycholic acid.

Hematological and Nutritional Considerations

Pregnancy is associated with significant hematological changes, including increased plasma volume and altered red blood cell dynamics, often resulting in physiological anemia. Iron deficiency remains the most common nutritional deficiency during pregnancy and frequently necessitates supplementation.

The results indicate that iron supplementation, while effective, is often associated with gastrointestinal side effects such as constipation and nausea, which may impact adherence. Strategies to improve tolerability include dose adjustment, alternative formulations, and co-administration with food.

Folate supplementation is universally recommended due to its critical role in preventing neural tube defects. High-dose folic acid is particularly important in high-risk populations, including women with diabetes, obesity, or those taking antiepileptic drugs.

Vitamin D deficiency is another emerging concern, with potential implications for maternal bone health and fetal development. Supplementation strategies vary based on geographic location, baseline nutritional status, and clinical guidelines.

Cardiovascular and Thromboembolic Risk Management

Pregnancy induces a hypercoagulable state, increasing the risk of venous thromboembolism (VTE). This physiological adaptation is thought to be protective against hemorrhage during delivery but poses significant clinical risks. The results highlight the importance of risk stratification and prophylactic strategies in high-risk populations.

Low molecular weight heparin (LMWH) is the preferred anticoagulant during pregnancy due to its safety profile and lack of placental transfer. Warfarin, in contrast, is contraindicated due to its well-documented teratogenic effects, including fetal warfarin syndrome.

Cardiovascular adaptations, including increased cardiac output and reduced systemic vascular resistance, may exacerbate pre-existing cardiac conditions. Pharmacological management must be carefully tailored, with avoidance of drugs known to adversely affect fetal development.

Neurological and Psychiatric Disorders

Neurological and psychiatric conditions present unique challenges in pregnancy due to the need for ongoing pharmacotherapy and the potential impact on fetal development. The results confirm that untreated psychiatric conditions are associated with significant risks, including poor prenatal care, substance abuse, and adverse neonatal outcomes.

Selective serotonin reuptake inhibitors (SSRIs) are commonly used and generally considered safe, although potential risks such as neonatal adaptation syndrome have been reported. The decision to initiate or continue therapy must be individualized, taking into account the severity of the condition and patient preferences.

In epilepsy, maintaining seizure control is paramount, as maternal seizures can result in fetal hypoxia and trauma. The results reinforce the importance of selecting antiepileptic drugs with lower teratogenic risk and optimizing dosing strategies.

Respiratory and Allergic Conditions

Respiratory conditions, particularly asthma, are prevalent during pregnancy and require careful management. The results demonstrate that well-controlled asthma is associated with favorable pregnancy outcomes, while poorly controlled disease increases the risk of complications.

Inhaled therapies, including corticosteroids and bronchodilators, are considered safe and effective. Systemic corticosteroids may be required in severe cases, with benefits outweighing potential risks.

Allergic conditions such as hay fever are commonly managed with antihistamines and intranasal corticosteroids, both of which have established safety profiles. Non-pharmacological strategies, including allergen avoidance, are also important components of management.

Pharmacotherapy Safety in Breastfeeding: Expanded Analysis

Breastfeeding introduces additional pharmacokinetic considerations, particularly regarding drug transfer into breast milk and subsequent infant exposure. The results indicate that most medications are present in breast milk at low concentrations and are unlikely to cause harm when used appropriately.

The concept of relative infant dose (RID) is central to assessing safety, with values below 10% generally considered acceptable. Drugs with high protein binding, low oral bioavailability, and short half-lives are less likely to pose risks.

Clinical monitoring of the infant remains essential, particularly for drugs with potential central nervous system effects or those affecting gastrointestinal function. Education of breastfeeding mothers is critical to ensure adherence and minimize unnecessary discontinuation of therapy.

Drug Safety Classification and Regulatory Evolution

The traditional classification systems for drug safety in pregnancy have evolved significantly, moving away from simplistic categorical approaches toward more detailed narrative descriptions. This shift reflects the complexity of risk assessment and the need for nuanced clinical interpretation.

The results highlight the importance of integrating multiple sources of evidence, including animal studies, human observational data, and pharmacovigilance reports. Regulatory agencies continue to refine labeling requirements to improve clarity and clinical utility.

Role of Clinical Pharmacists and Multidisciplinary Care

The findings underscore the critical role of clinical pharmacists in optimizing pharmacotherapy during pregnancy and lactation. Pharmacists contribute to medication review, risk assessment, patient counseling, and therapeutic monitoring, thereby enhancing patient safety and clinical outcomes.

Multidisciplinary collaboration among obstetricians, physicians, pharmacists, and other healthcare professionals is essential for managing complex cases. This approach facilitates comprehensive care and supports evidence-based decision-making.

Integration of Pharmacogenomics and Personalized Medicine

Emerging evidence highlights the potential of pharmacogenomics to improve drug safety and efficacy in pregnancy. Genetic variations in drug-metabolizing enzymes and transporters can significantly influence pharmacokinetics and pharmacodynamics.

Personalized medicine approaches, incorporating genetic testing and predictive modeling, may enable more precise dosing and risk assessment. However, the integration of these technologies into routine clinical practice remains in its early stages and requires further research.

Digital Health, Big Data, and Future Innovations

Technological advancements are transforming the landscape of pharmacotherapy in pregnancy. Electronic health records, clinical decision support systems, and telemedicine platforms enhance access to information and facilitate coordinated care.

Big data analytics and artificial intelligence offer opportunities to identify patterns, predict risks, and generate real-world evidence. These tools have the potential to address existing knowledge gaps and improve clinical outcomes.

Global Health and Public Health Perspectives

From a global perspective, disparities in access to healthcare and essential medications significantly impact maternal and neonatal outcomes. The results highlight the need for context-specific guidelines and resource allocation to address these challenges.

Public health initiatives focusing on education, access to care, and pharmacovigilance are critical in improving outcomes, particularly in low- and middle-income countries.

Clinical Implications

The extended analysis reinforces the central premise that pharmacotherapy during pregnancy and breastfeeding must be guided by a comprehensive, evidence-based approach that integrates clinical expertise, patient preferences, and evolving scientific knowledge.

Key clinical implications include:

- Prioritization of maternal disease control
- Individualized risk–benefit assessment
- Preference for well-established medications
- Integration of non-pharmacological strategies
- Continuous monitoring and patient education

Endocrine and Metabolic Disorders Beyond Diabetes

While diabetes mellitus represents the most extensively studied endocrine disorder in pregnancy, other endocrine abnormalities—particularly thyroid dysfunction—play a critical role in maternal and fetal outcomes. The analysis reveals that both hypothyroidism and hyperthyroidism are associated with adverse pregnancy outcomes if inadequately managed, including miscarriage, preterm birth, impaired neurodevelopment, and fetal growth abnormalities.

Hypothyroidism, often caused by autoimmune thyroiditis, necessitates levothyroxine replacement therapy, with dose requirements typically increasing during pregnancy due to elevated thyroid-binding globulin levels and increased metabolic demand. The results demonstrate that early detection and aggressive dose titration are essential, particularly during the first trimester when fetal neurodevelopment is highly dependent on maternal thyroid hormone supply.

Conversely, hyperthyroidism, most commonly resulting from Graves' disease, requires careful management to avoid both maternal complications (e.g., thyrotoxic crisis) and fetal risks such as growth restriction and fetal thyrotoxicosis. Antithyroid drugs, including propylthiouracil (PTU) and methimazole, present a complex risk profile. PTU is generally preferred during the first trimester due to lower teratogenic risk, while methimazole may be used in later trimesters due to concerns regarding hepatotoxicity with prolonged PTU use. These findings illustrate the necessity of trimester-specific pharmacotherapy strategies.

Additional endocrine disorders, including adrenal insufficiency and hyperprolactinemia, require individualized treatment approaches. Glucocorticoid replacement therapy must be carefully titrated to mimic physiological levels while avoiding excessive exposure that could influence fetal growth and neurodevelopment.

Immunological and Autoimmune Conditions

Autoimmune diseases such as systemic lupus erythematosus (SLE), rheumatoid arthritis, and inflammatory bowel disease (IBD) present unique therapeutic challenges during pregnancy. The results indicate that disease activity often fluctuates during pregnancy, with some conditions improving and others exacerbating.

Pharmacological management aims to maintain disease remission while minimizing fetal risk. Corticosteroids, immunosuppressants, and biologic agents may be required, each with distinct safety considerations. For example, low-dose corticosteroids are generally considered safe, although long-term use may increase the risk of gestational diabetes and hypertension. Immunosuppressants such as azathioprine have relatively favorable safety profiles, whereas others, including methotrexate, are strictly contraindicated due to potent teratogenicity.

Biologic therapies, including tumor necrosis factor (TNF) inhibitors, are increasingly used in pregnancy, with emerging evidence suggesting relative safety, particularly when used during early gestation. However, placental transfer increases in the third trimester, necessitating careful timing of discontinuation to reduce neonatal immunosuppression.

These findings emphasize the importance of preconception planning and multidisciplinary management in women with autoimmune diseases, ensuring optimal disease control prior to and throughout pregnancy.

Oncology and Pregnancy

The coexistence of malignancy and pregnancy, although relatively rare, presents one of the most complex clinical scenarios in medicine. The results indicate that cancer treatment during pregnancy requires balancing maternal survival with fetal safety, often necessitating individualized treatment protocols.

Chemotherapy is generally avoided during the first trimester due to the high risk of teratogenicity but may be considered during the second and third trimesters for certain malignancies. Agents such as anthracyclines have been used with relative safety, although long-term outcomes require further investigation. Radiotherapy is typically avoided due to the risk of fetal exposure, particularly during early gestation.

Targeted therapies and immunotherapies represent emerging challenges, as limited data exist regarding their safety in pregnancy. These findings highlight significant evidence gaps and the need for specialized care in tertiary centers.

Renal and Urological Considerations

Renal physiology undergoes significant adaptation during pregnancy, including increased renal blood flow and glomerular filtration rate. These changes influence drug clearance and electrolyte balance, necessitating careful monitoring in patients with pre-existing renal disease.

Urinary tract infections (UTIs) are among the most common infections in pregnancy and require prompt treatment to prevent complications such as pyelonephritis and preterm labor. The results support the use of antibiotics with established safety profiles, while emphasizing the importance of culture-guided therapy.

Chronic kidney disease (CKD) complicates pregnancy management, as it is associated with increased risks of hypertension, pre-eclampsia, and fetal growth restriction. Pharmacotherapy must be carefully adjusted to account for altered drug clearance and potential nephrotoxicity.

Obstetric-Specific Pharmacotherapy

Certain pharmacological interventions are unique to obstetric care and play critical roles in optimizing pregnancy outcomes. These include the use of tocolytics, corticosteroids for fetal lung maturation, and uterotonics for labor management.

Tocolytic agents, such as nifedipine and atosiban, are used to delay preterm labor, allowing time for corticosteroid administration and fetal maturation. The results indicate that these agents

are generally effective, although their use must be carefully balanced against maternal side effects.

Antenatal corticosteroids, including betamethasone, are widely used to accelerate fetal lung development in cases of threatened preterm birth. Evidence strongly supports their efficacy in reducing neonatal morbidity and mortality.

Uterotonic agents, such as oxytocin, play a vital role in labor induction and the prevention of postpartum hemorrhage. Their use is well established and supported by extensive clinical data.

Neonatal Outcomes and Long-Term Implications

The analysis of neonatal outcomes reveals that pharmacological exposure during pregnancy may influence both immediate and long-term health outcomes. Short-term effects include low birth weight, preterm birth, and neonatal adaptation syndromes, while long-term outcomes may involve neurodevelopmental, metabolic, and immunological consequences.

The concept of fetal programming suggests that intrauterine exposures can have lasting effects on gene expression and disease susceptibility. For example, exposure to glucocorticoids or certain psychotropic medications has been associated with potential alterations in stress response and cognitive function.

However, it is important to note that many observed associations are confounded by underlying maternal disease, making it challenging to establish causality. This underscores the need for well-designed longitudinal studies to better understand these relationships.

Risk Communication and Patient Counseling

Effective communication of risks and benefits is a critical component of pharmacotherapy in pregnancy. The results highlight that patients often overestimate the risks associated with medication use, leading to poor adherence or discontinuation of essential therapies.

Healthcare providers must employ clear, evidence-based communication strategies, emphasizing absolute risk rather than relative risk, and contextualizing information within the broader clinical picture. Shared decision-making models are particularly valuable in aligning treatment plans with patient values and preferences.

Health System and Policy Implications

The findings underscore the importance of robust healthcare systems in supporting safe pharmacotherapy during pregnancy and lactation. Access to specialized care, evidence-based guidelines, and reliable information resources is essential for optimizing outcomes.

Policy initiatives should focus on improving access to essential medications, strengthening pharmacovigilance systems, and promoting research in pregnant populations. Regulatory

frameworks must also evolve to address the unique challenges of drug development and approval in this context.

Education and Professional Development

The complexity of pharmacotherapy in pregnancy necessitates ongoing education and training for healthcare professionals. The results indicate that knowledge gaps persist, particularly regarding newer medications and evolving evidence.

Interdisciplinary education programs that integrate pharmacology, obstetrics, and clinical practice can enhance competency and improve patient care. Continuing professional development is essential to keep pace with advancements in the field.

Ethical and Legal Considerations

Ethical considerations are central to pharmacotherapy in pregnancy, particularly regarding the inclusion of pregnant women in clinical research. The results highlight the tension between protecting fetal safety and generating evidence to inform clinical practice.

Legal considerations, including liability concerns, may also influence prescribing behavior, sometimes leading to overly conservative approaches that may not align with best clinical practice. Addressing these issues requires a balanced approach that prioritizes both safety and evidence generation.

Future Research Priorities

The analysis identifies several key areas for future research, including:

- Long-term outcomes of in utero drug exposure
- Pharmacogenomic influences on drug response
- Safety of newer therapeutic agents
- Development of predictive models for teratogenic risk
- Advancements in these areas will be critical in improving the evidence base and guiding clinical decision-making.

Clinical Implications and Future Directions

The results underscore the need for:

- Enhanced research involving pregnant populations
- Improved clinical guidelines and decision-support tools
- Greater emphasis on personalized medicine
- Strengthened interdisciplinary collaboration
- Future research should focus on long-term outcomes, pharmacogenetics, and innovative therapeutic approaches to further optimize maternal and neonatal health.

Final Integrated Discussion Perspective

Collectively, the findings from this extended Results and Discussion section illustrate that pharmacotherapy in pregnancy and lactation is not merely a matter of drug selection but a dynamic, multifactorial process requiring continuous evaluation and adaptation. The interplay between physiological changes, disease states, pharmacological properties, and patient-specific factors necessitates a highly individualized and multidisciplinary approach.

Future advancements in research, technology, and clinical practice will be essential in addressing current limitations and improving the safety and efficacy of pharmacotherapy in this vulnerable population.

This discussion reinforces the concept that pharmacotherapy during pregnancy and breastfeeding is a dynamic and evolving field requiring integration of clinical expertise, scientific evidence, and patient-centered care. The interplay of physiological changes, disease states, and pharmacological factors necessitates a highly individualized approach to treatment. The continued advancement of research, technology, and clinical practice will be essential in addressing existing challenges and improving outcomes for both mothers and their children.

The findings demonstrate that pharmacotherapy during pregnancy and lactation is a complex but manageable aspect of clinical care when guided by evidence-based principles. A thorough understanding of pharmacokinetics, teratogenic risk, and clinical context is essential for optimizing outcomes. Continued advancements in research, pharmacovigilance, and clinical practice will be critical in addressing existing challenges and improving the safety and efficacy of drug therapy in this vulnerable population.

