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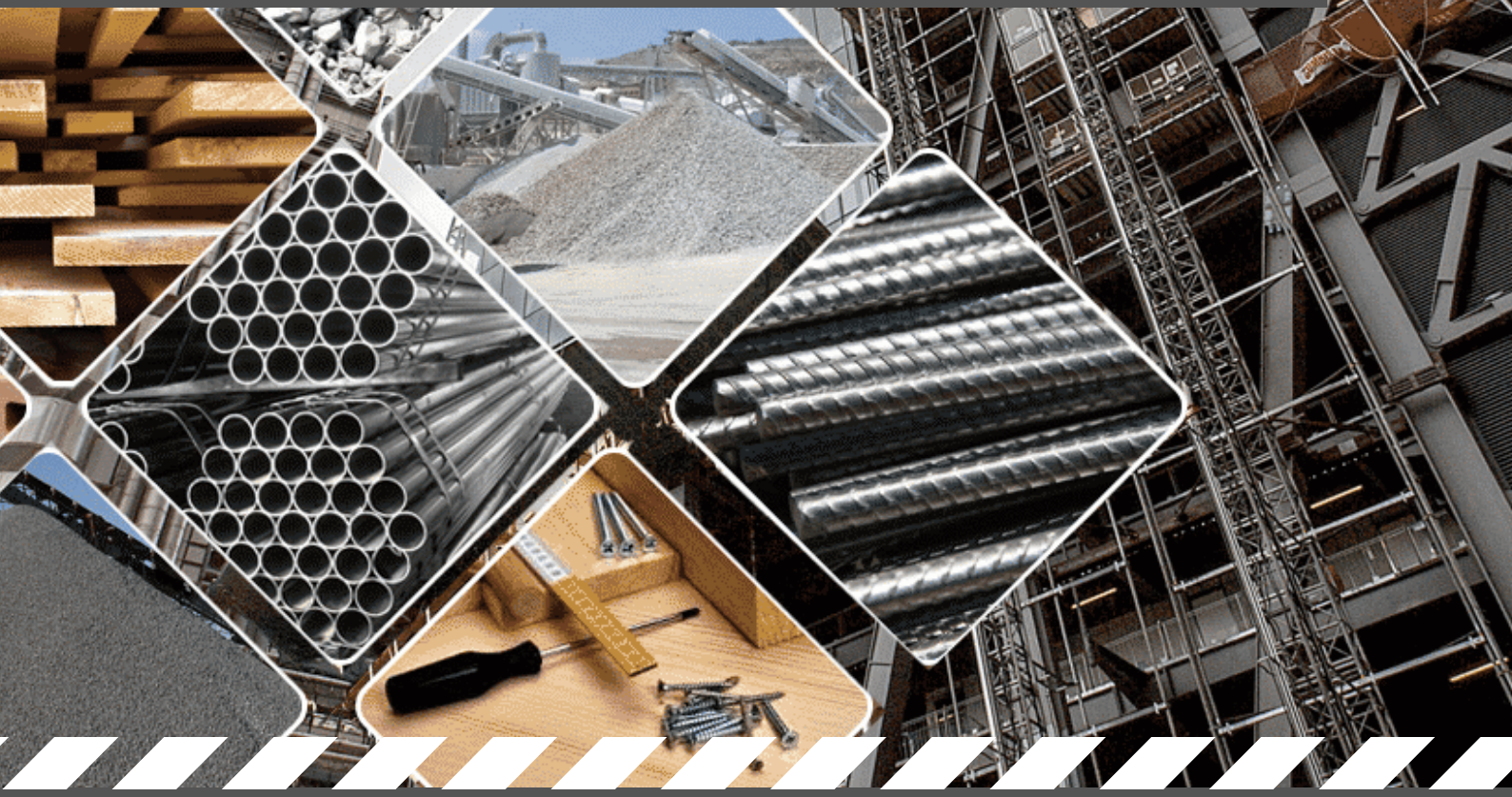

PROCEEDINGS BOOK

EDITORS:

Dr. Ethem İlhan Şahin

Dr. Jamal Eldin Fadoul Mohammed IBRAHIM

15 December 2024

Adana

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15 December 2024, Adana

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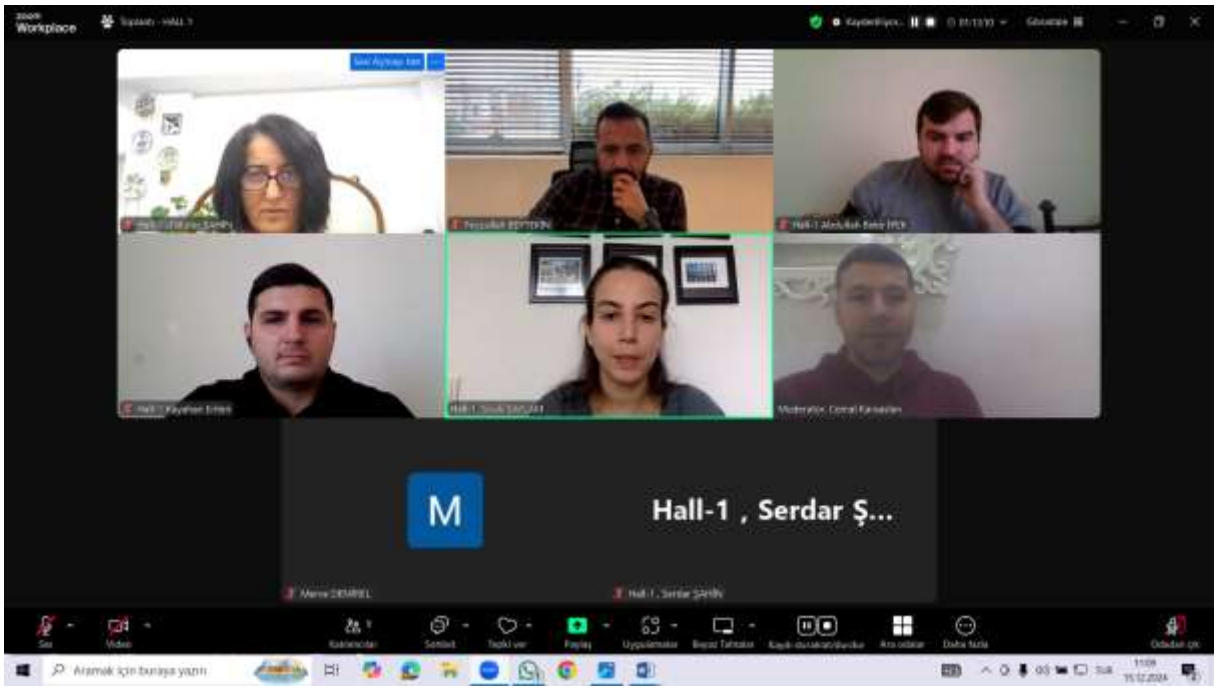


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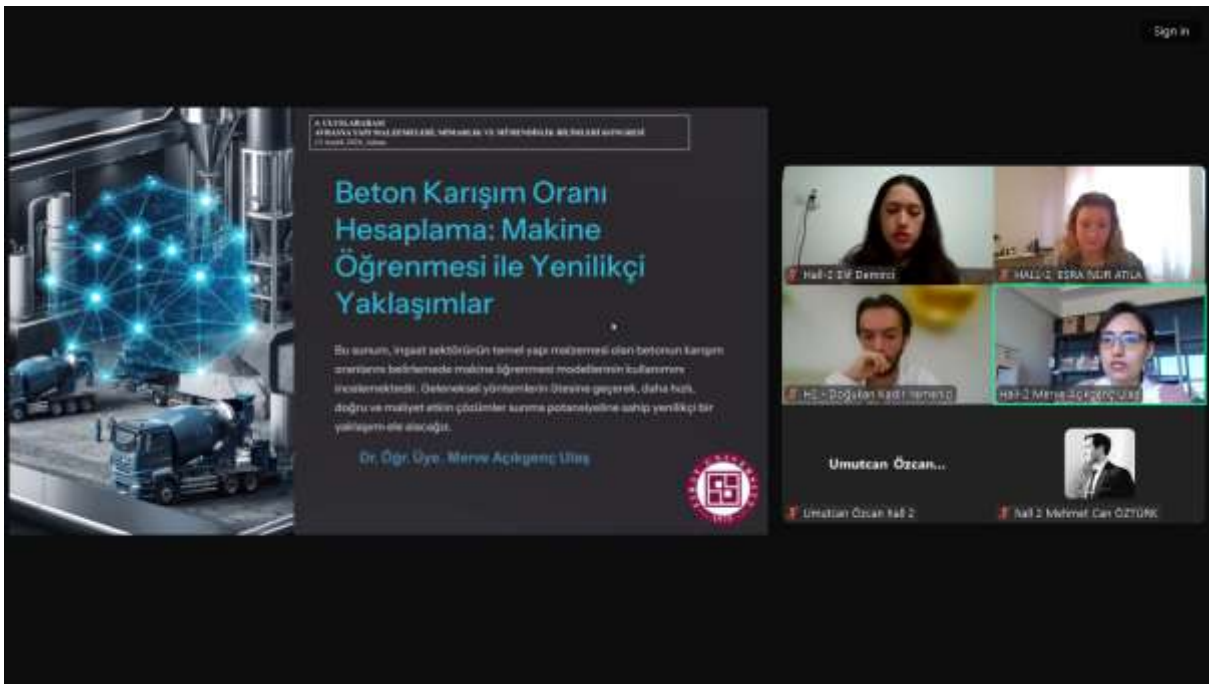
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Session-1, Hall-1