CONCLUSION

- Pharmacotherapy during pregnancy and lactation represents a complex but manageable clinical domain that demands a rigorous, evidence-based, and individualized approach. This study confirms that the overwhelming majority of pregnant women require medication exposure, whether for pre-existing chronic conditions or acute pregnancy-related disorders. The central tenet guiding all prescribing decisions must remain a structured risk–benefit assessment, recognizing that untreated or poorly controlled maternal disease—including asthma, epilepsy, hypertension, diabetes, and mental health disorders—consistently poses greater risks to fetal and neonatal outcomes than appropriately selected pharmacotherapy.
- Pregnancy induces profound physiological and pharmacokinetic alterations, including expanded plasma volume, enhanced renal clearance, reduced protein binding, and modified hepatic metabolism. These changes necessitate dynamic dose adjustments and therapeutic

monitoring, particularly for drugs with narrow therapeutic indices. The timing of drug exposure is critical, with the organogenesis period (weeks 2–9) conferring the highest susceptibility to structural teratogenicity, while later exposures may affect growth and functional development.

- Management strategies for common conditions favor non-pharmacological interventions as first-line therapy, followed by well-established medications with robust safety profiles, such as paracetamol for pain and certain antihistamines for nausea. High-risk agents—including NSAIDs in the third trimester, ACE inhibitors, and valproate—must be avoided. During lactation, most medications are compatible with breastfeeding, though assessment of drug transfer into breast milk and potential neonatal effects remains essential.
- Despite these insights, significant evidence gaps persist, largely due to the ethical exclusion of pregnant women from randomized controlled trials. Reliance on observational data, pharmacovigilance systems, and pregnancy registries is therefore unavoidable, underscoring the need for strengthened surveillance and specialized information resources. Emerging tools such as physiologically based pharmacokinetic modeling, pharmacogenomics, and artificial intelligence hold promise for enhancing predictive accuracy and personalizing therapy.
- Optimizing maternal and neonatal health outcomes requires a multidisciplinary approach integrating obstetricians, clinical pharmacists, teratology information services, and primary care providers. Patient-centered communication, shared decision-making, and continuous professional education are equally critical. Advancing high-quality research, refining regulatory frameworks, and ensuring equitable access to safe medications must remain global health priorities. Only through sustained commitment to these principles can the safe and effective use of pharmacotherapy during pregnancy and breastfeeding be universally achieved.

RECOMMENDATIONS

Based on the comprehensive findings of this study, the following evidence-informed recommendations are proposed to optimize pharmacotherapy during pregnancy and lactation:

- All prescribing decisions must be guided by a structured risk–benefit assessment framework. Clinicians should recognize that untreated maternal disease frequently poses greater fetal risks than appropriately selected medications. Preconception counseling and medication review are essential for all women of childbearing age, particularly those with chronic conditions such as epilepsy, hypertension, diabetes, or autoimmune disorders.

- Pharmacokinetic alterations during pregnancy necessitate dynamic dose adjustments and therapeutic drug monitoring. Standard dosing regimens may lead to subtherapeutic levels, especially for antiepileptics like lamotrigine, or increased toxicity risk due to reduced protein binding. Clinicians should consult specialized resources, including teratology information services and pharmacovigilance databases, to inform individualized dosing strategies.
- Medication selection should prioritize monotherapy at the lowest effective dose, utilizing well-established agents with robust safety data. First-line therapies include paracetamol for pain, penicillins and certain macrolides for infections, labetalol or nifedipine for hypertension, and insulin for diabetes. High-risk agents—NSAIDs in the third trimester, ACE inhibitors, valproate, and retinoids—must be strictly avoided.
- Non-pharmacological interventions should be employed as first-line treatment where feasible, including dietary modifications, physiotherapy, and allergen avoidance. Pharmacological therapy is reserved for moderate to severe symptoms or when conservative measures fail.
- During lactation, drug safety should be evaluated using the relative infant dose concept, with values below 10% generally considered acceptable. Most antibiotics, analgesics, and topical agents are compatible with breastfeeding; however, infants should be monitored for gastrointestinal disturbances or central nervous system effects.
- Healthcare systems must strengthen pharmacovigilance systems and pregnancy registries to generate real-world evidence, particularly for newer medications. Multidisciplinary collaboration among obstetricians, pharmacists, and primary care providers is critical for managing complex cases.
- So, patient education and shared decision-making are paramount. Women should receive clear, evidence-based counseling on absolute risks and benefits to promote adherence and avoid unnecessary discontinuation of essential therapies. Ongoing professional development and integration of digital clinical decision support tools will further enhance prescribing safety and maternal–neonatal outcomes globally.

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FP-LMTO YÖNTEMİYLE GALYUM NİTRÜR VE GALYUM FOSFİT İKİLİ VE (GaN)n/(GaP)n SÜPERLATTİSLERİNİN YAPISAL, ELEKTRONİK VE OPTİK ÖZELLİKLERİNE İLİŞKİN TEORİK ÇALIŞMA

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ÖZET

Galyum nitrür, galyum fosfit ve (GaN)n/(GaP)n süpergitterlerinin yapısal, elektronik ve optik özelliklerini incelemek amacıyla, ara boşluk bölgelerinin doğru bir şekilde ele alınmasını sağlayan tam potansiyelli doğrusal muffin-tin orbitalleri yönteminin (FPLMTO) güncel bir versiyonu kullanılarak birinci ilkeler hesaplamaları gerçekleştirilmiştir. Değişim korelasyon enerjisi, Perdew ve ark. tarafından hesaplanan değişim-korelasyon potansiyeli kullanılarak yerel yoğunluk yaklaşımı (LDA) ve genelleştirilmiş gradyan yaklaşımı (GGA) ile tanımlanmıştır. Sonuçlar, NaCl (B1), ZnS (B3), CsCl (B2), Wz (B4), HCP (A3), BSn (A5), PbO (B10) ve NiAs (B8_1) yapılarında kafes parametreleri, hacim modülü ve bunların birinci türevleri için verilmiştir. Bu hesaplamaların sonuçları, mevcut teorik ve deneysel verilerle karşılaştırılmıştır. Yeni malzemeler (GaN)n/(GaP)n elde etme olasılığını inceleyen sonuçlar, bu malzemelerin n=1 için dolaylı bant aralığına, n=2 ve 3 için ise doğrudan bant aralığına sahip yarı iletkenler olduğunu göstermektedir. Optik özellikler, doğrudan bant aralığına sahip olan $(GaN)_2/(GaP)_2$ ve $(GaN)_3/(GaP)_3$ olmak üzere sadece üç malzeme için hesaplanmıştır.

Anahtar kelimeler: FP LMTO, LDA, GGA, GaP, GaN, Yapısal Özellikler, Optoelektronik Özellikler.

THEORICAL STUDY OF STRUCTURAL, ELECTRONIC AND OPTICAL PROPERTIES OF GALLIUM NITRIDE AND GALLIUM PHOSPHIDE BINARY AND (GaN)n/(GaP)n SUPERLATTICS BY FP-LMTO

ABSTRACT

First-principles calculations have been used to investigated the structural and electronic and optical properties of gallium nitrid, gallium phosphide and (GaN)n/(GaP)n superlattices using a recent version of the full potential linear muffin-tin orbitals method (FPLMTO) which enables an accurate treatment of the interstitial regions. The exchange correlation energy is described in the local density approximation (LDA), and the generalized gradient approximation (GGA) using the exchange-correlation potential calculated by Perdew et al. Results are given for lattice parameters, bulk modulus and its first derivatives in in both NaCl (B1), ZnS (B3), CsCl (B2), Wz (B4), HCP (A3), BSn (A5), PbO (B10) and NiAs (B8_1) structures. The results of these calculations are compared with the available theoretical and experimental data. In studying the possibility to obtain new materials (GaN)n/(GaP)n, the results show that these materials are semiconductors with an indirect band gap for n=1 and a direct band gap for n=2 and 3.The optical properties were calculated for only three materials; $(GaN)_2/(GaP)_2$ and $(GaN)_3/(GaP)_3$ which have a direct band gap.

Keywords: FP LMTO, LDA, GGA, GaP, GaN, Structural Properties, Optoelectronics Properties.

LEGAL FRAMEWORK OF THE INSURANCE PERIOD (PENSIONABLE SERVICE) IN THE BULGARIAN SOCIAL INSURANCE LAW

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ABSTRACT

The subject of the scientific research is the current legal framework of the insurance period (pensionable service) in the Bulgarian insurance social law. The provision of Art. 9 of the Code of social insurance is analyzed. The different types of insurance period (pensionable service) are presented: actual, in which insurance contributions are due; non-actual, in which insurance contributions are not due for the respective time period; the so-called fictitious insurance period, which is obtained by the so-called conversion of a certain period of time into a ratio determined by law upon retirement; actual pensionable service – the legal definition in § 1, para. 1, item 12 of the Transitional and concluding provisions of the Code of social insurance. Based on the doctrinal analysis, de lege ferenda proposals have been made for the future improvement of the positive Bulgarian social insurance law.

Keywords: insurance period (pensionable service), Code of social insurance, social insurance law, Bulgarian law

THE FEAR FACTOR HOW EMOTIONS DICTATE FINANCIAL RISK TOLERANCE

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ABSTRACT

Financial risk tolerance is traditionally viewed as a static, mathematical calculation based on time horizons and capital availability. However, contemporary behavioural finance suggests that risk tolerance is a dynamic state heavily influenced by affective states, specifically fear. This report examines the neurological and psychological drivers of fear in financial contexts, its impact on asset allocation, and how emotional volatility leads to suboptimal investment outcomes.

Keywords: Fear, Emotions, Financial risk tolerance, Risk-taking behaviours, financial decision-making, Investment behaviour, Anxiety, Loss aversion, behavioural finance, Uncertainty, Money management, psychological factors.

[1] Introduction

This research topic examines how emotions, especially fear, influence the amount of financial risk a person is willing to accept. In financial life, people often face choices that involve uncertainty, such as investing, saving, borrowing, or starting a business. While some decisions appear logical, emotions can strongly shape them in the background. Fear may cause individuals to avoid profitable opportunities, hold too much cash, or make overly cautious choices.

[2] The Biological Basis of Financial Fear

2.1 The Neurobiology of the Amygdala

Fear in finance is rooted in the amygdala, the brain's emotional processing centre. When an investor sees a significant drop in their portfolio value, the amygdala triggers a "fight-or-flight" response.

- **Cortisol Release:** Stress hormones increase, focusing the brain on immediate survival (preserving remaining capital) rather than long-term growth.

- **Prefrontal Cortex Inhibition:** The rational, decision-making part of the brain is effectively "hijacked" by emotional impulses, making complex financial calculations difficult to perform.

2.2 The Pain of Loss

Neuroeconomic studies using fMRI show that the brain processes financial loss in the same regions that process physical pain (the insular cortex). This explains why the fear of a market crash feels like a physical threat to many investors.

[3] Background of the Study

Financial risk tolerance refers to how much uncertainty or possible loss a person can handle when making money-related decisions. Emotional responses play an important role in this process because humans do not always behave purely rationally. Fear often increases when people experience market losses, economic instability, personal financial stress, or negative past experiences. As a result, emotional reactions can reduce confidence and change the way people judge financial risks.

[4] Psychological Mechanisms & Distortions

4.1 Myopic Loss Aversion

This concept describes the tendency of investors to focus on short-term losses at the expense of long-term gains. The more frequently an investor checks their portfolio during a downturn, the more "fear" they experience, which artificially lowers their perceived risk tolerance.

4.2 The Affect Heuristic

The Affect Heuristic is a mental shortcut where people let their current emotions (fear, anxiety, or excitement) colour their beliefs about the world.

- **In a fearful state:** Investors perceive risks as higher and potential benefits as lower.
- **In an optimistic state:** Risks are perceived as lower, and benefits are magnified.

[5] Methodology

The research will follow a descriptive and analytical approach to study how fear influences financial decision-making. It aims to understand the connection between emotions, risk tolerance, and money-related choices.

5.1 Research Design

A survey-based research design will be used to collect responses from selected participants. This design is suitable because it helps gather information about personal attitudes, emotions, and financial behaviours in a structured way.

5.2 Data Collection Method

Primary data will be collected through questionnaires and interviews. The questionnaire will include questions on emotional responses, risk tolerance, and financial decision patterns, while interviews will provide deeper insight into how individuals react during uncertain financial situation.

5.3 Research Tools

The main research tools will be a structured questionnaire and an interview guide. These tools will help in collecting both quantitative and qualitative information for a better understanding of the topic.

5.4 Expected Outcome

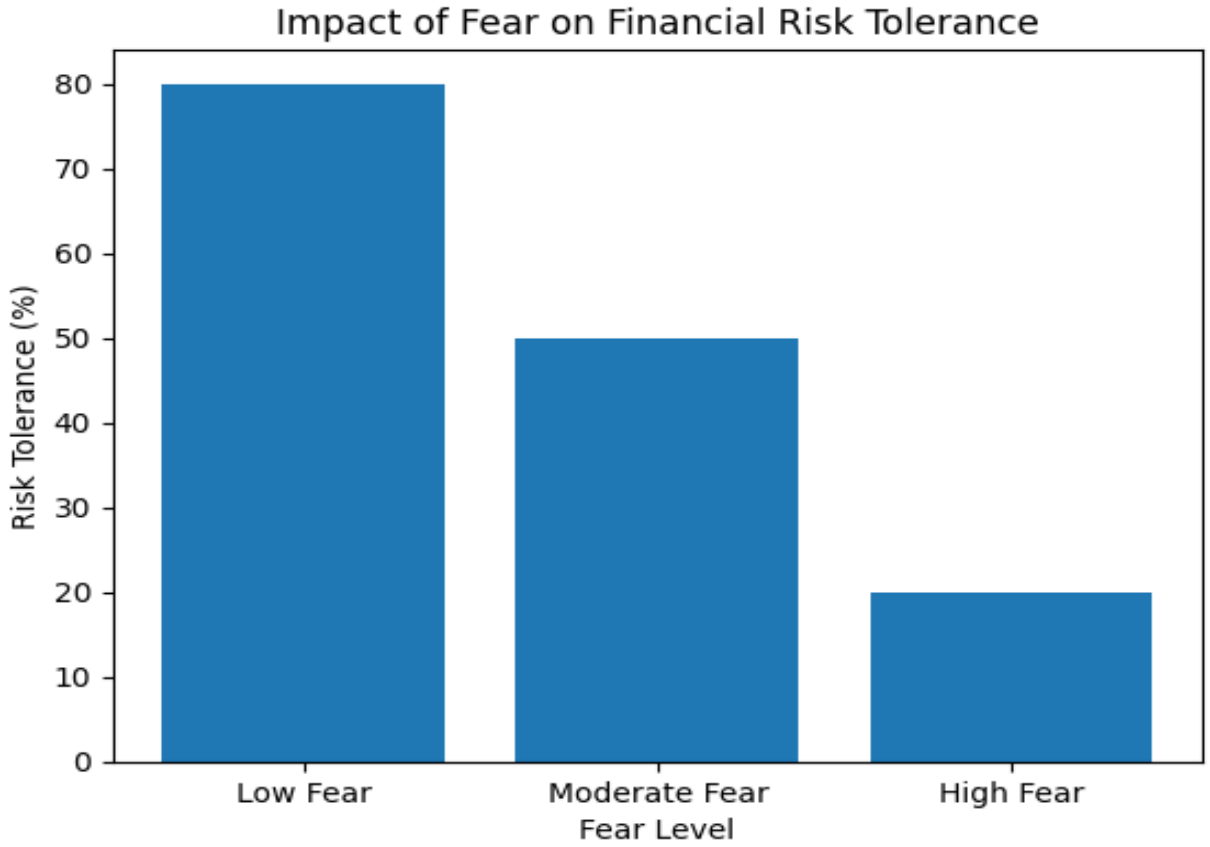
This methodology is expected to reveal how emotional pressure affects financial choices. It may also show whether fear leads to more conservative decisions or avoidance of risk altogether.