15.12.2024

Moderator: Assist. Prof. Dr. Cemal KARAASLAN

Meeting ID: 870 6274 8180 / Passcode: 151515

Ankara Local Time: 10:00 – 12:00

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PERFORMANCE EVALUATION OF RHEOLOGICAL MODELS FOR CARBON NANOTUBE-ENHANCED CEMENTITIOUS GROUTS	Kayahan ERİTEN Hamza GÜLLÜ	Gaziantep University, Türkiye
ANALYSIS OF SOIL LIQUEFACTION FORMULAS USING OPTIMIZATION ALGORITHMS	Abdullah Bekir İPEK Soner UZUNDURUKAN	Süleyman Demirel University, Türkiye
EFFECT OF CALCINATION TEMPERATURE AND DURATION ON THE COMPRESSIVE STRENGTH AND WATER RESISTANCE OF VOLCANIC ASH-BASED GEOPOLYMER MORTARS	Merve DEMİREL Cemal KARAASLAN	Iğdır University, Türkiye
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SUSTAINABLE USER COMFORT AND MATERIAL USE IN CONTEMPORARY HOUSING	Soufi SAYLAM	Başkent University, Türkiye

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Session-1, Hall-2
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Ankara Local Time: 10:00 – 12:00

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EXAMINATION OF THE COMBINED USE OF STEEL AND GLASS IN THE PRODUCTION OF ARCHITECTURAL SPACE THROUGH EXAMPLES	Esra Nur ATİLA	Bursa Uludağ University, Türkiye
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APPLICATIONS OF LIGHTWEIGHT POLYMER FACADES FOR SEISMIC RESILIENCE	Elif DEMİRCİ	İstanbul Esenyurt University, Türkiye
THE FUTURE OF CARBON CAPTURE TECHNOLOGIES IN SUSTAINABLE ARCHITECTURE WITH TIMBER STRUCTURES	Mehmet Can ÖZTÜRK	Osmaniye Korkut Ata University, Türkiye
THE USE OF PHASE CHANGE MATERIAL IN ARCHITECTURAL DESIGN	Doğukan Kadir YEMENİCİ Kübra Ekiz BARIŞ	Kocaeli University, Türkiye

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Meeting ID: 870 6274 8180 / Passcode: 151515
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Session-1, Hall-4
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Moderator: Subhashish Dey
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CONTENT

PROCEEDINGS BOOK

3D YAZICI İLE ÜRETİLEN PLA MALZEMELERDEEPOKSİ REÇİNE TAKVİYESİNİNİ ELASTİKİYET MODÜLÜNE ETKİSİ

EFFECT OF EPOXY RESIN REINFORCEMENT ON ELASTICITY MODULUS IN PLA MATERİALS PRODUCED WITH 3D PRINTER

***Nilüfer ŞAHİN*[1]**

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***Serdar ŞAHİN*[3]**

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ÖZET

PLA,(Polilaktik Asit) biyobozunur yapısı, çevre dostu özellikleri ve 3D yazıcılarda yaygın kullanım potansiyeli ile dikkat çeken bir termoplastik malzemedir. Bu özelliklerinin yanında, kırılgan yapısı ve mekanik dayanımının düşük olması PLA'yı yapısal uygulamalarda dezavantajlı duruma getirip kullanım alanının sınırlanmasına sebep olmaktadır. Bu çalışma, 3D yazıcı teknolojisi kullanılarak üretilen Polilaktik Asit (PLA) esaslı malzemelere epoksi reçine katkısının eklenmesiyle malzemenin mekanik performansında meydana gelen değişiklikleri değerlendirmektedir. Çalışmada, farklı oranlarda PLA (%10 ve %20 doluluk oranı) numuneleri üretilerek bu numunelere epoksi reçine katkı maddesi ilave edilmiş,uygulanan epoksi reçine katkı maddesinın hazırlanan numunenin maksimum elastisite modülü üzerinden mekanik performansları incelenmiştir.Uygulanan testler sonucunda,%10 doluluk oranına sahip PLA numunelerinde,epoksi reçine takviyesi elastikiyet modulünü %15 oranında düşürmüştür.Ancak 3D yazıcı ile hazırlanan numunenin yazdırma doluluk oranı %20 seviyesine çıkarıldığında,epoksi reçinenin elastikiyet modülündeki etkisi yalnızca %1'e düşmüştür.Bu sonuçlar,daha yüksek doluluk oranına sahip PLA malzemelerinin daha rijit bir iç yapıya sahip olduğunu ve uygulanan epoksi reçinenin mekanik özellikler üzerindeki etkisinin sınırlandığını göstermiştir.Ayrıca çalışma sonucunda epoksi reçine takviyesi ile PLA malzemelerin mekanik özelliklerinin optimize edilebilmesi için 3D yazıcı kullanılarak üretilen malzemelerin yazdırma doluluk oranlarının dikkatli seçilmesi gerektiği görülmüştür.Ayrıca çalışma ile bu tür malzemelerin gelecekte mühendislik ve endüstriyel uygulamalarda kullanılabilirliğini artırmak için hem malzeme oranlarının hem de üretim parametrelerinin optimize edilmesi gerektiği sonucuna varılmıştır.

Anahtar Kelimeler: biyokompozit, polilaktik asit, 3d yazıcı, epoksi reçine.

ABSTRACT

PLA (Polylactic Acid) is a thermoplastic material that attracts attention with its biodegradable structure, environmentally friendly properties and potential for widespread use in 3D printers. In addition to these features, its brittle structure and low mechanical strength make PLA disadvantageous in structural applications and limit its usage area. This study evaluates the changes in the mechanical performance of the material by adding epoxy resin additive to Polylactic Acid (PLA) based materials produced using

3D printer technology. In the study, different ratios of PLA (10% and 20% filling ratio) samples were produced and epoxy resin additive was added to these samples, and the mechanical performances of the epoxy resin additive applied were examined on the maximum modulus of elasticity of the prepared sample. As a result of the applied tests, epoxy resin reinforcement decreased the modulus of elasticity by 15% in PLA samples with a filling ratio of 10%. However, when the printing filling ratio of the sample prepared by 3D printer was increased to 20%, the effect of epoxy resin on the modulus of elasticity decreased to only 1%. These results showed that PLA materials with higher filling ratios have a more rigid internal structure and the effect of the applied epoxy resin on the mechanical properties is limited. In addition, the study showed that in order to optimise the mechanical properties of PLA materials with epoxy resin reinforcement, the printing filling ratios of the materials produced using 3D printers should be carefully selected. It was also concluded that both material ratios and production parameters should be optimised to increase the usability of such materials in engineering and industrial applications in the future..

Keywords: biocomposite, polylactic acid, 3d printer, epoxy resin.

AHŞAP YAPILARDA KARBON YAKALAMA TEKNOLOJİLERİNİN SÜRDÜRÜLEBİLİR MİMARİDEKİ GELECEĞİ

THE FUTURE OF CARBON CAPTURE TECHNOLOGIES IN SUSTAINABLE ARCHITECTURE WITH TIMBER STRUCTURES

Y.Mimar Mehmet Can ÖZTÜRK

Osmaniye Korkut Ata Üniversitesi, Mimarlık Tasarım Ve Güzel Sanatlar Fakültesi, Mimarlık Ana Bilim Dalı, Osmaniye, Türkiye

ÖZET

İklim değişikliği ve doğal kaynakların tükenmesi, yapı sektöründe sürdürülebilirlik odaklı çözümleri zorunlu kılmıştır. Ahşap malzemeler ve karbon yakalama teknolojileri, sürdürülebilir mimaride önemli bir yer edinmiş, gelecek için umut vaat eden iki temel unsur haline gelmiştir. Bu bildiri, ahşap yapıların karbon yakalama teknolojileriyle entegrasyonunu ve bu birleşimin sürdürülebilir mimarideki gelecekteki potansiyelini incelemektedir.

Ahşap, yenilenebilir yapısı ve karbon depolama kapasitesi sayesinde sürdürülebilir yapı tasarımında kritik bir rol üstlenmektedir. Yaşam döngüsü değerlendirme (LCA) analizleri, ahşap malzemelerin çevresel etkilerinin diğer yapı malzemelerine göre daha düşük olduğunu göstermektedir. Prefabrikasyon teknikleriyle birleşen ahşap yapı sistemleri, enerji verimliliğini artırırken atık oranlarının azaltılmasına da katkıda bulunmaktadır.