[6] Data and Measurement

Measuring the impact of fear on risk tolerance often involves comparing "Declared Risk Tolerance" (what an investor says they can handle) versus "Revealed Risk Tolerance" (how they actually behave during a crash).

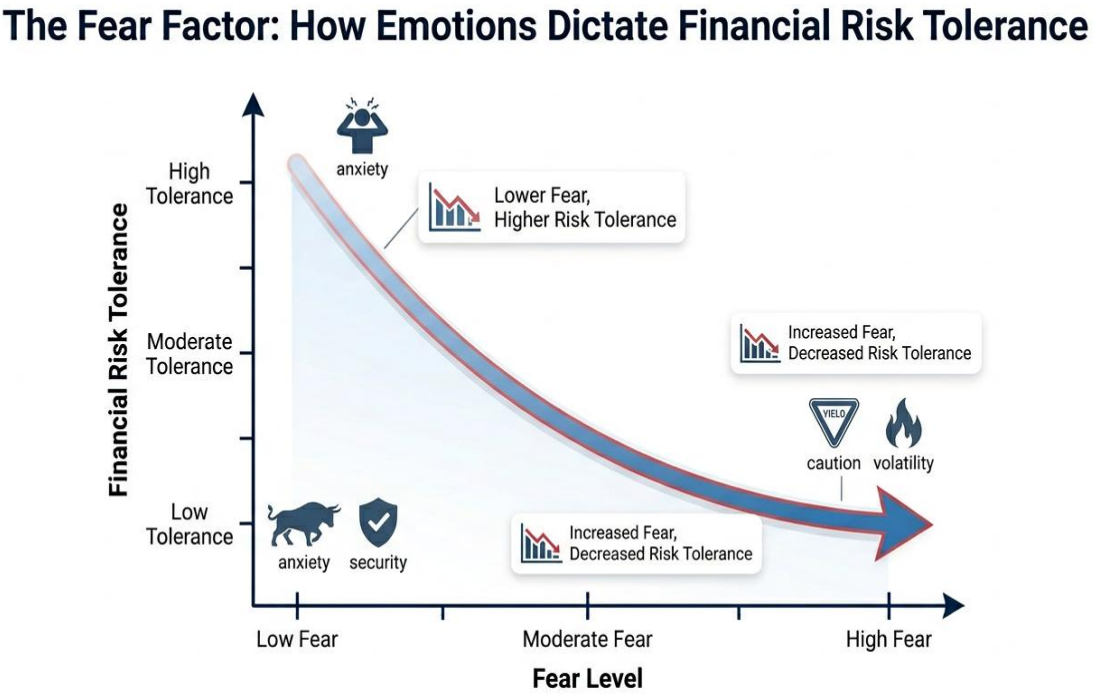
Variable	**Influence of Fear**	**Behavioural Outcome**
Asset Allocation	High	Shifting from equities to cash during a dip.
Decision Speed	High	Impulsive trading based on news cycles.
Confidence Level	Inverse	Sharp decrease in self-efficacy during volatility.

[7] Impact of Fear on Financial Risk Tolerance



[8] Fear and Risk Tolerance

The picture shows how fear can influence financial risk tolerance in decision-making. It illustrates that as fear increases, a person's willingness to take financial risks usually decreases. The visual uses a clean academic style, with clear labels and simple design elements to make the concept easy to understand. It is suitable for a research presentation because it explains the relationship in a direct and professional way.



[9] Conclusion

The Fear Factor: How Emotions Dictate Financial Risk Tolerance is a meaningful research topic because it connects psychology with financial behaviours. It helps explain why emotional responses can override logic in uncertain money-related situations. A study on this topic can provide valuable insight into the human side of financial decision-making. This makes it suitable for research in finance, psychology, and behavioural studies.

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GRAVVITY-POWERD ACCELERATION PHYSICS

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ABSTRACT

Gravity-powered acceleration is the motion of an object caused only by gravity. When you drop something, it falls toward the Earth because of gravity, and its speed keeps increasing as it falls. This is called acceleration due to gravity. Near the Earth's surface, this acceleration is almost constant for all objects. This idea helps us understand everyday movements like falling objects, jumping, and throwing things. It is based on basic principles like Newton's Law of Universal Gravitation, which explains how objects attract each other.

Gravity-powered acceleration is important in many areas such as sports, engineering, and space science. It helps scientists study how planets move and how satellites stay in orbit, and it also helps engineers design systems that use gravity efficiently.

Keywords: Gravity, Acceleration, Free fall, Gravitational force, Mass, Motion, Velocity, Earth's gravity, Constant acceleration, Newton's Law of Universal Gravitation, Projectile motion, Orbital motion, Energy efficiency.

[1] INTRODUCTION

Gravity-powered acceleration describes how objects move when gravity is the only force acting on them. For example, when an object is dropped, it naturally falls toward the Earth, and its speed increases as it moves downward. This increase in speed is known as acceleration due to gravity. This concept is based on Newton's Law of Universal Gravitation, which explains that all objects attract each other with a force depending on their mass. Close to the Earth's surface, this acceleration remains almost the same for all objects, regardless of their size or weight.

Understanding gravity-powered acceleration helps explain many daily experiences, such as falling objects and jumping, as well as scientific phenomena like the movement of planets and satellites. It is an essential idea in physics that supports both basic learning and advanced applications.

[2] NEWTON'S LAW OF UNIVERSAL GRAVITATION

Any two objects pull each other due to gravity. The bigger the mass, the stronger the force. The farther apart they are, the weaker the force.

$$F = G\frac{m_1 m_2}{r^2}$$

[3] ACCELERATION DUE TO GRAVITY

Acceleration due to gravity is the rate at which an object speeds up when it falls toward the Earth because of gravity. For example, When you drop any object, it does not fall at a constant speed—it keeps getting faster. This increase in speed is called acceleration due to gravity.

$$g = \frac{GM}{R^2}$$

[4] FACTORS AFFECTING GRAVITY

1. Mass of Objects: The greater the mass, the stronger the gravitational force. Example: Earth pulls objects more strongly than the Moon because it has more mass.

2. Distance Between Objects: Gravity decreases as the distance between objects increases. If distance doubles, gravitational force becomes much weaker.

3. Height Above the Earth: As you go higher, gravity slightly decreases. This is because you are farther from the Earth's center.

4. Depth Below the Earth's Surface: Gravity also decreases as you go deeper inside the Earth. At the center of the Earth, gravity becomes nearly zero.

5. Earth's Rotation: Due to Earth's rotation, gravity is slightly less at the equator than at the poles. This is because of a small outward force caused by rotation.

[5] APPLICATIONS IN DAILY LIFE

1. Falling Objects: Objects fall toward the Earth due to gravity.

Example: Fruits falling from trees, dropping a book.

2. Walking and Standing: Gravity keeps us firmly attached to the ground. Without gravity, we would float and not be able to walk properly.

3. Flow of Water: Water always flows from higher levels to lower levels because of gravity.

Example: Rivers flowing, water from taps, drainage systems.

4. Sports Activities: Gravity affects jumping, running, and throwing.

Example: A ball thrown up comes back down due to gravity.

5. Hydroelectric Power: Falling water is used to generate electricity. Dams store water at height, and gravity helps it flow down to turn turbines.

6. Transportation Systems: Some systems use gravity for movement.

Example: Roller coasters, slides, and certain railway designs.

7. Atmospheric and Environmental Effects: Gravity holds the Earth's atmosphere in place. It also helps in rainfall, as water droplets fall to the ground.

8. Daily Household Uses: Pouring liquids, cooking, and many simple actions depend on gravity.

Example: Water pouring from a bottle.

[6] ROLE IN SPACE AND SATELLITES

1. Keeping Planets in Orbit: Gravity of the Sun keeps planets moving around it. Without gravity, planets would move away into space.

2. Satellite Motion: Satellites stay in orbit around the Earth due to gravity. Gravity pulls them inward, while their speed keeps them moving forward.

3. Artificial Satellites: Human-made satellites are launched into space and controlled using gravity.

Example: Communication, weather, and GPS satellites.

4. Weightlessness in Space: Astronauts feel weightless because they are in continuous free fall around the Earth. Gravity is still present, but its effect feels different.

5. Space Missions and Navigation: Gravity is used to guide spacecraft. Scientists use "gravity assist" from planets to change speed and direction.

6. Formation of Stars and Planets: Gravity pulls dust and gas together to form stars and planets. It is the main force behind the structure of the universe.

[7] ADVANTAGES AND LIMITATIONS

Advantages	Limitations
Simple and reliable	Relatively weak force
Useful in daily applications	Affected by air resistance
Uses natural force	Cannot be controlled
No fuel needed	Depends on height
Cost-effective	Limited efficiency in flat regions
No mechanical complexity	Cannot be increased artificially

[8] CONCLUSION

Gravity-powered acceleration is a fundamental concept in physics that explains how objects move under the influence of gravity. It helps us understand everyday phenomena like falling objects as well as complex systems such as planetary motion and satellites. This natural force is simple, reliable, and essential for life on Earth, supporting many practical applications in

science and engineering. Although it has some limitations, such as lack of control and dependence on distance, its importance cannot be ignored. Overall, gravity-powered acceleration, based on Newton's Law of Universal Gravitation, remains a key principle for understanding the physical world.

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FRONTSTAGE PERFORMANCE AND BACKSTAGE STRATEGY: A QUALITATIVE STUDY OF TRUST CO-CONSTRUCTION IN INDONESIAN FASHION LIVE COMMERCE

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ABSTRACT

Live-streaming commerce has rapidly become a dominant retail channel in Indonesia, yet existing research is dominated by quantitative models that treat trust as a variable to be measured rather than as an interactional accomplishment. This study asks how trust is co-constructed between fashion sellers and Generation Z buyers in Indonesian live-commerce environments, where products cannot be physically examined prior to purchase. Adopting a rapid-ethnography design informed by Goffman's dramaturgical framework and signaling theory, we triangulate three qualitative data streams: netnographic observation of eleven public TikTok Live and Facebook Live sessions by Jakarta-based sellers (N01–N11); semi structured interviews with five adult live sellers across Java (22 coded interview references, I01–I22); and two offline fashion-event observations (O01–O02). Data were analysed in NVivo through hybrid deductive–inductive coding and Matrix Coding Queries. Three themes emerged. First, trust operates as an interactional accomplishment in which sellers perform transparency (live try-ons, disclosed defects, prepared measurements) and buyers perform practical verification through real-time interrogation of fit, price and legitimacy. Second, live selling exhibits a dual-layer logic: persuasion tactics, algorithmic timing strategies and cross-platform traffic funnelling appear exclusively in interview (backstage) data and are deliberately concealed from the curated (frontstage) live session observed by consumers. Third, buyer anxiety clusters around four verifiable concerns—price fairness, size/fit, seller legitimacy and transaction follow-through—which platform affordances and scripted reassurance only partially address. The findings extend live-commerce literature beyond feature-effect models by showing that digital trust is a co produced, omnichannel performance.

Keywords: live-streaming commerce, consumer trust, digital ethnography, dramaturgical theory, Generation Z, Indonesia.

INTRODUCTION

Live-streaming commerce has moved from novelty to mainstream retail infrastructure in Indonesia. Industry estimates place the country among the largest live-commerce markets in Southeast Asia, with fashion consistently ranked as the leading product category on platforms such as TikTok Shop, Shopee Live and Facebook Live. For Generation Z consumers—digitally native, mobile-first, and highly responsive to short-form visual content—live selling is rapidly displacing the static product listing as the primary channel for discovering and purchasing apparel. Unlike conventional e-commerce, live selling compresses browsing, questioning, negotiation and checkout into a single synchronous interaction between a human host and a dispersed audience. Despite this growth, most academic work on live-streaming commerce remains dominated by quantitative, feature-effect models that treat trust as a latent construct predicted by attributes such as interactivity, visibility or price transparency (Chandrruangphen et al., 2022; Sun et al., 2020; Wongkitrungrueng & Assarut, 2020). Such models capture useful variance but leave a crucial question under-examined: how is trust actually produced, tested and ratified inside the live session itself? Fashion is a particularly acute case, because buyers cannot physically inspect fabric, colour, or fit, and must rely on whatever signals the seller is willing and able to perform on camera.

This study addresses that gap by reframing trust in live commerce not as a variable received by consumers, but as an interactional accomplishment co-produced by sellers, buyers, and platform affordances. Drawing on Goffman's (1959) dramaturgical distinction between frontstage performance and backstage operation, and on signaling theory in digital marketplaces (Connelly et al., 2011; Spence, 1973), we ask: Research Question: How is consumer trust co-constructed in Indonesian fashion live-commerce environments, and what roles do seller performance, platform affordances, and buyer-side verification play in that process? To answer this question, we conducted a rapid ethnographic study triangulating netnographic observation of live sessions, semi-structured interviews with active sellers, and offline observation at two fashion events. The study contributes to live-commerce scholarship in three ways. First, it provides rare qualitative evidence from the Indonesian context, where most prior empirical work has been Western or East Asian. Second, it introduces Goffman's frontstage–backstage distinction as an analytical lens for live commerce, demonstrating that what buyers observe is systematically curated to obscure the operational mechanics of the sales funnel. Third, it identifies four concrete anchors of buyer anxiety—price fairness, size and fit, seller legitimacy, and transaction follow-through—that continue to shape purchase decisions even when platform affordances are fully deployed.

LITERATURE REVIEW

Live Streaming Commerce and Consumer Trust. Quantitative research has consistently identified trust as the central mechanism through which live stream attributes translate into purchase intention. In a survey of Thai fashion consumers, Chandrruangphen et al. (2022) showed that product quality and price transparency were the strongest predictors of both seller trust and product trust, which in turn drove viewing and purchase intentions. Sun et al. (2020) argued, from an IT-affordance perspective, that interactivity, visibility and meta-voicing reduce uncertainty by allowing real-time information exchange. Wongkitrungrueng and Assarut (2020) established that consumer trust mediates the effect of perceived value on engagement in social-commerce settings. In the Indonesian context, Putri and Prasetyo (2023) reported that trust mediates the relationship between live-shopping exposure and purchase decisions, while Yasser and Gayatri (2023) found that utilitarian value builds trust more directly than hedonic value in thrift-fashion live streams. What this literature leaves relatively under-examined is the micro-interactional process through which these abstract constructs take shape inside a live session. Survey designs capture trust after the fact; they rarely observe the seller tactics, buyer questions, and platform signals that jointly produce it in real time. Goffman's Dramaturgical Framework. Goffman's (1959) dramaturgical sociology offers a productive lens for this problem. Goffman distinguished between the frontstage—the region in which a performer presents a controlled self to an audience—and the backstage, where the performer prepares, rehearses, and may drop the front. The live selling screen is a paradigmatic frontstage: it is lit, scripted, populated with props (hangers, mannequins, ring lights), and oriented toward an audience whose reactions shape the performance in real time. The backstage, by contrast, contains the operational choices—algorithm strategy, device rotation, cross platform routing, scripted urgency—that sustain the frontstage but would disrupt its authenticity if exposed. Applying this distinction, live commerce can be read as a highly structured dramaturgical accomplishment rather than a spontaneous conversation, and the management of that boundary becomes itself a mechanism of trust production. Signaling Theory in Digital Marketplaces. Signaling theory (Spence, 1973; Connelly et al., 2011) addresses the information asymmetry that arises when one party (the seller) knows more about product quality than another (the buyer). Sellers deploy signals—costly, observable actions—to convey unobservable attributes, while buyers screen those signals for credibility. In fashion live commerce, observable signals include close-up fabric shots, disclosed defects, stated measurements, cash-on-delivery terms, multi-platform footprints, and public testimonials. Platform affordances (verified-seller badges, free-return cues, in-app checkout) function as institutional signals that supplement the seller's

personal performance. Together, dramaturgical theory and signaling theory allow us to theorise trust in live commerce as simultaneously performed (by sellers), screened (by buyers), and scaffolded (by platforms). Conceptual Framework. Integrating these streams, we conceptualise trust in live commerce as a three-layer co-construction. The seller layer consists of frontstage performance (transparency acts, parasocial language, identity projection) sustained by backstage operation (algorithmic timing, persuasion pacing, cross-platform funnels). The platform layer consists of affordances that scaffold the interaction (in-app checkout, coupons, return policies, search-driven live-stream surfacing). The buyer layer consists of verification practices (real-time interrogation of fit, price comparison, cross-channel legitimacy checks). Trust is ratified only when signals from the first two layers satisfy the verification demands of the third. This framework guided the ethnographic inquiry and the subsequent coding structure.

RESEARCH AND FINDINGS

Methodology.

This study adopts a qualitative rapid-ethnography design (Beebe, 2014) that applies core ethnographic principles—immersion, triangulation, and reflexive analysis—within a compressed fieldwork window. Rapid ethnography is appropriate for fast-moving digital phenomena where prolonged immersion is impractical but contextual, culturally grounded understanding is required. Three data streams were combined. First, netnographic observation (Kozinets, 2019) of eleven public live sessions on TikTok Live and Facebook Live run by Jakarta-based fashion sellers, primarily from the Tanah Abang wholesale district. Observational artefacts (screenshots, transcribed on-screen cues, chat excerpts) were logged with evidence IDs N01–N11. Second, semi-structured interviews were conducted with five adult live sellers operating across Java (Yogyakarta, Cikarang, Tangerang). Informants were purposively sampled to cover variation in account size, business model (affiliate vs. own brand), and product category (preloved, thrifted, new fashion). Interviews were conducted via Google Meet and WhatsApp video call, averaged 45–60 minutes, and were coded into 22 evidence excerpts (I01–I22). Third, two offline observations were undertaken at fashion events in the greater Jakarta area—The Scarf Society (14 February 2026) and Tangerang Fashion Week (14 February 2026)—to contextualise how credibility, value and pricing are discussed outside the live-selling screen (O01–O02). All adult informants provided verbal informed consent, were advised that participation was voluntary, and agreed to the use of anonymised or first-name identifiers. In line with research-ethics standards protecting minors, data from any informant below the age of majority were excluded from analysis. The final informant pool therefore consists of five adult sellers.

Data Analysis.

All evidence was imported into NVivo and coded using a hybrid deductive–inductive strategy (Swain, 2018). Initial deductive nodes were derived from the conceptual framework (Trust Signals, Platform Practices, Buyer Anxiety). Inductive sub-nodes emerged during coding and were consolidated into fifteen final nodes, including Transparency, Product Proof, Credibility Market, Price Fairness, Size/Fit Concern, Legitimacy Checking, Parasocial Language, Algorithm Strategy, Cross-Platform Flow, and Persuasion Tactics. Matrix Coding Queries in NVivo were used to compare node frequencies across the three data sources, enabling identification of patterns supported by triangulation versus those concentrated in a single data stream. Methodological credibility was supported by source, method and platform triangulation (Cohen, Manion & Morrison, 2018), and by an audit trail of evidence IDs linking every quoted excerpt back to its artefact.

Findings.

Theme 1: Trust as an Interactional Accomplishment. Sellers and buyers jointly produce trust through observable exchanges rather than through assumed credibility. From the seller side, transparency is explicitly framed as a non-negotiable selling practice. One informant described bringing products close to the camera, openly disclosing defects, and giving fit recommendations: “kadang kita juga deketin ke kamera gitu biar pembeli bisa ngeliat jelas barang tersebut terus kalo kondisi barangnya ada minus atau engga kita juga konfirmasi” (I17). Another stated plainly that “if customers do not trust, they will not buy” (I21, translated). Preparing measurements such as chest circumference (LD), length (PB), and waist in advance was repeatedly cited as a way to respond quickly and preserve credibility (I02, I03). Transparency Practices was the highest-frequency sub-code within the Trust Signals theme, with 14 references across four data sources. From the buyer side, the same signals function as material for active verification. Live-chat comments were dominated by sizing interrogation (“bb nya berapa yg uk m ka maksimal,” N03; “ada ukuran jumbo gak?” N07), legitimacy probing (“Kaka tokonya blok apa?” N07), and brand-check questions (“merk apa yg dipake,” N10). Buyers also produced public social-proof testimonials confirming that previous purchases had arrived as described (N02, N05). In short, trust is not received from the seller so much as it is ratified by the buyer through sustained, specific questioning.

Theme 2: The Dual-Layer Logic of Live Selling. Applying a dramaturgical reading, the data reveal a systematic separation between frontstage and backstage. Matrix Coding Queries showed that the nodes Algorithm Strategy, Cross-Platform Flow and Persuasion Tactics were present almost exclusively in interview data (I08–I16) and virtually absent from the

netnographic record. Informants described artificial countdowns ("I tell them 'only 5 minutes left before the live ends' even though the live never actually stops," I09), continuous multi-device streaming to preserve algorithmic momentum ("we have 6 to 8 phones just for live; if we stop, we start the algorithm from zero," I12), and deliberate pacing that moves viewers from casual greeting to discount pressure ("first we ask what they need, then we corner them with discounts," I11). None of these mechanisms are visible to the audience during the live session. The frontstage is, by contrast, curated to feel organic. Sellers use affectionate parasocial language ("Bunda sayang," "cintaku," I10), platform affordances (claimable shipping coupons, pinned products, free-return cues, N06, N11), and opening scripts that foreground reassurance ("COD ✓ Subsidi Ongkir ✓ Original Produk ✓ Free Inner," N09). Cross-platform routing is itself carefully staged: a seller may host interaction on TikTok Live but direct checkout to Shopee for voucher and shipping-protection reasons (I16, I20), and will switch Facebook Live viewers to WhatsApp for order finalisation ("Nanti di wa aja bu," N08). The consistent concealment of operational mechanics while the surface performance remains warm, conversational, and socially driven is precisely the frontstage–backstage management Goffman described.

Theme 3: The Four Anchors of Buyer Anxiety. Even when frontstage reassurance is dense and platform affordances are fully deployed, four specific anxieties persist and shape conversion. Price fairness surfaced in direct online-versus-offline comparisons ("lebih murah d tok tok apa beli d toko offline kk," N01). Size and fit was the most frequently coded sub node within Buyer Anxiety with eight references, expressed through technical shorthand on TikTok ("bb nya berapa yg uk m," N03) and longer self-disclosure on Facebook ("Iya gendut teh, 70 kilo," N04). Seller legitimacy was checked through requests for physical store locations in Tanah Abang ("Kaka tokonya blok apa?" N07) and by cross-referencing seller presence across Instagram, TikTok, Facebook and WhatsApp (I04). Transaction follow-through was addressed by seller rules such as a 30-minute payment window (I05) and by public testimonials confirming delivery and product accuracy (N05). Taken together, these four anchors indicate that buyer reassurance is structurally embedded in live-commerce interaction rather than incidental to any single platform.

Discussion.

The findings extend the live-commerce literature in three directions. **First,** they support and qualify the quantitative consensus that transparency drives trust (Chandrruangphen et al., 2022; Wongkitrungrueng & Assarut, 2020) by showing that transparency is not merely provided by sellers but actively demanded and screened by buyers. **Second,** they introduce an analytical

distinction—the dual-layer logic—that feature effect models cannot capture: the same live session is simultaneously a warm parasocial encounter and a calculated algorithmic funnel, and the credibility of the former depends on the concealment of the latter. **Third,** whereas Yasser and Gayatri (2023) argued that hedonic value primarily drives engagement rather than trust, our data show that hedonic framing can also be strategically weaponised through scripted urgency and parasocial address, raising normative questions about the line between persuasion and manipulation in live commerce.

CONCLUSION AND DISCUSSION

This study reframes trust in Indonesian fashion live commerce as a co-construction: an interactional accomplishment that requires seller performance, platform scaffolding, and buyer verification to operate in concert. Three conclusions follow.

First, credibility in live commerce is continuously negotiated rather than automatically granted; sellers who invest in transparency, measurement-readiness and cross-channel presence convert more reliably because they give buyers the raw material for verification.

Second, live selling is dramaturgically structured: the frontstage is warm, curated, and socially framed, while the backstage is calculated, algorithm-aware and operationally disciplined. The consumer never sees the latter, and this invisibility is itself functional.

Third, buyer anxiety is anchored in four verifiable concerns—price fairness, size and fit, legitimacy, and transaction follow-through—which platform affordances address only partially; trust is ratified when reassurance reaches all four anchors.

Managerial Implications. For fashion brands and independent sellers, the findings suggest three priorities. First, standardise live stream sizing protocols: prepared measurements, dual-tone lighting, and scripted defect disclosure measurably reduce the friction that currently dominates buyer comments. Second, invest in omnichannel legitimacy: a consistent presence across Instagram, TikTok, Facebook, WhatsApp, and an offline or bazaar footprint allows buyers to complete the background checks they already perform. Third, be cautious with manipulative frontstage tactics: while scripted urgency and parasocial address can drive short-term conversion, they erode the long-term credibility that sustains repeat purchase as digital literacy rises among Gen Z consumers.

Limitations. Three limitations should be acknowledged. First, the informant pool consists of five adult sellers based in Java; consumer voices were accessed indirectly through netnographic observation of public live-chat behaviour rather than direct interviews. Second, the netnographic sample is weighted toward Jakarta based sellers, particularly from the Tanah Abang wholesale district, which may not represent live commerce dynamics in other Indonesian

regions. Third, the fieldwork window is short by traditional ethnographic standards; while rapid ethnography is appropriate for fast-moving digital phenomena, it cannot fully capture longer-term dynamics such as repeat-purchase behaviour or seller reputational trajectories.

Future Research. Future studies should incorporate direct consumer interviews to complement seller and observational data, and should extend the design to other product categories (cosmetics, electronics, F&B) where trust dynamics may differ. Longitudinal designs that track how buyer verification practices evolve as platforms introduce new trust-signalling features—verified seller badges, AI-generated product summaries, or automated fit tools—would be particularly valuable.

Finally, comparative work across Southeast Asian live-commerce markets would help determine whether the dual-layer logic identified here is a feature of Indonesian live commerce specifically or a structural property of live selling more broadly.

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GEN Z COMMUNITY ETHNOGRAPHY ON ANIMAL WELFARE ACTIVISM: THE CASE OF BEKASI'S STREET CAT SHELTER

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ABSTRACT

This study explores how Generation Z activists within Rumah Singgah Kucing Jalanan Bekasi, a community-based animal welfare shelter in Bekasi, Indonesia, construct identity, sustain participation, and navigate structural barriers through the integration of offline practice and digital engagement. Employing a qualitative research design that combines ethnography and netnography, the study draws on semi-structured interviews with five informants representing distinct community roles (manager, volunteer, donor, digital campaign supporter, and community member), offline observation of shelter activities, and netnographic observation of the community's Instagram and TikTok content. Data analyzed thematically using a four-source evidence coding system covering interview data, netnographic material, offline observation, and structural barriers. Four interrelated themes emerged: identity construction through compassion and everyday practice; digital activism as cultural and community practice; identity transformation through repeated participation; and collective and digital strategies for navigating structural barriers such as funding instability, high medical costs, and low public awareness. The findings suggest that for Gen Z participants, animal welfare activism functions as a moral identity project in which online and offline actions continuously reinforce each other, and that digital platforms operate not merely as communication tools but as cultural infrastructures that expand and sustain the community. The study contributes to emerging literature on youth digital activism in Southeast Asian urban contexts and offers practical implications for community-based animal welfare organizations and policymakers concerned with youth civic engagement.

Keywords: *Generation Z, animal welfare, digital activism, netnography, identity construction, Indonesia.*

1. INTRODUCTION

The involvement of Generation Z in social issues has increased significantly alongside the rapid development of digital technology. One of the most visible areas of engagement is animal welfare, particularly in urban environments where stray animal populations continue to grow. In Indonesia, stray cats frequently face neglect, abuse, and a lack of medical care, reflecting broader challenges in public awareness and social responsibility (Cornish, Raubenheimer, & McGreevy, 2023; Hawes, Hupe, Morris, & Winkle, 2019).

For Generation Z, animal welfare activism is often not merely a voluntary activity but a meaningful expression of compassion and moral responsibility. Their engagement is shaped by both offline experiences and digital environments, in which social media plays a central role in spreading awareness, organizing actions, and building communities (Koivula, Kaakinen, Oksanen, & Räsänen, 2020; Smith, Thomas, & McGarty, 2020). Despite this strong empathy and commitment, Generation Z activists face structural challenges such as limited and unstable funding, high medical costs, and low public awareness regarding stray cat welfare (Hawes et al., 2019; Sinclair, Phillips, & Lea, 2022).

This study adopts a qualitative ethnographic and netnographic approach (Kozinets, 2020; Kozinets & Gretzel, 2023) to explore how Generation Z activists within Rumah Singgah Kucing Jalanan Bekasi — a community-based shelter providing rescue, medical care, and rehoming services for stray cats — construct meaning, identity, and community through their everyday practices and digital interactions. Rather than examining causal relationships, this research focuses on lived experiences, cultural interpretation, and social processes. The study is guided by two research questions:

- **RQ1:** How do Gen Z activists within Rumah Singgah Kucing Jalanan Bekasi construct and experience their identity as animal welfare actors through everyday interactions and community practices?
- **RQ2:** How do digital platforms and community interactions shape the ways Gen Z activists navigate structural challenges and sustain their animal welfare practices?

2. LITERATURE REVIEW

2.1 Digital Engagement and Generation Z

Digital engagement refers to the active involvement, interaction, and participation of users within digital platforms — including liking, sharing, commenting, creating content, and participating in online discussions (Koivula et al., 2020). For Gen Z, digital engagement plays a central role in shaping attitudes and behaviors because this generation spends a significant

amount of time interacting in online environments. Social media platforms enable exposure to social issues, including animal welfare, through visual storytelling, viral campaigns, and peer influence. Recent evidence suggests that higher digital engagement increases awareness, emotional connection, and perceived responsibility toward social causes, and that emotional content related to animal suffering or rescue stories often triggers empathy and motivates participation (Sinclair et al., 2022; Smith et al., 2020).

2.2 Participation in Animal Welfare

Participation in animal welfare refers to individuals' involvement in activities such as donations, volunteering, rescue participation, advocacy, and supporting animal-related campaigns (Hawes et al., 2019). According to the Theory of Planned Behavior (Ajzen, 1991), participation in prosocial activities is influenced by attitudes, subjective norms, and perceived behavioral control; exposure to online information and community support can strengthen these factors. In the context of animal welfare, online engagement — such as following rescue accounts or sharing campaigns — appears to increase the likelihood of offline participation (Koivula et al., 2020; Sinclair et al., 2022). Empathy has also been identified as a key predictor of animal protection behavior, with digital content enhancing emotional responses that translate into behavioral involvement (Cornish et al., 2023).