Karbon yakalama teknolojileri ise, inşaat sektöründen kaynaklanan sera gazı emisyonlarını azaltmaya yönelik yenilikçi bir yaklaşım sunmaktadır. Hem üretim süreçlerinde hem de yapıların kullanım ömürleri boyunca karbon salınımını minimize eden bu teknolojiler, ahşap yapı sistemleriyle bir araya geldiğinde etkili bir karbon dengeleme stratejisi oluşturabilir.

Bu çalışmada, ahşap yapılarda karbon yakalama teknolojilerinin entegrasyonunun çevresel, ekonomik ve toplumsal faydaları ele alınmakta, bu yenilikçi yaklaşımların sürdürülebilir mimaride geleceği şekillendirme potansiyeli değerlendirilmektedir.

Sonuç olarak, ahşap malzemeler ve karbon yakalama teknolojilerinin birlikte kullanımı, sürdürülebilir mimarinin temel taşlarından biri olarak öne çıkmaktadır. Bu bildiri, söz konusu entegrasyonun yapı sektöründe daha yaygın bir şekilde benimsenmesi için farkındalık oluşturmayı ve yeni araştırmalara ilham vermeyi amaçlamaktadır.

Anahtar kelimeler: Sürdürülebilir mimari, ahşap yapılar, karbon yakalama teknolojileri, çevresel sürdürülebilirlik, yenilenebilir malzemeler.

ABSTRACT

Climate change and the depletion of natural resources have made sustainability-oriented solutions imperative in the construction sector. Timber materials and carbon capture technologies have emerged as two essential elements in sustainable architecture, promising significant potential for the future. This paper examines the integration of carbon capture technologies into timber structures and evaluates the potential of this combination in shaping the future of sustainable architecture.

Timber, with its renewable properties and carbon storage capacity, plays a critical role in sustainable building design. Life cycle assessment (LCA) analyses demonstrate that timber materials have significantly lower environmental impacts compared to other building materials. When combined with prefabrication techniques, timber building systems enhance energy efficiency while reducing waste rates.

Carbon capture technologies offer an innovative solution to reducing greenhouse gas emissions from the construction sector. By minimizing carbon emissions during production processes and throughout

the lifespan of buildings, these technologies, when integrated with timber systems, can form an effective carbon balancing strategy.

This study explores the environmental, economic, and social benefits of integrating carbon capture technologies into timber structures, evaluating their potential to shape the future of sustainable architecture.

In conclusion, the combined use of timber materials and carbon capture technologies is highlighted as a cornerstone of sustainable architecture. This paper aims to raise awareness and inspire new research on the broader adoption of this integration within the construction sector.

Keywords: Sustainable architecture, Timber structures, Carbon capture technologies, Environmental sustainability, Renewable materials

ZEMİN SIVILAŞMASI FORMÜLLERİNİN OPTİMİZASYON ALGORİTMALARI İLE İNCELENMESİ

ANALYSIS OF SOIL LIQUEFACTION FORMULAS USING OPTIMIZATION ALGORITHMS

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ÖZET

Bu çalışma, Türkiye Bina Deprem Yönetmeliği (TBDY 2018)'nde bulunan zemin sıvılaşması formüllerinin doğruluk ve etkinliğini artırmak amacıyla optimizasyon algoritmalarının uygulanmasını incelemektedir. Zemin sıvılaşması, özellikle deprem etkisi altında yer alan bölgelerde, yapı güvenliği ve zemin stabilitesini doğrudan etkileyen önemli bir mühendislik problemidir. Bu fenomene ilişkin tahmin yöntemleri, genellikle ampirik veya yarı-ampirik formüller aracılığıyla yapılmaktadır. Ancak bu formüllerin etkinliği çeşitli zemin özellikleri, jeolojik koşullar ve deprem parametrelerine bağlı olarak değişkenlik göstermektedir. Çalışmada mevcut zemin sıvılaşması formüllerinin performansını iyileştirmek ve tahmin doğruluğunu artırmak amacıyla modern optimizasyon algoritmalarının kullanımı kapsamlı bir şekilde ele almıştır.

Öncelikle sıvılaşma tahmininde kullanılan parametreler, saha verileri ve deneysel sonuçlar temel alınarak yeniden kalibre edilmiştir. Genetik algoritmaların geniş çözüm arama kapasitesi, parçacık sürü optimizasyonunun hızlı yakınsama yeteneği ve yapay sinir ağlarının karmaşık verileri modelleme kabiliyeti analiz edilmiştir. Optimizasyon uygulamaları, zemin sıvılaşması formüllerinde hata oranlarını azaltmış ve tahmin doğruluğunu artırmıştır. Bu yöntemler, sıvılaşma riskinin daha hassas ve olasılıksal olarak değerlendirilebileceğini göstermiştir.

Sonuçlar, optimizasyon algoritmalarının zemin sıvılaşması analizlerinde teorik modellerin iyileştirilmesi ve mühendislik uygulamalarında pratik çözümler sunulması açısından önemli bir katkı sağladığını ortaya koymaktadır. Çalışma bu yaklaşımların gelecekteki zemin sıvılaşması analizleri için daha güvenilir ve uyarlanabilir modeller geliştirme potansiyelini vurgulamaktadır.

Anahtar Kelimeler: Zemin Sıvılaşması, Optimizasyon Algoritmaları, Genetik Algoritma, Yapay Sinir Ağı, İnşaat Mühendisliği

ABSTRACT

This study examines the application of optimization algorithms to improve the accuracy and efficiency of the soil liquefaction formulas included in the Turkish Building Earthquake Code 2018. Soil liquefaction is a critical engineering problem that directly affects structural safety and soil stability, particularly in regions subject to seismic activity. Prediction methods for this phenomenon are typically based on empirical or semi-empirical formulas. However, the effectiveness of these formulas varies depending on soil properties, geological conditions, and earthquake parameters. This study comprehensively addresses the use of modern optimization algorithms to enhance the performance of existing soil liquefaction formulas and improve predictive accuracy.

In the study, the parameters used in liquefaction predictions were recalibrated based on field data and experimental results. The extensive solution-searching capacity of genetic algorithms, the rapid convergence ability of particle swarm optimization, and the modeling capability of artificial neural networks for complex data were analyzed. Optimization applications reduced error rates in soil liquefaction formulas and improved prediction accuracy. These methods demonstrated that liquefaction risks could be evaluated more precisely and probabilistically.

The results highlight that optimization algorithms significantly contributes to improving theoretical models in soil liquefaction analyses and providing practical solutions in engineering applications. This study underscores the potential of these approaches for developing more reliable and adaptable models for future soil liquefaction analyses.

Keywords: Soil Liquefaction, Optimization Algorithms, Genetic Algorithm, Artificial Neural Network, Civil Engineering

REDUCING EARTHQUAKE RISKS IN BURSA INDUSTRIAL ZONES: RESILIENCE AND SUSTAINABILITY STRATEGIES

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ABSTRACT

Earthquakes pose significant threats to industrial areas and structures, leading to economic losses as well as social and environmental impacts. The damage to critical infrastructures causes disruptions in production and supply chains, jeopardizing urban resilience and sustainable development goals. In this context, strategic planning and structural measures to reduce earthquake risks in industrial zones are of great importance.

This study was conducted to identify potential earthquake risks in industrial areas and independent industrial structures within the boundaries of Bursa Province and to develop strategies to reduce these risks. Within the framework of resilience and sustainability, the measures to be taken before, during, and after an earthquake are discussed.

The study addresses key concepts such as hazard, risk, and vulnerability; it analyzes the factors that cause damage and losses in industrial areas. By combining qualitative and quantitative analysis methods, both structural and non-structural risks were identified, and solution proposals for mitigating these risks were presented. Additionally, based on data from past earthquakes, laws and regulations regarding industrial areas in Turkey and around the world were reviewed, and the measures that should be taken to make buildings and settlements earthquake-resistant were explained. The strategic importance of industrial areas in contributing to urban resilience was evaluated within the framework of the concept of resilience.

Keywords: Earthquake, Industrial Zones, Resilience, Sustainability, Risk Reduction

SÜRDÜRÜLEBİLİR KULLANICI KONFORU VE ÇAĞDAŞ KONUTLARDA MALZEME KULLANIMI

SUSTAINABLE USER COMFORT AND MATERIAL USE IN CONTEMPORARY HOUSING

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ÖZET

Enerji tüketimindeki artış ve enerji kaynaklarının hızla tükenmesi, küresel çevre sorunları ve iklimsel özelliklerdeki değişikliklerle birlikte gelecek nesiller için endişe ve kaygı yaratmaktadır. Bu bağlamda, doğal kaynakların kullanılması ve sürdürülebilir çözümlerin iç mekân tasarımına dahil edilmesi kritik önem taşımaktadır. Öte yandan sürdürülebilir iç mekân tasarımı, kullanıcının fiziksel ve psikolojik gereksinimlerinden bağımsız olarak düşünülemez. Sürdürülebilir yaklaşımda, insanın en çok zaman geçirdiği ve barınma ve yaşama ihtiyacının yanı sıra çevresel, sosyal, kültürel ve ekonomik gelişimini sağlayan konut, iç mekân tasarımı anlamında doğayla uyumlu, enerji kaynaklarını verimli kullanımı ve kullanıcı konforunu sağlayan yapılar olarak oluşulmalıdır. Bu anlamda konut iç mekan tasarımında kullanıcı ihtiyaçları, çevresel, iklimsel, işlevsel ve sosyo-kültürel özellikler ile beraber düşünüldüğünde, sürdürülebilirliğin ve uzun süreli etkin kullanımın temelini oluşturmaktadır.

İç mekanda kimlik kazanımı sağlayan ve mekanın karakteristik özelliklerini ortaya çıkaran malzeme faktörü, aynı zamanda işlevsel, estetik ve psikolojik sürdürülebilirliği sağlayan önemli etkendir. Bu çalışmada, iç mekan tasarımında malzeme kullanımın işlevsel, estetik ve psikolojik etkileri ile beraber, kullanıcının sürdürülebilir konforunda olan etkileri araştırılacaktır. Çalışma kapsamında, sürdürülebilir iç mekân tasarımında seçilen malzemenin mekân organizasyonu, çevresel ve iklimsel gereksinimler, enerji kullanımı ve kullanıcı konforu üzerinde etkileri tartışılacaktır. Sonuç olarak çağdaş konutlarda seçilen malzemenin sürdürülebilir yaklaşımı anlamında, mekânın kimliği, iç mekân organizasyonu ve kullanıcının işlevsel ve estetik konforunu nasıl etkilediğini örnekler üzerinden incelenecektir.

Anahtar Kelimeler: Sürdürülebilir tasarım, kullanıcı konforu, fiziksel gereksinimler, psikolojik ve estetik konfor, konut iç mekân tasarımı

ABSTRACT

The increase in energy consumption and the rapid depletion of energy resources, together with global environmental problems and changes in climatic characteristics, create concern and anxiety for future generations. In this context, it is critical to utilise natural resources and incorporate sustainable solutions into interior design. On the other hand, sustainable interior design cannot be considered independently from the physical and psychological needs of the user. In the sustainable approach, housing, where people spend the most time and provide environmental, social, cultural and economic development as well as the need for shelter and living, should be formed as structures that are compatible with nature in terms of interior design, efficient use of energy resources and user comfort. In this sense, when user needs are considered together with environmental, climatic, functional and socio-cultural features in residential interior design, it forms the basis of sustainability and long-term effective use.

The material factor, which provides identity in the interior space and reveals the characteristic features of the space, is also an important element that provides functional, aesthetic and psychological sustainability. In this study, the functional, aesthetic and psychological effects of the use of materials in interior design, as well as the effects on the sustainable comfort of the user will be investigated. Within the scope of the study, the effects of the material selected in sustainable interior design on space organisation, environmental and climatic requirements, energy use and user comfort will be discussed.

As a result, it will be examined through examples how the material selected in contemporary residences affects the identity of the space, interior space organisation and the functional and aesthetic comfort of the user in terms of sustainable approach.

Keywords: Sustainable design, user comfort, physical needs, psychological and aesthetic comfort, residential interior design.

APPLICATION OF A NEW APPROACH TO ASSESSING THE PERFORMANCE OF A COMPLEX TECHNICAL SYSTEM

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ABSTRACT

Nowadays, the solution of the problem of monitoring and diagnostics of complex technical objects at all stages of its functioning is one of the main tasks in the theory of information and the construction of measuring systems. It is important to foresee possible malfunctions at the planning stage of the device model and minimize them during its operation.

Embedded systems have been widely developed today, since they allow analyzing the parameters of a certain measuring system without the necessary removal of measuring devices and sensors from the object. Most of them are built of some kind of measuring system with a set of sensors and microprocessor systems that control the macroscopic parameters of the device with a given degree of accuracy and with the required polling frequency.

At the same time, it is important to ensure the synchronicity of the sensor polling procedure, as well as to calibrate them in accordance with the mode in which they operate. It is impossible to exclude the fact that there are always probabilities of false alarm errors and missing a goal. The main task is to minimize these deviations, since they can make a significant error in the measurement results. It is worth considering the fact that when building an information and measurement system, the accuracy of each subsequent block should be no worse than the previous one.

Key words: technical system, data processing, correlation.

ASSESSING THE EFFECT OF BRICK POWDER ON THE MECHANICAL BEHAVIOR OF ECO-FRIENDLY CONCRETE

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ABSTRACT

The demand for concrete, driven by infrastructure and urbanization, exerts pressure on natural resources and jeopardizes the ecosystem. Integrating recycled materials into concrete can meet this demand without sacrificing quality. This study investigates the mechanical properties of environmentally sustainable concrete incorporating brick powder (BP) as a substitute for sand in fine aggregates. We utilized a combination of destructive and non-destructive testing techniques to assess the characteristics of the concrete. We formulated concrete mixtures by gradually replacing sand with brick powder in proportions ranging from 5% to 25%, and evaluated them for workability, compressive strength, and split tensile strength in comparison to conventional concrete. The results demonstrate that substituting 10% of sand with brick powder enhances strength by 29.94%, diminishes workability by 42.66%, and elevates split tensile strength by 8.74%. Regression analysis validated a robust correlation among compressive strength, ultrasonic pulse velocity (UPV), and rebound number. The incorporation of 10% brick powder improves concrete's mechanical properties and promotes sustainable construction methodologies.

Keywords: Brick powder; workability; strength, Schmidt hammer; ultrasonic velocity.

BUILDING A SUCCESSFUL BUSINESS RELATIONSHIP: A SOCIAL CAPITAL SYSTEMATIC REVIEW.

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ABSTRACT

social capital as a strategy for building a successful business relationship has been grossly under research by many scholars. As a result, this paper aimed to systematically review extant social capital articles and make suggestions for further research based on identified gaps. The study adopted the Systematic Quantitative Assessment Techniques (SQAT) in identifying and analysing 60 English peer-reviewed journal articles on social capital published between 2019 to 2024 from six high quality academic databases: Emerald, Taylor and Francis, Elsevier, Springer, Sage, and Wiley. The study revealed that most of the articles focused on social capital as a tool for enhancing SMEs performance. Majority of the articles were empirical in nature, with most of the studies utilizing social capital theory as theory that underpinned their study. A large number of the reviewed studies were conducted in Asia and Europe, with Spain being the country with highest publications. Surveys being the most prominent research methods and Structural Equation Modelling (SEM) being the most utilized data analytical techniques. The significant contribution of this study is that it is a new addition to the social capital field, offering insights as to the context of extant social capital scholarship, as well as identifying research gaps for future researchers to explore.

Keywords: Social Capital, Social Capital Theory, Systematic Quantitative Assessment Techniques, Systematic Review.

1.0 INTRODUCTION

In today's interconnected world, the success of a business often hinges not just on its products or services, but on the strength and quality of its relationships (Akomea *et al.,* 2023). As such, businesses now adopt social capital as the network of relationships that business owners build both within and outside the organization. These relationships influence knowledge sharing and collaboration that enhances the success of business organization (Zirena-Bejarano *et al.,* 2024). More so, Stasa Ouzký and Machek (2024) affirmed that social capital plays a pivotal role in shaping business performance by fostering collaboration, enhancing innovation and building customer loyalty. Furthermore, business organization that leverage on social capital can gain access to valuable resources and business opportunities that may not be available through traditional market mechanisms. This relationship fosters business connections that attract new customers and ultimately improve profitability of business organisation (Kim *et al.,* 2024).

As business organizations seek to thrive in competitive markets, understanding the impact of social capital becomes essential. By cultivating trust and connectivity within their networks, businesses can improve operational efficiency, drive creative solutions and ultimately achieve sustainable growth (Dar and Mishra, 2020). Considering the potential benefit of social capital to entrepreneurs globally, it is of great importance that the social capital field be explored in depth, as the concept could be what is needed by businesses to established successful relationship with stakeholders**.** As such, this study conducted a quantitative and systematic analysis of 60 articles in the field of social capital, in a bid to highlight trends and gaps which will serve as reference points for future research. In addition, the study recommended and offers propositions on possible ways to bridge such identified gaps

The remainder of this paper is organized as such: The methodology of the study is expounded, followed by the discussion of the findings and suggestions for future research. Lastly, the conclusion, limitations and future research opportunities based on such limitations are discussed.

2.0 METHODOLOGY

This study employed the "Systematic Quantitative Assessment Technique" (SQAT) developed by Pickering & Byrne (2013) in analysing the existing peer-reviewed journal articles on social capital. The step-by-step approach of the technique helped the researchers to identify gaps in the reviewed journals, such as the geographical distribution, theories adopted, methodologies used, focal themes, as well as the nature of the articles reviewed (Pickering & Byrne, 2013).

For an effective systematic review, the technique adopts five steps and the application of each step in this study is described in Table 1. 60 peer-reviewed English social capital articles met the criteria for selection, based on the six databases used by the researchers.