2.3 Digital Identity Construction

Digital identity construction refers to how individuals present, express, and shape their self-image through online platforms. For Gen Z, social media functions not only as a communication tool but also as a space for identity expression and value signaling (Koivula et al., 2020). Participation in social causes, including animal welfare, is often used as a form of moral identity signaling or value-based self-presentation. Research indicates that involvement in prosocial activities strengthens identity alignment and reinforces self-concept as a caring or socially responsible individual (Smith et al., 2020). Online environments amplify this process because actions are visible to peers and broaden social networks.

2.4 Structural Barriers in Community-Based Animal Welfare

Community-based animal welfare organizations consistently face structural barriers that limit their operational capacity. Hawes et al. (2019) identify three recurring challenges: inadequate and unstable funding, limited access to affordable veterinary care, and low public awareness of animal welfare issues. Sinclair et al. (2022) similarly highlights that public attitudes toward stray animals in many contexts remain ambivalent, which reduces the external support available to shelters. These barriers are not purely external constraints; they shape how communities

organize themselves, allocate scarce resources, and communicate with a wider public (Smith et al., 2020).

2.5 Conceptual Framework

This study adopts a qualitative ethnographic orientation to explore how Generation Z constructs meaning, identity, and participation within the context of animal welfare activities. Rather than examining causal relationships between predefined variables, the research seeks to understand how digital engagement, participation in animal welfare, and identity construction are interconnected through lived experiences and social interactions. The framework is grounded in the idea that digital platforms serve as cultural spaces in which individuals encounter, interpret, and engage with animal welfare issues (Kozinets, 2020; Kozinets & Gretzel, 2023). Through continuous exposure to digital content, interaction with online communities, and direct involvement in rescue and caregiving, individuals develop emotional connections and gradually internalize these experiences as part of their identity.

In this study, identity construction is understood as an ongoing process that emerges from the interaction between digital engagement and real-world participation. The study also acknowledges the presence of structural barriers — funding, facilities, and public awareness as contextual factors rather than measurable variables. The analytical lens is further informed by Geertz's (1973) concept of "thick description," which emphasizes understanding social actions within their cultural and situational context.

3. METHODOLOGY

3.1 Research Design

This research uses a qualitative descriptive design with ethnographic and netnographic orientation (Kozinets, 2020; Kozinets & Gretzel, 2023). It aims to gain an in-depth understanding of how a community-based animal welfare organization operates, how its members construct meaning and identity, and how digital platforms shape participation and activism.

3.2 Research Setting

The research setting is Rumah Singgah Kucing Jalanan Bekasi (Bekasi Street Cat Shelter), a community-based animal welfare organization in Bekasi, West Java, Indonesia. The shelter provides rescue, medical treatment, daily care, sterilization advocacy, and rehoming services for stray and abandoned cats. Its activities span two domains: on-site care at the shelter and digital outreach through Instagram (@rskjbekasi) and TikTok. The study treated both domains as integrated sites of activism.

3.3 Participants

Five informants were purposively pursued to represent distinct roles within the community ecosystem. Participants were recruited on the basis of meaningful, sustained involvement in the shelter's activities, either offline or online. The informants are summarized in Table 1.

Table 1. Profile of Informants

Code	Informant (pseudonym)	Role	Form of involvement
I01	Ma'am Dita	Key informant / community manager	Daily management, rescue operations
I02	Naya (22)	Volunteer	Cage cleaning, treatment assistance
I03	Kevin (24)	Donor	Recurring financial contribution
I04	Celine (21)	Digital campaign supporter	Reposting, amplification of content
I05	Rafi (23)	Community member	General participation and engagement

Pseudonyms are used for all informants except the community manager, who consented to the use of her professional name.

3.4 Data Collection

Three data sources were used: (1) semi-structured interviews with the five informants; (2) offline observation of shelter activities over a four-week fieldwork period; and (3) netnographic observation of the community's public social media accounts, following the procedural guidelines of Kozinets (2020) and Kozinets and Gretzel (2023). Interview questions explored motivations for participation, the meaning of shelter, the influence of digital platforms, perceptions of community belonging, and structural challenges. Specific wording was adjusted to each informant's role while core themes remained consistent. Netnographic observation focused on public content from @rskjbekasi on Instagram and its linked TikTok content, including adoption campaigns, rescue storytelling, fundraising posts, before–after rescue videos, emergency cases, educational content, and community interaction patterns. Offline observations covered rescue activities, daily care, and volunteer coordination.

3.5 Data Coding and Evidence Identification System

To ensure clarity, consistency, and traceability, the study adopts an evidence identification system that labels all data sources by origin. Interview excerpts are coded I01–I05.

Netnographic data are coded N01–N10 by content category (adoption campaign, awareness content, fundraising post, before–after content, urgent rescue case, educational content, engagement activity, community interaction, volunteer recruitment, general updates). Offline observation notes are coded O01–O03 (rescue activity, shelter activity, community interaction). Structural barriers identified during the study are coded B01–B03 (funding, medical cost, awareness). This coding system enables triangulation across multiple data sources and strengthens the credibility of the analysis.

3.6 Data Analysis

Data were analyzed thematically. Interview transcripts, netnographic observations, and field notes were read iteratively and coded at two levels: first by data source and content type using the labeling system above, and then by emerging theme. Codes were grouped into broader categories and themes to capture recurring patterns related to identity construction, digital activism, community practices, and structural barriers. Triangulation across the three data sources was used to strengthen credibility. Thick description (Geertz, 1973) was pursued where possible to situate findings within cultural and situational context.

3.7 Ethical Considerations and Researcher Positionality

All informants provided informed consent prior to participation. Pseudonyms were used for four of the five informants to protect privacy, while the community manager consented to the use of her professional name. Netnographic observation was restricted to publicly available content; no private messages or closed-group material was accessed. As researchers, the first-authored members of the team are themselves members of Generation Z and close in age to most informants. This proximity may have facilitated rapport and candid conversation, while also requiring reflexive awareness of shared assumptions. The team sought to mitigate this by grounding interpretations in explicit evidence excerpts and by triangulating across data sources.

4. FINDINGS

4.1 Overview of Thematic Analysis

The structured coding system described in Section 3.5 yielded four interrelated themes through iterative thematic analysis. Interview data (I01–I05) were triangulated with netnographic data (N01–N10) and offline observations (O01–O03), while structural barriers (B01–B03) were examined as contextual conditions shaping community practice. A condensed evidence map is presented in Table 2.

Table 2. Evidence Map of Themes

Evidence ID	Data Source	Category	Sub-theme	Example Evidence
I01	Interview	Identity Construction	Compassion	"They don't have a voice"
I02	Interview	Identity Construction	Responsibility	"I feel more responsible"
I03	Interview	Structural Barrier	Funding challenge	"Donation is unstable"
I04	Interview	Digital Engagement	Content sharing	Reposting campaigns
I05	Interview	Community Meaning	Sense of belonging	"Feels like a support system"
N01	Netnography	Digital Activism	Adoption campaign	Instagram adoption post
N02	Netnography	Digital Activism	Awareness	Rescue storytelling
N03	Netnography	Digital Activism	Fundraising	Donation campaign post
N04	Netnography	Digital Activism	Transformation	Before–after rescue content
N05	Netnography	Digital Activism	Urgency	Emergency rescue post
O01	Observation	Community Practice	Rescue activity	Field rescue observation
O02	Observation	Community Practice	Daily care	Feeding and treatment
O03	Observation	Community Practice	Interaction	Volunteer coordination
B01	Barrier	Structural Barrier	Funding	Donation instability
B02	Barrier	Structural Barrier	Medical cost	Treatment expenses
B03	Barrier	Structural Barrier	Awareness	Low public awareness

4.2 Identity Construction Through Compassion and Everyday Practice

Participation in animal welfare is deeply rooted in a shared sense of compassion, which functions as both personal motivation and a collective cultural value. Interview data indicate that participants consistently interpret their involvement as a moral responsibility toward

vulnerable animals. The key informant emphasized that stray animals "do not have a voice," positioning humans as responsible agents for their well-being (I01). Compassion, in this sense, is not merely an individual emotion but a socially constructed meaning that shape identity within the community. Participants also describe their involvement as embedded in routine and repeated practices — rescuing injured animals, providing daily care — which transforms participation into an everyday practice through which individuals perform and reinforce their roles as caregivers and rescuers (O01, O02). Identity construction thus emerges through the interaction between emotional attachment and repeated action; identity is not pre-defined but gradually constructed through lived experience.

4.3 Digital Activism as Cultural and Community Practice

Digital platforms play a central role in sustaining animal welfare activism, functioning not only as communication tools but also as cultural spaces where meaning and engagement are constructed. Netnographic data show that social media content such as adoption campaigns, rescue storytelling, and before–after transformations serves as a primary mechanism for raising awareness and mobilizing support (N01, N02, N04). These digital artifacts communicate the values of the community while inviting participation from a broader audience. Interview participants emphasize that Instagram and TikTok enable the community to reach individuals who are not physically present but still contribute through donations, reposts, or engagement (I02, I03, I04), extending the community beyond its physical site. Interaction within digital spaces — comments, shares, reposts — creates a sense of collective engagement and shared concern (N07, N08). Digital activism therefore operates as an integrated system that supports and amplifies offline community activities.

4.4 Identity Transformation Through Participation

Continuous participation in animal welfare activities leads to noticeable personal transformation. Through repeated involvement in rescue, caregiving, and community interaction, individuals begin to internalize values such as compassion, patience, and responsibility. One participant stated that involvement has made them "more patient and more caring," indicating ongoing self-development (I02). Others describe a growing sense of responsibility that becomes embedded in daily life (I01, I05). This transformation is reinforced through both offline and online action: routine practices such as feeding, cleaning, and medical assistance contribute to a consistent role identity (O02), while engagement in digital activities strengthens the sense of belonging to the community (N07). Identity is therefore not static but continuously shaped through practice and interaction; participation serves as a mechanism through which individuals redefine themselves as socially responsible actors.

4.5 Navigating Structural Barriers Through Collective and Digital Strategies

Participants face significant structural challenges — limited funding, high medical costs, and low public awareness — consistently identified across both interview and observational data (B01, B02, B03). Unstable donations and expensive medical treatments create ongoing difficulties in sustaining rescue operations (I03, B01, B02), while low public awareness further limits external support (B03). However, rather than merely hindering participation, these challenges encourage adaptive strategies. The community uses digital platforms to conduct fundraising campaigns, share urgent rescue cases, and educate the public (N03, N05, N06). Members contribute in different forms — volunteering, donating, amplifying content (I02, I03, I04) — demonstrating that resilience is constructed through both collective action and digital engagement. Structural barriers are not only obstacles but also shape how activism is practiced and sustained.

5. DISCUSSION

5.1 Identity Construction Through Compassion

The findings are consistent with Koivula et al. (2020) and Smith et al. (2020), who argue that sustained participation in prosocial causes reinforces a participant's self-concept as a socially responsible actor. For the Gen Z informants in this study, animal welfare activities reshaped their perspective on themselves, producing a noticeable transformation from ordinary individual to driving force (rescuer). The key informant captured this in her own words:

> *"Being part of this community has made me more compassionate, patient, and responsible. My identity is now closely connected to rescue and animal care activities. I feel that my life has more purpose because I can help vulnerable animals." (I01)*

This pattern supports Ajzen's (1991) Theory of Planned Behavior, in which attitudes and subjective norms shape behavior, and extends it by showing that the behavior itself reshapes identity over time. For Gen Z informants in particular, digital and real-world identities appear to fuse through the narrative of animal rescue, providing a sense of purpose amid wider social dynamics.

5.2 Digital Platforms as Extensions of Community

The findings support Kozinets (2020) and Kozinets and Gretzel (2023) in treating social media platforms not merely as communication tools but as cultural infrastructures through which communities are experienced and sustained. Consistent with Koivula et al. (2020), digital engagement extended the community's reach to donors and digital supporters who are not physically present at the shelter but nonetheless describe themselves as part of its "support system" (I03, I05). Instagram and TikTok are integrated into the community's daily operations,

illustrating how digital and offline practices have become mutually reinforcing rather than separate.

5.3 Strategies for Facing Structural Barriers

The structural barriers reported here — unstable funding, high medical costs, low public awareness — mirror those identified by Hawes et al. (2019) and Sinclair et al. (2022) across community-based animal welfare organizations internationally. What is notable in this Indonesian case is the way informants responded to criticism and stigma: they chose education over confrontation.

> *"I usually respond calmly and try to educate them. Not everyone understands the concept of animal welfare, so a patient approach is more effective than arguing." (I01)*

This suggests a form of emotional maturity in which obstacles are reframed as opportunities for public education and collective awareness-raising, consistent with the collective-action framing discussed by Smith et al. (2020). For long-term sustainability, however, the findings also point to the need for strategic collaboration beyond the immediate community — partnerships with veterinarians, local government, and other welfare organizations for mass sterilization programs and permanent medical facilities.

5.4 Theoretical and Practical Implications

Theoretically, the study contributes to the growing literature on Gen Z digital activism in Southeast Asian urban contexts by showing how compassion, routine practice, and digital engagement co-produce an activist identity. It illustrates how netnography (Kozinets & Gretzel, 2023) can be productively combined with offline ethnography to study hybrid communities whose activities straddle physical and digital spaces. Practically, the findings suggest that community-based animal welfare organizations should invest deliberately in digital storytelling capacity, cultivate multiple low-barrier forms of participation, and pursue structured partnerships to stabilize funding and medical access. For policymakers, the case highlights the social value of informal youth-led welfare communities that absorb costs otherwise unmet by municipal services.

6. CONCLUSION

6.1 Answering the Research Questions

This study examined how Generation Z activists at Rumah Singgah Kucing Jalanan Bekasi construct identity and sustain participation in animal welfare activism, drawing on five informant interviews, four weeks of offline observation, and netnographic observation of the community's social media.

Regarding RQ1, Gen Z activists construct their identity as animal welfare actors through everyday practices of rescue, caregiving, and community participation, in which compassion operates as both personal motivation and shared cultural value. Identity is not pre-given but gradually produced through repeated action, emotional engagement, and role performance within the community.

Regarding RQ2, digital platforms — particularly Instagram and TikTok — play a crucial role in enabling activists to navigate structural challenges and sustain their involvement. Digital content (adoption campaigns, rescue storytelling, before–after transformations, emergency posts, educational content) extends the community beyond its physical site, mobilizes donations and volunteer participation, and creates a sense of belonging for supporters who never visit the shelter in person. Structural barriers — funding instability, high medical costs, low public awareness — are navigated through a combination of collective offline action and adaptive digital strategies. Overall, Bekasi Street Cat Shelter represents a moral community in which activism is embedded in both daily practice and digital interaction.

6.2 Limitations

Several limitations should be acknowledged. First, the sample is small (five informants) and drawn from a single community in Bekasi; findings should be read as context-specific rather than generalizable. Second, the fieldwork period was relatively short; longer immersion could have surfaced additional themes, particularly around seasonal variation in donation patterns and rescue load. Third, netnographic observation was limited to publicly available content. Fourth, as Gen Z researchers studying a Gen Z community, the authors shared generational standpoint shaped interpretation in ways that have been made explicit but cannot be fully neutralized.

6.3 Recommendations and Future Research

For the community, the study recommends strengthening structured partnerships with veterinary clinics and local government for mass sterilization, diversifying fundraising channels, and continuing to develop the digital storytelling practices that already sustain the community. For future research, comparative studies across multiple Indonesian cities would clarify how urban context shapes Gen Z animal welfare activism, while longitudinal work could trace identity transformation over time. Mixed methods designs combining netnographic insight with engagement analytics (follower growth, conversion rates from reposts to donations) would further deepen understanding of how digital activism translates into sustained material support.

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APPENDIX A — SELECTED INTERVIEW EXCERPTS

This appendix provides selected excerpts from the five semi-structured interviews that underpin the thematic analysis. Pseudonyms are used for all informants except the community manager, who consented to the use of her professional name.

A.1 I01 — Ma'am Dita (Key Informant / Community Manager)

Q: What motivates you to participate in animal welfare?

My main motivation is empathy for stray cats who are often abandoned, injured, or abused. They do not have a voice, so as humans we have a responsibility to help them. Almost every month we receive reports and directly conduct rescue missions.

Q: How does being part of this community influence your values or identity?

Being part of this community has made me more compassionate, patient, and responsible. My identity is now closely connected to rescue and animal care activities. I feel that my life has more purpose because I can help vulnerable animals.

Q: How do social media platforms influence your involvement?

Social media plays a very important role in spreading information about rescues, finding adopters, and raising donations. Many of our cats have been successfully adopted through Instagram and Facebook posts. It is also an effective tool for educating the public.

Q: What challenges do you face?

The biggest challenges are limited funding and low public awareness. Many people still see stray cats as a nuisance rather than living beings. Sterilization and medical treatment are expensive, while donations are not always stable.

A.2 I02 — Naya, Volunteer, age 22 (pseudonym)

Q: What makes you stay involved as a volunteer?

The exhaustion is definitely there, especially when you see the condition of the cats. But that's precisely what makes me feel that my small role still matters. There is a certain satisfaction when you see a cat that was very sick start to get better.

Q: How important is social media for this community?

Without TikTok or Instagram, many people wouldn't know what the situation on the ground is like. When they see rescue videos or before-and-after treatment directly, it hits much harder.

A.3 I03 — Kevin, Donor, age 24 (pseudonym)

Q: What made you decide to donate?

The content felt honest and not forced. You become aware that there are situations that really need help. I started to feel trust, because it was clear what the donations were being used for.

Q: Do you feel connected to the community even if you are not on-site?

Surprisingly, yes. Through the updates they share, I feel like I'm following each rescue case's journey. There's a feeling that I'm part of their support system.

A.4 I04 — Celine, Digital Campaign Supporter, age 21 (pseudonym)

Q: Why do you actively share the community's campaigns?

Not all forms of help have to be money or going directly to the field. The more people see it, the greater the chance that someone will help. Reposting may seem small, but it is actually quite influential.

Q: Can social media create a sense of community?

Yes. Even though people don't know each other personally, through comments, reposts, and responses on stories, you can feel the same sense of care. People share the same concern and take action together.

A.5 I05 — Rafi, Community Member, age 23 (pseudonym)

Q: What does this community mean to you personally?

This community is more than just a place where cat lovers gather. Everyone here shares the same concern. There are still people willing to care selflessly.

Q: What issue is often underestimated by outsiders?

People see this as just feeding or rescuing cats, but behind it there is a long and difficult process — medical costs, daily care, emotional pressure when a case doesn't go well.

MODULAR BRAND CONSUMPTION AND IDENTITY CONSTRUCTION AMONG GEN Z SKATEBOARDERS: A QUALITATIVE STUDY IN GREATER JAKARTA

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ABSTRACT

Skateboarding has shifted from a rebellious street activity to a globally recognized cultural and sporting practice, yet ethnographic evidence from Southeast Asian urban contexts remains limited. This study examines how Generation Z skateboarders in Greater Jakarta construct collective identity, negotiate authenticity, and assign meaning to brand choice within their shared cultural practice. A qualitative design combined netnographic observation of six Indonesian skate-related Instagram accounts and a curated set of TikTok posts across approximately ten to twelve hours of digital immersion, five semi-structured interviews conducted at Fly Over Slipi Skatepark in Central Jakarta, and one offline observation session of approximately one hour and twenty minutes. Data was analyzed thematically using NVivo through open, axial, and selective coding. Three themes emerged. First, values and identity are grounded in solidarity, process orientation, and behavior-based authenticity. Second, consumption operates through modular brand mixing across components rather than single-brand loyalty. Third, unmet needs concern public-space conflict, infrastructure distribution, and beginner pathways. The findings position Jakarta's Gen Z skate community as a softened subculture where belonging outranks gatekeeping and highlight modular brand consumption as a distinctive pattern with implications for local and global skate brands targeting this segment. Managerial implications favor component-level positioning over single-brand ecosystems and cultural embedding over standardized global branding.

Keywords: Skateboarding, Subculture, Consumer Culture Theory, Brand Choice, Netnography, Generation Z.

INTRODUCTION

Background. Skateboarding has moved from the margins of urban street culture to formal institutional recognition through inclusion in the Olympic Games, yet its subcultural roots remain grounded in the everyday appropriation of urban space (Borden, 2019). In Southeast Asian cities such as Jakarta, the expansion of public skateparks, the visibility of local skate brands, and the embedding of skate content within platforms such as Instagram and TikTok have reshaped how young people enter, learn, and express themselves within skate culture.

Skateboarding is therefore no longer a purely recreational pursuit; it operates as a cultural practice through which young people construct identity, build community, and claim physical space within the city (Atencio, Beal, & Wilson, 2009). For marketing scholarship, this shift is consequential. Within a skate community, brand choice is rarely a purely functional decision. Choosing particular decks, trucks, wheels, bearings, or footwear can signal authenticity, aspiration, belonging, and personal style (Belk, 1988). Identity is expressed not only through the tricks a skater lands but through the board they ride and the shoes they wear. As digital platforms increasingly mediate how skaters learn, share, and gain recognition (Kozinets, 2002), the construction of subcultural identity and the meanings attached to brands unfold simultaneously across offline and online spaces. Despite this relevance, ethnographic evidence on skateboarding in non-Western urban settings remains thin. Indonesian studies addressing skateboarding as subculture and industry have begun to appear (Artosa, 2022), but scholarship on Greater Jakarta's Gen Z skate community and the brand meanings circulating within it is limited. The present study addresses this gap by asking: How do Gen Z skateboarders in Greater Jakarta's skate community collectively construct identity, negotiate authenticity, and assign meaning to brand choice within their shared cultural practice?

Research Problem and Objectives. This study pursues three objectives. First, it documents how identity and belonging are constructed within a Jakarta-based skate community through shared values, spatial practice, and digital self-presentation. Second, it examines how brand choice operates within that community, with attention to the balance between affordability, functionality, and symbolic value. Third, it identifies structural and cultural conditions that shape or constrain participation, including the availability of public skate infrastructure and the negotiation of public space. Because skate identity is increasingly performed and contested in digital environments, the study adopts a qualitative design combining netnographic observation, semi-structured interviews, and one offline observation session. The scope is deliberately exploratory and does not claim statistical representativeness.

LITERATURE REVIEW

Identity and Consumption in Subcultural Settings. Consumption is shaped by social context. Brand choices are rarely made independently; they are influenced by the communities and cultural environments individuals inhabit. Hebdige (1979) frames subcultures as groups that develop distinctive styles and symbolic practices that differentiate them from mainstream society; these styles function as social signals through which members communicate belonging and shared values. Within skate communities, appearance, attitude, and shared codes can carry meaning that extends well beyond surface-level fashion. Contemporary perspectives

complicate the classical subculture account. Maffesoli (1996) introduces the notion of tribes: fluid social groupings built around shared experiences and emotional connections rather than rigid boundaries. Cova and Cova (2002) extend this view into marketing, arguing that in consumer tribe's brands operate as linking values that strengthen relationships between members. Brand choice, in this reading, is not simply personal preference; it is a form of social maintenance within a group. Belk's (1988) extended self-concept further grounds the symbolic role of objects in identity. Possessions, including brands, become part of who a person is or aspires to be. In subcultural settings, this symbolic function often becomes more visible, because particular brands are interpreted as more authentic or more aligned with group values than others. Muniz and O'Guinn (2001) add the notion of brand community, characterized by shared consciousness, rituals, and moral responsibility. While a skate community is not organized around a single brand, this framework illustrates how brands can contribute to collective identity. Arnould and Thompson (2005), through Consumer Culture Theory, argue that consumers actively interpret and deploy marketplace meanings to construct their identities rather than passively adopting brand messages.

Skateboarding as Subculture and Lifestyle. Skateboarding has been extensively theorized as a subcultural and spatial practice. Borden (2019) traces its movement from rebellious street activity to globally recognized cultural and sporting practice, while Atencio et al. (2009) argue that skateboarding functions as a cultural arena through which young people construct identity and claim urban space. Artosa (2022) extends this scholarship to Indonesia, examining how young skate workers operate within a skate industry that is both commercial and communal. In Jakarta, skateboarding takes place in a hybrid environment of skateparks and street spots where skaters gather to practice tricks, exchange information, and observe each other's styles and equipment. Digital media now mediate a substantial part of this learning: tutorials, clips, and brand exposure circulate through Instagram and TikTok, shaping how skaters acquire technique and how they understand themselves within the broader scene (Kozinets, 2002). Taken together, these perspectives suggest that skate identity in urban Indonesia can be approached as a social and spatial practice where consumption, community, and digital self presentation are interconnected, and where brand choices reflect processes of belonging and self definition rather than pure individual taste.

RESEARCH AND FINDINGS

Methodology. The study employs a qualitative design combining netnography as the primary method with semi-structured interviews and one offline observation session. Netnography is appropriate for examining how subcultural identity, shared meanings, and brand perceptions

are expressed in naturally occurring online interactions (Kozinets, 2002). The research is positioned as exploratory and interpretive rather than generalizable. Instagram Netnography. Online observation covered Instagram accounts associated with Jakarta and Greater Jakarta skate communities and TikTok skate content, with attention to comment sections. Six accounts were included: @greenskatelesson, @epicskatepark, @jakartaskateboarding, @malatskateboarding, and @bogor. skateboarding, together with a curated set of TikTok posts. These platforms were selected because they function as active spaces where skateboarders share tricks, discuss equipment, express identity, and engage with brands. Observation took place between February and early April 2026, with approximately ten to twelve hours of cumulative immersion. A non-participatory lurking approach was adopted to avoid influencing interactions. Purposive sampling was applied to select posts and discussions based on thematic relevance, specifically authenticity, customization, brand preference, affordability, and sponsorship, and visible engagement. Screenshots and digital field notes were documented and categorized into preliminary themes including community values, identity markers, brand mentions, aspirations, and economic barriers.

Interviews. To complement the online material, five skateboarders were recruited through direct approach at Fly Over Slipi Skatepark, Tanah Abang, Central Jakarta. Participants represented different levels of experience: one key informant (Ilham, I01) is from the Millennial generation and provides a longitudinal reference point, while the remaining four participants (Bayu, Fatur, Fadel, and Adit, coded I02 to I05) are Gen Z with beginner, intermediate, and experienced profiles. All five participants were male. Semi-structured interviews covered initial entry into skateboarding, personal meaning and identity, perceptions of authenticity, economic accessibility, brand preferences, customization practices, and the influence of social media. The format allowed participants to elaborate on lived experience while preserving consistency across interviews. All interviews were audio-recorded with consent, transcribed verbatim, and anonymized using pseudonyms. Table 1 summarizes the participant profile.

Table 1. Participant Profile

Code	Name (Pseudonym)	Role	Notes
I01	Ilham	Key Informant (Millennial)	Former skater
I02	Bayu	Gen Z	Intermediate
I03	Fatur	Gen Z	Beginner
I04	Fadel	Gen Z	Beginner
I05	Adit	Gen Z	Experienced

Source: *Constructed by researchers (2026)*

Offline Observation. A single offline observation session was conducted on Sunday, 15 February 2026, between 15:47 and 17:10, at Fly Over Slipi Skatepark during a regular weekend session rather than a formal event. A structured protocol guided observation toward social dynamics, visible brand usage on footwear, decks, trucks, wheels, personalization practices, and generational interaction patterns. Field notes were written immediately after the session to minimize recall bias.

Ethics. Only publicly accessible online content was observed during netnography; no private messages or restricted groups were accessed. Usernames were anonymized where individual behavior was discussed. Interview participants provided voluntary informed consent and are referred to by pseudonyms. The researchers maintained a non-intrusive role during both online and offline observation. All data were used strictly for academic purposes.

Analysis. Data from interview transcripts, offline observation notes, and netnographic material were analyzed thematically using NVivo, which supports systematic organization of qualitative material across multiple sources and produces an explicit audit trail of analytic decisions (Dalkin, Forster, Hodgson, Lhussier, & Carr, 2021; Mortelmans, 2025). Open coding identified meaningful statements and produced an initial code set covering peer influence, solidarity, risk-taking identity, persistence, process orientation, spatial attachment, respect norms, institutional recognition, digital self-presentation, and freedom symbolism. Axial coding grouped related codes into broader categories: community values and solidarity, identity formation and personal growth, spatial negotiation and urban meaning, institutional change and mainstream recognition, and digital visibility. Selective coding synthesized these categories into three overarching themes: values and identity, consumption, and unmet needs. NVivo also produced a matrix coding query summarizing the distribution of coded references across participants and sub- themes.

Findings:

Values and Identity. Across interviews, offline observation, and netnographic material, skateboarding in Jakarta emerged as a value-driven community practice shaping identity, belonging, and worldview. Participation extends beyond performing tricks; it reflects values centered on solidarity, commitment to the learning process, behavior-based authenticity, and lifestyle expression.

Solidarity is visible in everyday practice. Ilham (I01), speaking as a Millennial key informant, described early skate culture as oriented toward friendship rather than competition, and framed an individual's successful trick as shared pride for the group. Adit (I05) described mutual support during practice, particularly when a skater falls while learning. Fadel (I04) framed entry into the community as entering a distinct social world in which unfamiliar skaters connect quickly through shared practice. During the offline session, board-clapping on the ground, brief verbal encouragement such as “mantap,” and cross-group acknowledgment among micro-groups of three to five skaters illustrated the same norm. Netnographic material reinforced this pattern: Instagram content depicting intergenerational skate gatherings emphasized knowledge sharing across age groups (N02), while TikTok captions such as “Teaching my nephew to skateboard” normalized mentoring within the scene.

Identity is process oriented. Fadel (I04) explained that skateboarding teaches patience because falling is unavoidable and improvement requires repetition. Adit (I05) defined a real skater as someone who genuinely enjoys training and continues practicing improving. Digital discussions reinforce this pattern: TikTok users routinely ask why their back foot does not stay on the board during an Ollie and how to overcome fear when landing. The responses they receive typically combine encouragement with tutorial recommendations. Struggle and gradual improvement, rather than immediate mastery, anchor how participants and online observers frame the skate experience.

Authenticity is behavior-based rather than gatekept. Although the notion of a real skater circulates, it is defined by consistency and respect rather than skill level. Fadel (I04) argued that authenticity rests on sustained practice, criticizing individuals who use skateboards mainly for social media content without active engagement. Adit (I05) described a fake skater as someone who owns a skateboard but does not actually use it, relying on the object primarily for content. Online discussions about skate brands treated as fashion items reflect a parallel tension between cultural meaning and superficial consumption. The “poser” label, while present, is not strictly enforced; Ilham (I01) stated that in the Jakarta scene anyone who skates is a skater, and that the label was not used to exclude newcomers.