Table 1: Description and application of SQAT

S/N	Step	Application in current study
1.	Define topic	Social capital
2.	Formulate research questions	Five research questions: i. Where were these articles written? ii. What were the natures of published Social Capital articles? (Conceptual and Empirical) iii. Which theory/theories was/were adopted in these articles? iv. What research methods were employed in the research? v. What were the specific themes explored in the articles?
3.	Identify key words	"Social Capital"
4.	Identify and search databases	6 databases explored: Elsevier; Emerald; Sage; Springer; Wiley; Taylor and Francis; "All in title" search using single search: "Social Capital"
5.	Read and assess publications	i. Abstracts of articles found were read and where it was necessary, the entire paper was read to ensure that all the research questions were answered. ii. Literature reviews, book chapters, conference proceedings and a systematic review article were not included; only peer-reviewed conceptual and empirical papers were taken.

60 peer-reviewed social capital articles met the selection criteria from six high quality academic databases. Table 1 shows the topic of articles published between 2019 to 2024, countries where the articles were written, the natures of articles published, theories adopted in these articles, research methods, method of data collection and specific themes explored in the articles. Also, the key words used for the search was "social capital", the entire articles were read to ensure that all the research questions raised were answered. Only peer-reviewed articles were included and not conference proceedings or book chapters. Table 2 presents the social capital articles breakdown by publisher. Table2. social capital articles reviewed by publisher (2019-2024)

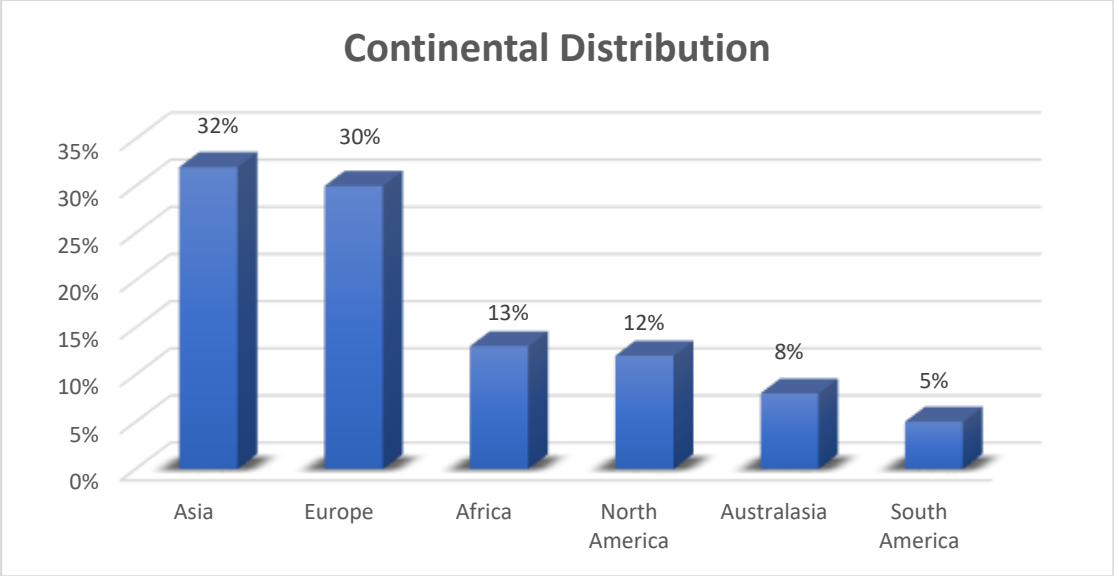
Table2. social capital articles reviewed by publisher (2019-2024)

S/N	Database	Number of Social Capital Articles
1.	Emerald	10
2.	Sage	10
3.	Elsevier	10
4.	Wiley	10
5.	Springer	10
6.	Taylor and Francis	10
	Total	**60**

3.0 FINDINGS, DISCUSSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Geographical Distribution of Social Capital Articles.

The geographical distribution of the 60 Social Capital articles reviewed in this study is presented in Figure 1:

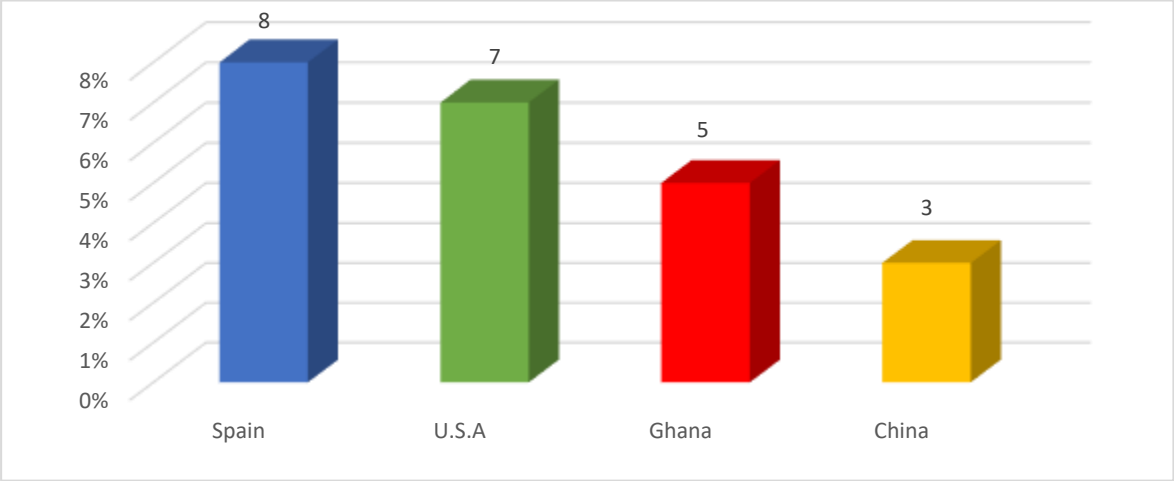


Source: Authors Review (2024)

It can be observed from Figure 1 that Asia had the highest number of published articles (19), representing 32% followed by Europe (18), representing 30%, of the articles and Africa (8), representing 13% of the articles respectively. More so, 12% representing 7 articles were found from North America, 8% representing 5 articles were found from Australasia and 5% representing 3 articles were found from South America. Based on the number of articles across the continents, it is obvious that South America and Australasia had the least number of scholarly papers in the area of interest, and this indicates a geographical gap in the social capital research. This is surprising considering that Australasia continent has good entrepreneurial ecosystem, particularly in technology and sustainable industries that foster trade agreements within the continent and other region, including the EU and Asia which facilitate easier access to markets and encourage cross-border commerce (Marjan *et al.,* 2024; Aritenang, 2021; Setini, *et al.,* 2020).

However, Language differences and varying communication styles among entrepreneurs can hinder effective collaboration and smooth business relationship among stakeholders (Knorst *et al.,* 2022; Zirena-Bejarano, 2024). It could be argued that the reason for a lack of extant English social capital articles in South America is because English is not the primary language spoken in this continent, and that perhaps the articles have been written in Spanish or Portuguese. While this argument intuitively makes sense, a counter-argument could be made that English is not the lingua franca of the Asian continent, yet it has the highest number of English social capital articles across the six databases examined in this study. Therefore, it is important that social capital researchers should focus on investigating the effect of social capital in Australasia and South America as there is a dearth of scholarly articles in these two continents, at least in the six databases utilized for this review.

From a country perspective, the article highlights that only twenty- eight (28) countries published social capital articles included in the systematic review. Figure 3 illustrates the top four countries where social capital research was conducted. The analysis showed that Spain is the country with the highest number of articles (8) and accounting for 13%, followed by U.S.A (12%), and Ghana (8%), and China (5%). Also, all four of the leading countries are depicted in Figure 2