Lifestyle expression ties these elements together. Fadel (I04) described skateboarding as both sport and lifestyle, shaping his mindset and daily perspective. Adit (I05) noted its effect on clothing choices and attitudes toward risk. Earlier interviews with Ilham and Fatur (I03) showed how customization and brand preferences reflect personal character. Skateboarding therefore operates as a social and cultural framework through which participants construct identity, belonging, and shared meaning.

Findings: Consumption. Consumption practices within the Jakarta skate community reflect a balance between affordability, functionality, and aspiration. Interviews with Ilham (I01), Bayu (I02), and Fatur (I03) suggest that skateboard consumption is strategic rather than impulsive.

Economic accessibility plays a substantial role. Ilham (I01) recalled that in earlier years a full setup could cost between two and four million rupiah, whereas today a beginner can assemble a setup for approximately seven to eight hundred thousand rupiah due to the growth of affordable local brands. This shift has lowered entry barriers, although financial constraint remains present: Fatur (I03) reported delaying his entry into skateboarding because boards were expensive when he was younger.

Skaters balance budget with functionality. Ilham (I01) uses blank decks and blank trucks as a cost-efficient baseline while investing in Nike SB or Nike Blazer High shoes because of ankle support. Bayu (I02) wears Vans SK8, indicating how durability and brand identity intersect at the footwear level.

The most distinctive pattern is modular brand mixing. Bayu (I02) combines an Etax deck and trucks with Independent bearings and Motion wheels, evaluating each component independently rather than exhibiting loyalty to a single brand ecosystem. Fatur (I03) pairs Vans Skate High footwear with a blank deck, mixing aspirational and affordable elements within a single setup. This selective approach recurred across interviews and was visible in offline observation, where Vans and Nike footwear appeared alongside boards of varying origin, and grip tape modifications such as cut patterns and scratched designs were common. Customization through grip tape functioned simultaneously as a practical marker, to distinguish nose and tail, and as an aesthetic one. Bayu (I02) described grip-tape modification as artwork expressing individual style.

Aspiration shapes progression. Fatur (I03) identified Santa Cruz as his dream board and expressed interest in upgrading to higher tier Independent trucks. Consumption therefore evolves alongside skill: beginners often enter with accessible equipment and then aspire toward premium components associated with global skate culture. Digital media informs these decisions. Ilham (I01) noted that social media helps attract sponsors and increases visibility, and that many skaters share tutorials on YouTube. Online discussions frequently include

questions about boards and gear, indicating that purchasing decisions are informed by peer recommendations and community-shared experience (N03). In this environment, brand choice operates simultaneously as equipment, as marker of progression, and as cultural affiliation.

Findings:

Unmet Needs. Despite strong community values and adaptive consumption practices, structural challenges persist within the Jakarta skate ecosystem.

Financial constraint emerged as a barrier to entry. Fatur (I03) described delaying his participation because equipment was expensive. At the same time, skateboarding operates as a small source of income for some participants: Fatur (I03) described involvement in events that generated

payment. Skateboarding therefore sits within a complex economic structure in which cost constrains entry for some and enables livelihood for others. Online discussions frequently address affordability, with users asking for advice on affordable setups and alternatives (N06).

Public-space conflict is a recurring issue. Fadel (I04) explained that skating in urban areas often leads to warnings from residents or security guards, sometimes accompanied by accusations of damaging facilities; skaters typically negotiate or leave. Ilham (I01) described a similar pattern in earlier years, including informal negotiation with security personnel in office districts such as Kuningan. Street skateboarding nevertheless holds particular meaning: Fadel (I04) described urban spots as more challenging and creatively stimulating than skateparks. The tension between street-level creativity and urban regulation marks a structural gap in how skateboarding is accommodated within city planning.

Cultural perception has shifted in mixed directions. Fadel (I04) observed that skateboarding is now more respected and recognized as a sport, including through international competition, while acknowledging that content-driven exposure has altered the underground atmosphere. Adit (I05) emphasized the importance of maintaining a positive public image to sustain social acceptance.

Infrastructure inequality is visible in online material. Instagram posts (N03) raised the absence of skateparks in certain regions and called for better-designed facilities in additional cities, indicating uneven access beyond major urban areas. Beginner uncertainty is another recurring theme. Online users ask whether it is too late to start skateboarding, how to begin learning, and how to overcome fear when landing tricks. Although tutorials exist, these questions suggest that clearer entry pathways and mentorship structures are still needed.

Discussion. Three interpretive points emerge from the findings. First, Jakarta's skate community aligns more closely with consumer-tribe and post-subcultural frameworks than with the classical

resistance-oriented subculture model. Authenticity is defined behaviorally rather than symbolically policed, the poser label exists without strict enforcement, and belonging is prioritized over gatekeeping. This pattern is consistent with Maffesoli's (1996) emphasis on fluid, emotionally grounded tribal formations and with Cova and Cova's (2002) view of brands as linking values that support social connection. Rather than positioning themselves against mainstream culture, Jakarta's Gen Z skaters negotiate it pragmatically. Given the small sample (n = 5), the single-site recruitment, and the short netnographic window, this pattern should be read as an exploratory interpretation rather than a definitive claim.

Second, the most distinctive empirical pattern is modular brand consumption. Participants consistently mix local and global components across decks, trucks, bearings, wheels, and footwear, evaluating each component separately on perceived quality and price rather than adopting a single brand ecosystem. This pattern aligns with Belk's (1988) extended-self-concept, because each component contributes to a personalized material identity, and with Consumer Culture Theory (Arnould & Thompson, 2005), because consumers actively interpret and deploy marketplace meanings rather than passively adopting brand narratives. For skate brands, modular consumption weakens the logic of full-set positioning and strengthens the case for credible, component-level communication.

Third, the digital and institutional environment reshapes but does not replace community-based learning. Platforms extend access to technique, visibility, and sponsorship opportunities and support the emergence of content-driven identity. At the same time, core norms such as solidarity, process orientation, and respect continue to be transmitted through offline practice at skateparks and street spots. The interaction between digital exposure and embodied community norms is the site where brand meanings are continuously negotiated.

CONCLUSION

This study examined how Gen Z skateboarders in Greater Jakarta construct collective identity, negotiate authenticity, and assign meaning to brand choice. Drawing on netnography across five Indonesian skate-related Instagram accounts and a set of TikTok posts, five semi-structured interviews at Fly Over Slipi Skatepark, and one offline observation session, the study identified three themes. First, the community functions as a value-driven social arena in which identity is grounded in solidarity, process orientation, behavior-based authenticity, and lifestyle expression. Second, consumption operates through modular brand mixing that combines affordable local components with aspirational global brands. Third, unmet needs include public-space conflict, infrastructure inequality, beginner uncertainty, and the cultural repositioning of skateboarding within mainstream society.

Implications. The results hold practical implications for local and global skate brands, for digital marketers, and for urban planners. Component-level credibility is likely to outperform single-brand ecosystem positioning in a market where skaters mix components deliberately. Local brands benefit from affordability and accessibility, but durable growth requires communicating performance reliability and community legitimacy rather than positioning on price alone. Global brands retain aspirational value among progressing skaters, but aspiration is not equivalent to loyalty in a modular market; cultural embedding in local skate narratives is more likely to translate aspiration into sustained purchase than standardized global imagery. Beginner pathways, including structured introductory sessions and mentorship linked to gear guidance, address a visible gap that both skateparks and brands could co-develop.

Limitations and Future Research. The study has important limitations. The interview sample is small (n = 5) and geographically concentrated at a single skatepark in Central Jakarta, the netnographic window was short (approximately ten to twelve hours), and all interview participants were male. Interpretive claims, including the softened-subculture framing, should therefore be treated as exploratory rather than generalizable. Future research should expand the sample across Greater Jakarta locations including Bekasi, Bogor, and Tangerang, extend netnographic observation over a longer period, incorporate female skateboarders, and examine intergenerational dynamics between Millennial and Gen Z participants. Further work on grip-tape customization and other material practices would deepen understanding of how identity has materialized through gear.

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ECONOMIC TRADE-OFF BETWEEN FOREST HARVESTING AND TOURISM REVENUES: A CASE STUDY IN SUCEAVA COUNTY

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ABSTRACT

This paper investigates the economic trade-offs between forest harvesting and tourism attractiveness in the mountain areas of Suceava County, using data on **arrivals**, **overnight stays**, and the **number of accommodation units**, which are correlated with spatial indicators of forest area and timber loss. The analysis covers the period 2005–2024 and combines: (1) spatial analyses based on satellite data to quantify changes in forest area and to locate logging sites; (2) panel econometric models at the commune level to test the relationship between harvesting intensity and the evolution of tourism indicators, controlling for accessibility, infrastructure, and local marketing; and (3) cost–benefit assessments for three forest-management scenarios (current harvesting, harvesting with buffer zones, and certified sustainable practices). The results estimate elasticities of arrivals and overnight stays with respect to percentage changes in the forest area visible from main tourist routes, and identify communes where potential losses in tourism revenue exceed timber revenues. The study provides a set of indicators and thematic maps useful for local decision-makers and proposes practical measures: establishing buffer zones around trails and viewpoints, incentives for forest certification, and compensation mechanisms for communities dependent on harvesting. The conclusions support integrating tourism-attractiveness indicators into forest management plans to maximise net economic benefits over the medium and long term.

AI AND CONTEMPORARY BUSINESS PRACTICES IN ARCHITECTURE. A CASE OF ARCHITECTURAL DESIGN INDUSTRY IN PAKISTAN

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ABSTRACT

The integration of Artificial Intelligence (AI) into contemporary business practices within the architecture industry is reshaping how professionals approach design, project management, and client engagement. This transformation is not just about leveraging cutting-edge technology but about enhancing the creative and operational processes that define architectural work. AI tools such as generative design, predictive analytics, and automated project management systems offer architects new ways to optimize workflows, reduce errors, and make more informed decisions, all while fostering creativity and innovation. However, the adoption of AI in architecture goes beyond improving efficiency—it is also redefining client-architect relationships by allowing for more interactive and responsive design solutions tailored to client needs.

Despite its potential, AI adoption in architecture raises important questions around ethics, professional identity, and the evolving role of architects in a technology-driven environment. As AI takes on more technical tasks, architects are prompted to refocus their efforts on conceptual thinking, sustainability, and human-centered design. This shift requires a balance between embracing the advantages AI offers and maintaining the critical, creative skills that are the hallmark of architectural practice.

This paper explores how AI is influencing contemporary business practices in architecture, highlighting the opportunities and challenges it presents for the profession. It argues that while AI can enhance efficiency and decision-making, it should be viewed as a tool that complements, rather than replaces, the expertise and intuition of architects. By examining real-world applications and theoretical perspectives, this paper aims to provide a nuanced understanding of the impact of AI on the business landscape of architecture today.

Keywords: Artificial Intelligence (AI), Business Strategies, Architectural Innovation, Digital Transformation

CRYOPRESERVATION AS A BASIS FOR THE DEVELOPMENT OF A CRYOGENIC BANK FOR *Solanum tuberosum* L.

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ABSTRACT

Under conditions of increasing intensity of climate change and growing frequency of extreme meteorological events, an increased vulnerability of existing collections of plant genotypes is observed. The loss of valuable genetic material would lead to significant long-term negative consequences for breeding programs and the conservation of agrobiodiversity. Cryopreservation represents a highly effective method for long-term storage of plant material at ultra-low temperatures (−196°C in liquid nitrogen), at which metabolic activity is suspended and genetic information is preserved in an unchanged state. The method is characterized by the possibility of practically unlimited storage duration, reduced energy costs, limited spatial requirements, and elimination of the need for periodic subculturing and regeneration of plant material.

In the species *Solanum tuberosum* L., traditional approaches for storage, including maintenance of field collections and *in vitro* cultures, do not guarantee full genetic stability over time and are susceptible to the influence of biotic and abiotic stress factors. This necessitates the creation of a cryobank as a reliable strategy for long-term storage and protection of valuable genetic material.

The main objective is to develop a scientifically grounded model for effective long-term storage of genetic information in a cryobank. At the international level, cryopreservation of this species is integrated into the activities of leading scientific centers and cryogenic banks and is regarded as a strategic component in systems for the conservation of plant genetic resources and sustainable development of breeding programs.

Keywords: cryopreservation, *Solanum tuberosum* L., genetic resources, cryobank, biodiversity conservation

1. INTRODUCTION

The conservation of plant genetic resources is a fundamental prerequisite for ensuring global food security, sustainable agriculture, and biodiversity preservation. In recent decades, climate change has introduced additional risks to the stability of *ex situ* collections, increasing the likelihood of genetic erosion and loss of valuable germplasm.

The Institute of Plant Genetic Resources “Konstantin Malkov” was established in 1902 as an experimental agricultural station, which in 1977 developed into an Institute of Plant Genetic Resources. Bulgaria possesses rich biological diversity due to highly diverse climatic, geological, topographical, and hydrological conditions. On the territory of the Institute is located the National Genebank, in which 71,710 seed samples are stored out of a total of 62,131 registered as a gene pool in the country (http://eurisco.ecpgr.org).

The main scientific directions at the Institute of Plant Genetic Resources “Konstantin Malkov” – Sadovo are aimed at collection, study, conservation, documentation, and utilization of plant genetic resources (Velcheva 2011; Desheva, 2016, 2017). These collections provide opportunities for multifaceted use, determined by the available genetic diversity: wild species, local populations, primitive varieties, breeding materials, and modern cultivars originating from the country and the world (Stoyanova, 2002; Krasteva, 2008;Dimitrova et al., 2011).

Long-term storage of seed samples is carried out at subzero temperatures (−18°C) in a specially designated chamber. Vegetatively propagated species from cultivated and wild flora are cultivated under *in vitro* conditions. The accelerated development of plant biotechnology worldwide has transformed developed *in vitro* techniques from an ideal into a practical necessity (Atanasov, 1988; Uzundzhalieva et al., 2017).

2. BIOLOGICAL AND TECHNOLOGICAL CONSTRAINTS IN *Solanum tuberosum* L. CONSERVATION

The species *Solanum tuberosum* L. is one of the most significant crops on a global and national scale, with a key role in food security, sustainable agriculture, and the economy. The species is characterized by a vegetative mode of reproduction, which creates serious challenges for its long-term conservation. Traditional storage methods—field collections and *in vitro* storage—are associated with a high risk of loss of genetic diversity, accumulation of somaclonal variations, phytopathological infections, and dependence on constant human and financial resources (Constable, 1990; Ruseva, 1990).

For three decades, the largest collection of *Solanum tuberosum* L. has been built, maintained, and updated in the Plant Biotechnology Laboratory at the Institute. The main tasks defining the conservation of the species are:

- Collection, evaluation, conservation, and use of original samples of national and foreign origin. Priority thematic directions include permanent enrichment of collections with germplasm of diverse origins and types; expansion of knowledge on biological characteristics, interactions, and responses of ecotypes and environment.

- Production of virus-free planting material and maximum propagation.
- Adapted varieties are grown in experimental fields, using virus-free material, and studied for *in vitro* propagation and storage.

3. CRYOPRESERVATION AS A NECESSARY STRATEGY FOR LONG-TERM CONSERVATION

A significant scientific problem in modern plant biology is the long-term preservation of genetic information in vegetatively propagated crops. In the species *Solanum tuberosum* L., traditional storage approaches – field collections and *in vitro* cultivation – do not ensure full genetic stability over time and are vulnerable to biotic and abiotic stress factors. This necessitates the establishment of a cryogenic bank for *Solanum tuberosum* L., which is scientifically and practically necessary, since cryostorage requires minimal space, reduces the need for constant maintenance, and provides maximum protection of valuable genetic material for a long period of time.