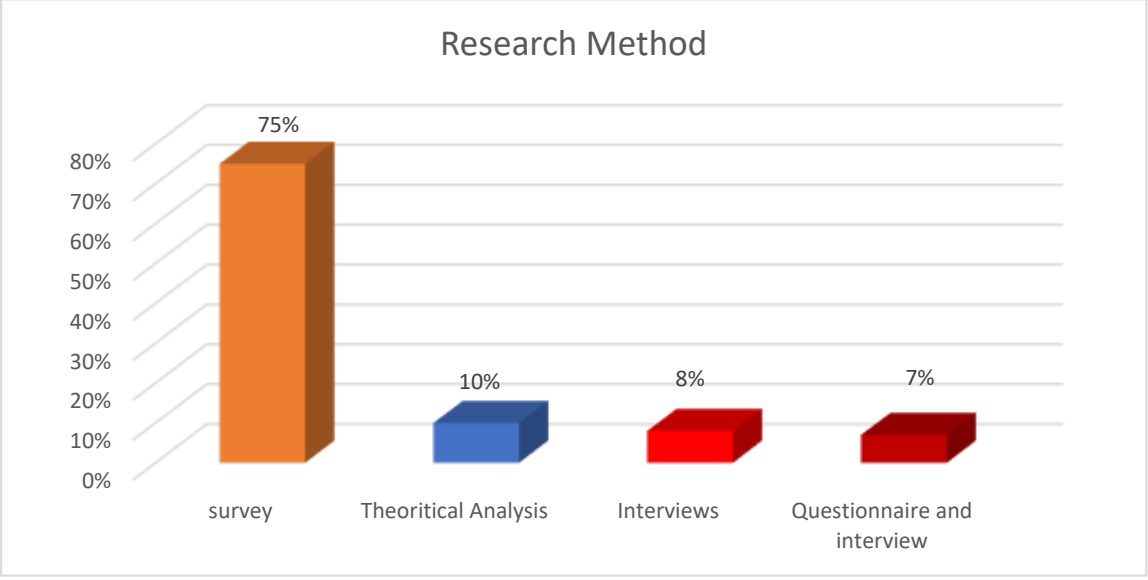


Top Four Countries by Research on Social Capital

A review of country analyses revealed that Spain is the country with highest number of articles on social capital. The reason might be due to the fact that Spanish culture encourage personal relationships and trust that foster collaboration among business practitioners and networking opportunities (Ripollés and Blesa, 2020). Sarmiento Prieto *et al.*, (2022) affirmed that Spain's geographical location makes it an ideal hub for trade between Europe, Africa, and the Americas. This accessibility attracts international businesses through social relationship. Researchers across all countries should prioritize social capital as intangible resources built through social relationship that can be utilized to create a successful business relationship and deliver value to shareholders.

Research Methods

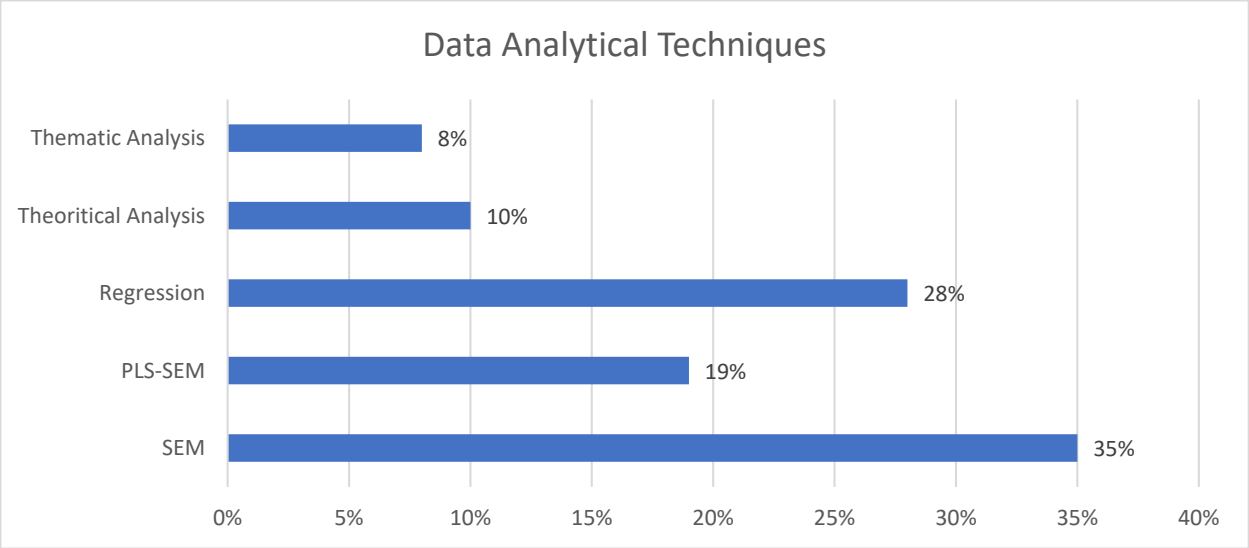
Figure 3: depicts the research methods adopted in each of the 60 social capital studies reviewed in this study.



Source: Authors Review (2024)

Based on the findings, 75% of the reviewed articles employed survey method in which structured questionnaires were administered to stakeholders for their responses regarding various issues underlying social capital (Tiwasing and Sawang 2022; Wu *et al.*, 2022; Santos *et al.*, 2023; Huang *et al.*, 2021). This was followed by articles using theoretical analysis (10%) which comprises of theories and models development as well as conceptual clarity that will enable a deeper understanding of existing concepts of social capital (Marjan *et al.*, 2024; Jeble *et al.*, 2022; Birasnav *et al.*, 2019). More so, 8% of the studies

adopted interview approach which involved collection of data directly from the person involved in the use of social capital as a strategy to build a successful business relationship with customers (Gubbins *et al.*, 2021; Aritenang, 2021).



The papers that adopted mixed method (qualitative and quantitative) are (7%) which involved the use of interview to gain insights that can inform the development of questionnaires instruments which will allow the researchers to explore social capital as a strategy for successful business relationship thoroughly by capturing both numerical data and personal experiences of the respondents (Ripollés and Blesa, 2020; Han *et al.*, 2022; Lee and Hallak, 2020).

The reviewed analysis revealed that majority of the social capital articles adopted survey with the use of structured questionnaires to elicit information from the respondents. The use of structured questionnaires to collect data limit the richness of data as nuances in respondents' thoughts are limited by fixed answers provided in the instruments (Wu *et al.*, 2022). However, mixed research method that comprises of the use of interview and questionnaires to collect data from respondents is the least research method utilized in this study (Ripollés and Blesa, 2020; Han *et al.*, 2022; Lee and Hallak, 2020). This method enriches the research process by combining the strengths of both qualitative and quantitative approaches, leading to a more nuanced and reliable understanding of social capital phenomena by capturing respondents' experience and numerical data (Yen *et al.*, 2022). Therefore, it is recommended that future social capital studies should adopt mixed research method of data collection in order to address the limitation of single method of data collection so that the results generated could be more robust and reliable.

The data analysis techniques of the 60 social capital articles reviewed in this study is presented in Figure 4:

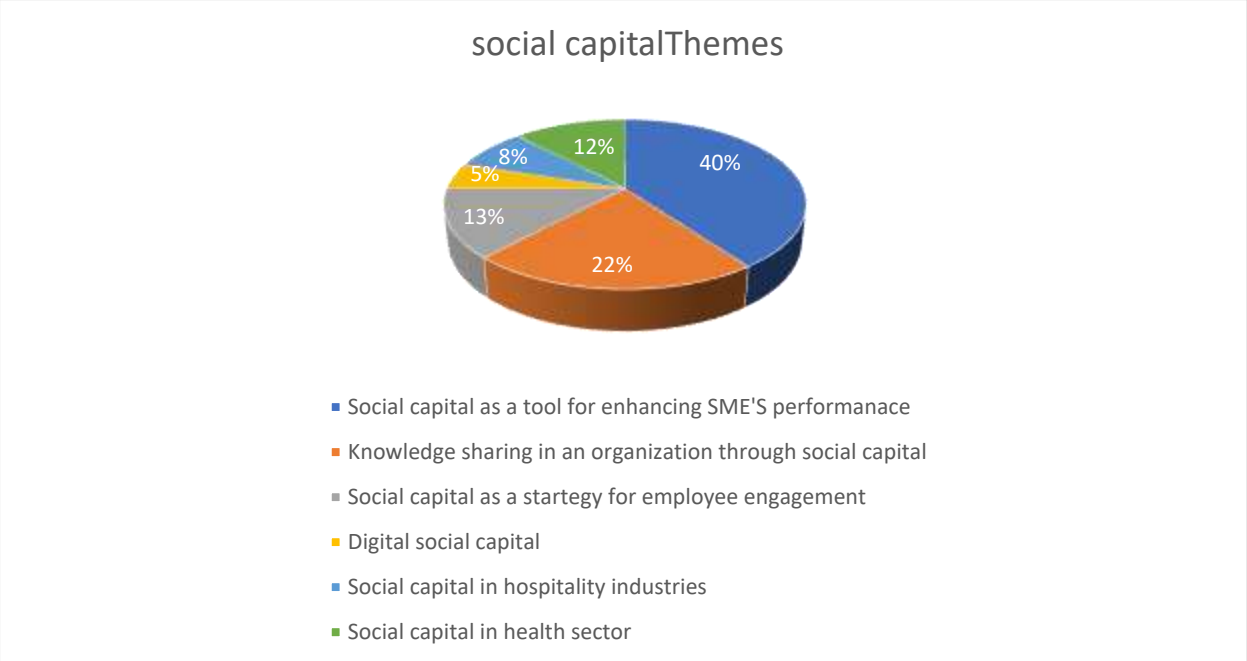
Sixty (60) empirical articles were reviewed in terms of the data analysis method adopted by the researchers. Out of the reviewed articles, twenty- one (21) articles representing 35% employed Structural Equation Model (SEM) as a method of data analysis for their studies, while seventeen articles (17) representing 28% used Multiple Regression as method of data analysis for their studies. Others were eleven (11) representing 19% of the reviewed article utilized Partial Least Square- Structural Equation Model (PLS-SEM) as a method of data analysis for their studies. More so, six (6) articles representing 10% used Theoretical Analysis and five (5) articles representing 8% employed Thematic Analysis as method of data analysis.

The reviewed analysis revealed that majority of the social capital articles utilized Structural Equation Model (SEM) as technique for their data analysis. The reason might be due to the fact that Structural Equation Model (SEM) allows researchers to examine direct and indirect relationship, which helps in understanding the interdependencies between variables unlike the traditional regression techniques that focuses on a single outcome variable at a time (Ripollés and Blesa, 2020; Yen *et al.*, 2022; Wu *et al.*,

2022; Tiwasing and Sawang 2022). However, thematic analysis is the least method of data analytical techniques which involves organizing and structuring data systematically in order to understand the meaning behind respondents' experiences and providing insights into social capital perspectives (Delilah Roque *et al.*, 2022; Brandhorst, 2023). However, Structural Equation Model (SEM) as the most utilized method of data analysis should be employ by future researchers on social capital because it allows researchers to examine direct and indirect relationship, which helps in understanding the interdependencies between variables of study.

Social Capital Themes

In this section a total of six themes, which were the focus point of the researchers were discovered and summarised in Figure 3. Based on the 60 articles reviewed. Social capital as a tool for enhancing SMEs performance was the theme with highest percentage (40%). The researchers focus on social capital as vehicle of building specific resources (tangible or intangible resources) that allows SMEs to have beneficial social ties that enhance business growth (Tiwasing and Sawang 2022; Ibeku and Nwagwu, 2024; Boateng *et al.*, 2020; Lee and Hallak, 2020; Sarmiento Prieto *et al.*, 2022). Follow by 22% of the authors that analysed knowledge sharing in an organisation through social capital (Santos *et al.*, 2023; Wu *et al.*, 2022; Han *et al.*, 2022). The researchers examined social capital as an act of social relationship that facilitates mutual exchange of knowledge among employees and reciprocal exchange of ideas that enhance organisational performance (Setini, *et al.*, 2020; Gubbins *et al.*, 2021). More so, (13%) of articles examined social capital as a strategy for employment engagement (Ali et al, 2024; Çiftçi, and Karadag, 2023; Yen *et al.*, 2022). The researchers examined the value of social networks within the workplace and how they can enhance job satisfaction, commitment, and overall performance (Çiftçi, and Karadag, 2023). The fourth most common theme, representing only (12%) of the articles reviewed, focused on social capital in health sector (Delilah Roque *et al.*, 2022; Knorst *et al.*, 2022; Tukamuhabwa *et al.*, 2023). The scholars considered social capital an important factor that is essential for fostering trust, improving patient outcomes, enhancing community health, and promoting equitable access to health care (Tukamuhabwa *et al.*, 2023).

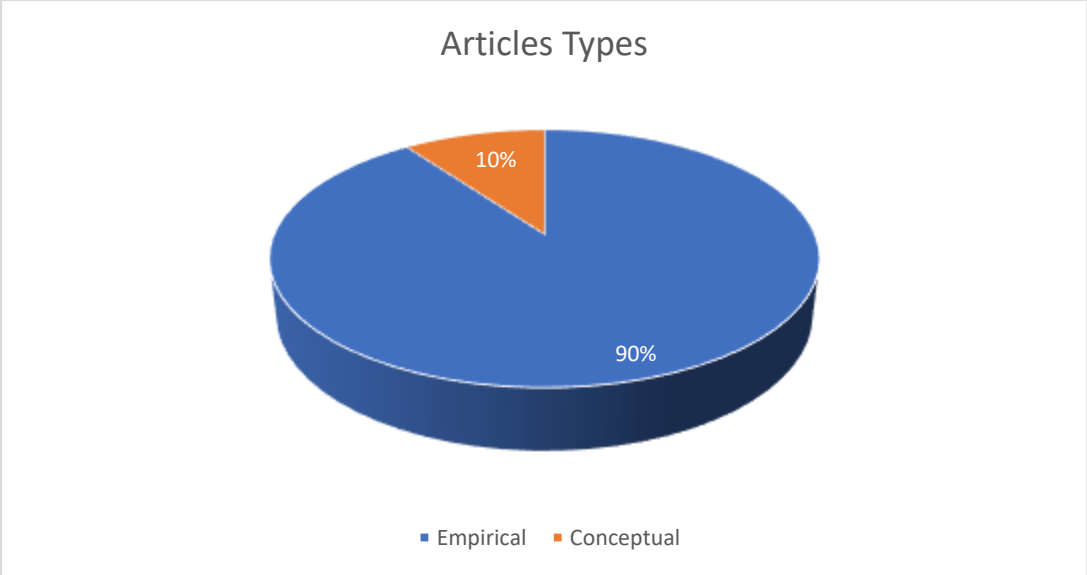


The articles that explored social capital in hospitality industry represented (8%) of articles reviewed. (Huang *et al.*, 2021; Ghorbanzadeh *et al.*,2023). These scholars ascertain the effect of social capital approach to promote cooperation and coordination among hotel employees and units in order to improve the quality of services delivery and operational efficiency (Ghorbanzadeh *et al.*,2023). Digital social capital was the least-researched theme (5%), with only three study investigating the role of digital social capital in enhancing family- owned business in both developed nations (Hammad and Naggar,

2023; Brandhorst, 2023). This finding is surprising, considering that in 21st century, digital social capital enables businesses to connect with a wide range of people and facilitate exchange of resources through social media platforms, which in turn enhance the performance of business in today's competitive business environment (Brandhorst, 2023). Therefore, digital social capital should thus be at the forefront of social capital research, and the fact that it is not, should serve as a challenge to future researchers in social capital.

ARTICLE TYPE

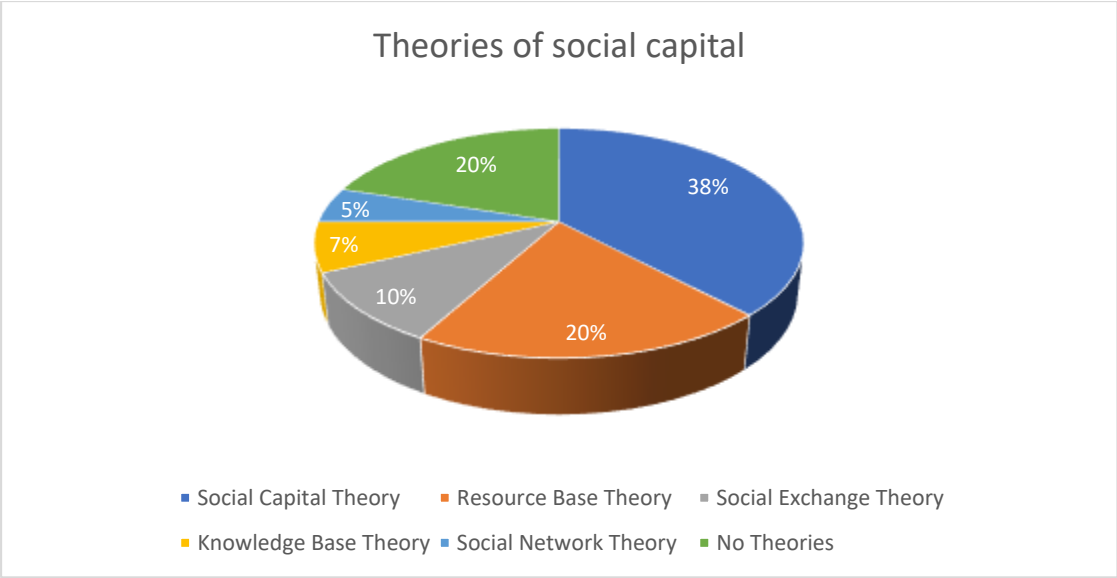
Figure 4 illustrates the classification of the 60 articles based on their nature as either conceptual or empirical. In this study, conceptual articles were those that dealt with theoretical development and conceptual clarity that will enable a better understanding of existing concepts of social capital. In contrast, empirical articles involve the collection and analysis of data on social capital through observations, surveys, experimentation and other research methods which produced verifiable results (Difference between conceptual and empirical, 2011).



It can be observed from Figure 4 that 90% (54 out of 60) of the articles reviewed were empirical (Tiwasing and Sawang 2022; Wu *et al.*, 2022; Santos *et al.*, 2023; Huang *et al.*, 2021), while the remaining 10% (6 out of 60) were conceptual in nature (Marjan *et al.*, 2024; Jeble *et al.*, 2022; Birasnav *et al.*, 2019).Conceptual studies are wholly based on the deep reflection and a critical analysis of the various issues affecting a subject matter. As it relates to social capital, it would be fruitful if future researchers could reflect deeply on the various issues affecting social capital and come up theoretical frameworks by proposing new ideas or different models that can guide empirical research.