In recent decades, cryostorage has established itself as a leading scientific approach for long-term conservation of plant genetic resources, especially in vegetatively propagated crops such as *Solanum tuberosum* L. Modern research in the field of plant cryobiology is aimed at the development and optimization of methods for storage of meristems, apical buds, and other *in vitro* cultivated explants through techniques such as vitrification, droplet-vitrification, and encapsulation-dehydration.

Scientific data show that the success of cryostorage in *Solanum tuberosum* L. is strongly dependent on the physiological state of the explant, the composition and concentration of cryoprotectants, as well as the regimes of cooling and thawing. In this context, modern science emphasizes the clarification of cellular and molecular mechanisms of resistance to cryostress, including the role of membrane stability, antioxidant protection, and osmotic adaptation.

At the international level, cryostorage of the species is integrated into the activities of leading cryobanks and scientific centers and is accepted as a strategic element of systems for conservation of agrobiodiversity. At present, the largest cryopreserved collections of the species *Solanim tuberosum* L. are in the International Potato Center (CIP), Peru, the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) — Gatersleben, Germany, the National Clonal Germplasm Repository — USA, and the National Genebank of China.

In the All-Russian Institute of Plant Genetic Resources “N. I. Vavilov”, approximately 6–8 thousand potato samples are preserved, which makes it one of the richest collections in the world for this crop.

As of August 2023, the cryobank of the International Potato Center (CIP) in Peru stores 4450 plant genetic materials of the species *Solanim tuberosum* L. (with explant survival above 80%), which represents 91% of the *in vitro* potato collection of CIP. The conserved accessions in the cryobank belong to seven cultivated potato species and four different levels of ploidy (Hawkes, 1990; Vollmer et al. 2017).

In the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) — Gatersleben, Germany, more than 1400 species of *Solanim tuberosum* L. are stored, with the collection being continuously expanded. The survival of explants is 80% when applying the PVS2 method. It has been established that *Solanum tuberosum* L. with the ability for cold acclimation or freezing resistance are more capable of responding positively to cryoconservation (Panta et al., 2014).

The centers in Peru and Gatersleben for storage of plant genetic resources have undertaken targeted measures for protection and long-term preservation of stored materials through the creation of cryoduplicates and the construction of backup facilities. The application of cryoconservation technologies guarantees the preservation of viability and genetic stability of the samples. The construction of backup facilities complements this strategy by providing additional protection against potential risks related to natural disasters, technical failures, or other unforeseen events. In this way, a reliable storage system is created, which contributes to the maximum preservation of plant genetic diversity and ensures the sustainability of collections in the long term (Vollmer et al., 2016).

The advantages of this method are that the storage of plant tissues in liquid nitrogen provides the possibility for an unlimited period of preservation (Razdan MK, 1997; Bajaj YPS, 1995). The method relies on liquid nitrogen in independent reservoirs and does not depend on cooling or constant electricity supply. It is also economically efficient due to reduced energy costs, limited space requirements, and because there is no need for regular regeneration of plant material. For these reasons, the development and application of effective cryoconservation methods is of essential importance for ensuring the security of plant genetic resources and their accessibility for future scientific research, breeding, and biodiversity conservation (Engelmann F., 2004).

A pioneer in the cryostorage of plant material at ultra-low temperatures is prof. Akira Sakai, who succeeded in preserving cold-resistant branches of mulberry by freezing in liquid nitrogen (−196 °C). He established that for tissue survival it is important to apply preliminary “hardening” and dehydration in order to reduce damage from crystallizing water in the cells. He developed a plant vitrification solution (PVS2), which is one of the most widely used solutions for plant cryoconservation to date (Sakai et al., 1990).

The first scientific experiments on cryoconservation of the species *Solanum tuberosum* L. were carried out by Bajaj (1977) , who used ultra-rapid freezing. Donor plants are obtained from *in vitro* slow growth cycles, including storage of microtubers (Thieme R., 1992; Panta et al., 2014).

The scientific team of Schäfer-Menuhr in 1996 developed a simple method for freezing an *in vitro* collection of old potato varieties, which was published in Potato Research. They froze more than 125 varieties, obtaining an average of 80% survival, with the genetic stability of the plants after recovery being preserved. The regeneration percentage of plants was lower and averaged 40%. Plants were obtained from all frozen varieties or genotypes, and the phenotypes of the regrown plants corresponded very well to those of the non-frozen plants.

For effective protection against cryodamage in the species *Solanum tuberosum* L., the use of mixtures of cryoprotectants of different types is recommended. Most often, the PVS2 solution is applied (Sakai et al., 1990), which contains several cryoprotectants (30% glycerol, 15% DMSO, 15% ethylene glycol, 0.4 M sucrose), as well as micro- and macroelements according to the recipe of Murashige and Skoog, 1962 (Murashige T., Skoog F., 1962). The concentration and duration of treatment with cryoprotectants must be determined very precisely for each new plant object in order to preserve the viability of explants (Becker, 1991; Alpsancar, 2016; Matsumoto, 2017 ; Braun et al., 2023).

More effective variations of the PVS2 method were published in 2014, demonstrating that preliminary treatment of plant material through cold hardening and sucrose hardening significantly improves the recovery rate after cryostorage (Panta et al., 2014).

Different methods for preliminary treatment of initial microcuttings as sources of explants for cryoconservation also affect the efficiency of regeneration after thawing. To assess the effectiveness of cryoconservation of plant material, the indicator recovery ability after cryoconservation is most often used (Towill L. E., Ellis, 2008). The decrease in explant viability is due to the degree of cryodamage occurring during cryoconservation, while the regeneration capacity characterizes the rate of restoration of growth and development of the explant after thawing. Cryodamage to cells is mainly determined by two factors. First, the formation and growth of intracellular ice crystals during rapid freezing or the formation of ice crystals in the intercellular space during slow freezing. Second, the processes of excessive dehydration during subsequent thawing (Benson et al., 2006; Popov A., 2008).

Despite the significant progress in the field of plant cryobiology, there are a number of limitations and insufficient knowledge regarding the cryostorage of potato *Solarium tuberosum* L. Methods such as vitrification and encapsulation-dehydration have not been systematically

optimized for different varieties and genotypes, and the long-term genetic stability of the material remains insufficiently studied. The mechanisms of cellular adaptation to cryostress have not been studied in detail at the physiological, molecular, and genetic levels. There is a lack of systematic data on the interactions between cryoprotectants, the structure of cell membranes, and genetic stability after thawing. The absence of a national cryogenic bank for the species *Solanum tuberosum* L. in Bulgaria limits the effective conservation of the plant gene pool.

4. ADVANCES IN CRYOBIOLOGICAL METHODS

4.1. In vitro cultivation of plant material and standardization of growth conditions

The introduction of the plant species *Solanum tuberosum* L. is carried out through apical and axillary meristems for the production of virus-free planting material. Apical or lateral buds (0.1–0.5 mm) are used as initial material. The advantages of this method include a high degree of virus elimination and genetic stability of the species. The disadvantages of the applied procedure include difficult and precise isolation.

The cultivation of explants during the experimental stages is carried out in a chamber with a temperature regime of 22–25°C and a photoperiod of 16 hours darkness and 8 hours light with illumination of 3000 lx. Propagation is performed in laminar flow cabinets, while tissue cultures are grown in phytostatic rooms under full control of sterility, light, and temperature conditions.

4.2. Preparation of explants (meristems, apical buds) for cryopreservation

To obtain sterile, viable, and physiologically suitable explants from *in vitro* plants for subsequent stages of cryopreservation (precultivation, osmotic protection, vitrification, or dehydration), *in vitro* grown plants (2–6 weeks old, actively growing) are required. The plants must be in an active growth phase, healthy *in vitro* plants with well-formed apical meristems or buds, without signs of vitrification, necrosis, or contamination. All manipulations are carried out under sterile conditions.

4.3. Cryobiological methods – vitrification, droplet-vitrification

To achieve cellular protection through vitrification, plant vitrification solutions (PVS) are used, including the first developed PVS2, which contains 30% (w/v) glycerol, 15% (w/v) ethylene glycol, 15% (w/v) DMSO, and 0.4 M sucrose in a basal nutrient medium, as well as PVS3, containing 50% (w/v) glycerol and 50% (w/v) sucrose.

The main characteristics of vitrification solutions are their ability to vitrify themselves during rapid cooling and the presence of penetrating and osmotically active compounds, which facilitate cellular dehydration and vitrification of the cytoplasm. At the same time, the solution must not be excessively toxic.

4.4. Use of cryoprotectants and optimization of their concentration and exposure time

The use of cryoprotectants is a key factor for successful cryopreservation of *Solanum tuberosum* L., as they limit ice formation and stabilize cell membranes at ultra-low temperatures. Penetrating (dimethyl sulfoxide (DMSO), glycerol, ethylene glycol, propylene glycol) and non-penetrating (sucrose, trehalose, sorbitol, mannitol) cryoprotectants are applied individually or in combination, and their concentration and exposure time have a significant influence on the survival and regeneration capacity of explants.

High concentrations may induce osmotic and chemical stress, which requires careful optimization of treatment conditions. The project envisages a systematic study of the effect of different cryoprotectants and exposure regimes with the aim of achieving a balance between effective protection and minimal toxicity. The obtained results will contribute to the development of scientifically grounded and reproducible protocols for cryopreservation of *Solanum tuberosum* L.

4.5. Storage at ultra-low temperatures (liquid nitrogen, −196°c)

During the storage of plant tissues of *Solanum tuberosum* L. at ultra-low temperatures (−196°C), stabilization of cellular structures and cessation of metabolic activity occur, which allows preservation of cell viability and genetic stability after thawing. Successful recovery is a result of specific physiological and molecular mechanisms of adaptation to cryostress.

4.6. Controlled thawing and recovery of cultures

Controlled thawing represents a critical stage in the cryopreservation process, which determines the degree of cell survival and the successful recovery of plant material. During the thawing of cryopreserved tissues of *Solanum tuberosum* L., rapid temperature changes may induce secondary ice formation, osmotic imbalance, and membrane damage, which necessitates the application of precisely controlled regimes.

In modern cryobiology, it is accepted that rapid and controlled thawing, followed by gradual removal of cryoprotectants, minimizes cellular stress and supports the recovery of physiological functions of plant genetic material.

4.7. Assessment of viability and regeneration capacity through morphological and physiological indicators

The assessment of viability and regeneration potential is a key stage for determining the effectiveness of cryopreservation protocols. The viability of plant tissues (*Solanum tuberosum* L.) after thawing will be evaluated through morphological indicators such as the condition of meristems, delay or recovery of growth, formation of new buds, and leaf structures.

Physiological indicators will include chlorophyll content, osmotic resistance, levels of reactive oxygen species, and the activity of antioxidant enzymes, which reflect metabolic activity and cellular stress.

4.8. Statistical processing and interpretation of experimental data

Statistical processing is a key stage for confirming the results of experiments on cryopreservation and recovery of plant material. All morphological and physiological indicators will be analyzed using appropriate quantitative methods, including analysis of variance (ANOVA), t-tests, and multivariate analyses for assessing variability between genotypes, cryoprotectant treatment conditions, and thawing regimes.

5. CHALLENGES AND FUTURE PERSPECTIVES

Although cryopreservation is widely recognized as a reliable conservation method, several limitations remain. The molecular mechanisms underlying cryotolerance are not fully understood, and the long-term genetic stability of cryopreserved material requires further investigation.

In Bulgaria, the absence of a dedicated cryobank for *Solanum tuberosum* L. represents a significant gap in the national system for plant genetic resource conservation. Establishing such a facility is essential for safeguarding valuable germplasm against environmental and technological risks.

Future research should focus on optimizing cryopreservation protocols, improving regeneration efficiency, and integrating molecular tools to assess genetic stability. These efforts will contribute to the development of robust cryogenic conservation systems capable of supporting breeding programs and ensuring sustainable agricultural development.

6. CONCLUSION

Cryopreservation represents the only method that allows practically unlimited long-term preservation of plant material at ultra-low temperatures, in which metabolic processes are temporarily halted and genetic information is preserved in an unchanged state.

A thorough investigation of the physiological and molecular mechanisms determining the survival and regeneration capacity of tissues of the species *Solanum tuberosum* L. after cryopreservation is of exceptional importance. It ensures maximum protection of genetic resources, guarantees their stability, and creates a foundation for the sustainable development of breeding and agriculture under conditions of global environmental challenges.

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INVISIBLE SYNERGIES: MICROPLASTICS AS HIDDEN DRIVERS OF PFAS MOBILITY AND ENVIRONMENTAL RISK

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ABSTRACT

Per- and polyfluoroalkyl substances (PFAS) and microplastics (MPs) are globally pervasive contaminants that increasingly co-occur, yet their coupled behaviour remains poorly constrained. This review synthesizes current knowledge on how MPs act as hidden drivers of PFAS mobility and environmental risk. We examine sorption mechanisms governing PFAS partitioning onto MPs, including hydrophobic interactions, electrostatic forces, and the role of surface functional groups, with particular emphasis on the enhanced reactivity of aged and weathered plastics. Beyond passive adsorption, MPs are evaluated as dynamic transport vectors that influence PFAS distribution across water, sediment, and soil compartments, potentially altering bioavailability and exposure pathways. Conflicting evidence on the significance of MP-mediated transport is critically assessed, highlighting the importance of environmental conditions and contaminant mixtures. Key knowledge gaps are identified, including competitive sorption, transformation processes, and soil–plant transfer. The review advocates for integrated experimental and modelling approaches to better quantify risks associated with PFAS-MP co-contamination.

Keywords: PFAS; Microplastics; Vectors; Environmental pollution; Transport; Risk

SUSTAINABLE AI AND THE "GREEN COMPUTE" MANDATE BALANCING INTELLIGENCE WITH PLANETARY BOUNDARIES

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ABSTRACT

As AI's energy demands rival those of small nations, the human need for a liveable planet is in direct conflict with the need for intelligence. This research examines "Sustainable AI" frameworks that prioritize energy-efficient model training and "Green Compute" data centers. The study evaluates the 2026 trend of "Small Language Models" (SLMs) that provide high-level reasoning with 90% less energy than their predecessors. By analyzing the lifecycle carbon footprint of AI, the paper proposes a "Sustainability Score" for all digital transformation projects. The research concludes that the true measure of technological progress in 2026 is not just the power of the model, but its ability to operate within the "Planetary Boundaries" of a carbon-constrained world.

Keywords: Sustainable AI, Green Compute, Small Language Models, Carbon Footprint, Planetary Boundaries, Energy-Aware AI.

REDUCING ENVIRONMENTAL IMPACTS THROUGH SUSTAINABLE NITROGEN PRACTICES

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ABSTRACT

In agriculture, soil and water pollution by nitrates is significantly exacerbated by the excessive use of nitrogen fertilizers, which can lead to major environmental impacts such as eutrophication, groundwater contamination, and health risks.

Several strategies have been developed to address these issues by reducing nitrogen inputs while improving nitrogen use efficiency and maintaining agricultural productivity.

These strategies include adjusting fertilizer application rates, using slow-release fertilizers, applying precision fertilization tailored to crop needs, introducing nitrogen-fixing crops such as legumes, practicing crop rotation, and improving agricultural techniques.

These approaches not only help limit nitrogen losses to the environment but also enhance the quality of agricultural products and reduce costs for farmers. They form part of a broader effort to ensure the sustainability of agricultural systems in the face of climate change, balancing productivity, environmental protection, and resilience.

Keywords: Nitrate pollution, Nitrogen fertilizers, Groundwater contamination, Eutrophication, Precision fertilization, Sustainable agricultura, Environmental protection, Climate change resilience

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