Theories of social capital

This section provides an overview of theories utilized in the extant social capital scholarship covered in this study. It can be observed from Figure 5 that twenty-three (23) articles representing 38% adopted the social capital theory as the most utilized theory in building a successful business relationship with stakeholders. The second most utilized theory was the Resources - based theory used in 12 articles representing 20%, followed by social exchange theory, featuring six (6) articles representing 10%. Knowledge base theory was utilized by four (4) articles representing 6% of the total theory. Theory of social network being the least theory utilized in the reviewed articles is (5%). However, 12 articles representing 20%, of the papers reviewed possessed no theoretical underpinning to support their research (Setini, *et al.*, 2020; Knorst *et al.*, 2022; Brandhorst, 2023).



social capital theory was developed by Bourdieu in (1986). The theory assumed that social relationship enhances the performance of SMEs by building a sense of shared value with the customers (Zirena-Bejarano *et al.*, 2024; Gubbins *et al.*, 2021; Wu *et al.*, 2022; Santos *et al.*, 2023); Resources - based theory was developed by Birger Wernerfelt in (1984). The theory focuses resources as a key indicator of attaining superior performance of the SMEs (Tiwasing and Sawang 2022; Huang *et al.*, 2021; Marjan *et al.*, 2024). Social exchange theory was developed by Blau in (1964). It also assumed that social relations facilitate exchanged of resources between individuals and organisation (Sarmiento Prieto *et al.*, 2022; Çiftçi, and Karadag, 2023). Knowledge-based theory was developed by Conner in (1991). The theory assumed that superior knowledge is considered to be the main creator of sustained competitive advantage in SMEs sector (Wu *et al.*, 2022; Han *et al.*, 2022). Social network theory was developed by Jacob Moreno in (1930). The theory explains how people level of connection facilitates flow of vital information that will enhance business performance (Hammad and Naggar, 2023; Brandhorst, 2023). Considering the important of theoretical articles in providing a strong starting point for the analysis of theories of social capital concept and better understanding of the concepts. Swanson *et al.* (2020) emphasized that theoretical studies make social capital research more meaningful and generalizable. This represents a major gap in social capital research which future scholarship should address.

4.0 CONCLUSION AND RECOMMENDATIONS

This paper considered 60 peer–reviewed journal articles dealing with social capital which were examined based on five major classifications: geographical distribution, article types, research methods, themes, and theories adopted. The findings indicated that Asia had the highest number of articles related to social capital. The articles were mostly empirical studies and survey with social capital theory as the theory that underpinned their studies. The research findings were limited by the fact that only journal articles were included in the review, excluding book chapters and conference proceedings. Another limitation is the fact that a little word search was utilized rather than a key word search.

To address these limitations, the following recommendations for future research across the six (6) databases utilized in this study are proposed:

1. Future reviews should include book chapters and conference proceedings in order to have comprehensive understanding of social capital schemes.

2. Researchers should emphasize conceptual research and theoretical studies in order to have conceptual clarity and make social capital research more meaningful and generalizable.

3. Future research should focus on mixed research method in order to overcome the biases and shortcomings structured questionnaires.

4. Potential researchers should base their studies theoretical studies make social capital research more meaningful and generalizable.

5. There is a need for studies on investigating the impact of social capital in Australasia and South America, as there is a dearth of articles in these two continents.

6. Finally, future research should explore the key word search term which will produce a significant number of the papers for the review.

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PERFORMANCE EVALUATION OF RHEOLOGICAL MODELS FOR CARBON NANOTUBE-ENHANCED CEMENTITIOUS GROUTS

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ABSTRACT

Ground modification enhances soil properties and mechanical behavior to support structural integrity through various mechanical, hydraulic, physical, chemical, and inclusion-confinement methods. Grouting, a technique that combines physical and chemical processes, involves injecting pressurized fluidized materials to strengthen, densify, or reduce soil permeability. Portland cement is the most commonly used binder for grouting applications, as it is in other areas of civil engineering. To improve cement-based grouts' mechanical, chemical, and engineering properties, admixtures, fibers, and nanomaterials are employed. Nanomaterials, such as carbon nanofilaments (SWCNTs, MWCNTs, CNFs), offer extraordinary mechanical properties (e.g., TPa-level Young's modulus, GPa-level tensile strength), making them promising reinforcements. The workability of cementitious grouts, defined by rheological behavior, viscosity, and yield stress, is crucial for practical application. Using the right rheological model is essential for accurately assessing grout workability by characterizing flow behavior, including yield stress and viscosity, under different conditions. Selecting an appropriate model ensures precise flowability, stability, and performance predictions, which are critical for optimizing grout applications in various field conditions.

To assess the performance of rheological models in carbon nanotube-enhanced cementitious grouts, 20 mix designs were prepared with varying water-to-binder (w/b) ratios (0.50, 0.75, 1.00, 1.25, and 1.50) to suit different grout applications (e.g., sealing, compaction, or injection). The binder proportions (Portland cement and CNT matrix) were varied by adding 0.05%, 0.10%, and 0.30% SWCNTs by weight of the solution, with each ratio including a control grout containing only Portland cement for comparison. Each mixture was tested in a rotational rheometer immediately after stirring. The performance of rheological models (i.e., Bingham, Modified Bingham, Herschel-Bulkley, Cross, and Carreau-Yasuda) was compared for each mixture's rheometer results using statistical metrics and Akaike Information Criterion (AIC) to account for the trade-off between the goodness of fit of the model and its simplicity. For high w/b ratios and low CNT additions, the Herschel-Bulkley model excelled in prediction, fit, simplicity, and compatibility with high shear rates, which were beyond the scope of this study. Similarly, the Cross model demonstrated the best performance in these aspects for low w/b ratios and high CNT additions.

Keywords: Grouting, Cementitious grouts, Carbon nanotubes (CNTs), Rheological models

INTRODUCTION

Grouting is a vital ground modification technique, essential for enhancing the mechanical behavior of soils and ensuring the structural integrity of technical projects. It involves injecting fluidized materials under pressure into voids within the ground or between the ground and adjacent structures to create stronger, denser, and less permeable soil or rock formations (Hausmann, 1990). Grout materials are primarily categorized into chemical and cementitious types. The selection of suitable grout material is vital because of its effect on grout's mobility, penetrability, cohesion, bleed potential, setting time, and

solubility (Han, 2015). Even though chemical grouts offer a broader range of properties and can be suitable for specific applications where cementitious grouts may not perform as effectively, cementitious grouts, primarily composed of Portland cement, are widely preferred due to their abundant raw material availability, high strength, being non-toxic and safe, offering excellent consolidation performance, and ease of preparation (Coduto et al., 2016; da Rocha Gomes et al., 2023). To improve the above-mentioned traits and decrease the disadvantages of cement-based materials (i.e., low tensional strength compared to compressive strength, cracking due to chemical shrinkage during hardening), improving cementitious grouts with admixtures and fibers is sensible.

Nanomaterials get attention in the geotechnical engineering field because soil scientists and engineers can be considered the original nanotechnologists, as they work with clay particles—ultra-fine materials that require advanced scientific techniques such as X-ray analysis or scanning electron microscopy for detailed investigation (Thomas et al., 2022). Carbon nanofilaments (nanotubes and nanofibers), with their exceptional mechanical and chemical properties, offer significant potential to address these challenges. For instance, the axial Young's modulus of single-walled carbon nanotubes (SWCNTs) reaches the terapascal (TPa) scale, while their tensile strength often exceeds gigapascal (GPa) levels (Khang et al., 2008; Salvetat et al., 1999; Treacy et al., 1996; Yu et al., 2000). In addition to their remarkable mechanical properties, SWCNTs possess unique electronic and chemical characteristics (Yury Gogotsi, 2006), making them among the most promising nanomaterials for enhancing cement-based materials, i.e., grouts.

The accurate prediction of workability, injectability, and pumpability in such enhanced grouts requires robust rheological models. These models, such as Bingham, Modified Bingham, Herschel-Bulkley, Cross, and Carreau-Yasuda, describe the flow behavior of grout under different shear conditions, offering insights into its performance during mixing, transportation, and injection. This study evaluates the performance of these models for carbon nanotube-enhanced cementitious grouts using 20 mix designs with varying water-to-binder ratios and CNT contents. Rheological measurements were analyzed using statistical metrics and the Akaike Information Criterion (AIC) to balance model accuracy and complexity. The findings aim to guide the selection of optimal models for diverse grout applications, improving performance in practical scenarios.

EXPERIMENTAL STUDY

Materials

The materials used in the binder composition of the grout mixtures, Portland cement (PC) and single-walled carbon nanotubes (SWCNTs), have been illustrated in Fig.1. The cement (PC) was an ordinary Portland cement, comparable to ASTM C150/C150M-24. The carbon nanotubes are single-walled carbon nanotubes (SWCNTs) synthesized using the catalytic CVD method, which decomposes hydrocarbons on a catalytic metal surface (Predtechenskiy et al., 2022). The SWCNTs are at a 10% concentration matrix for industrial applications produced by Tuball. SWCNTs appear as fiber-like structures due to their high aspect ratio under transmission electron microscopy (TEM), as shown in Fig.2. The structural properties of SWCNTs provided by the manufacturer are present in Table 1.

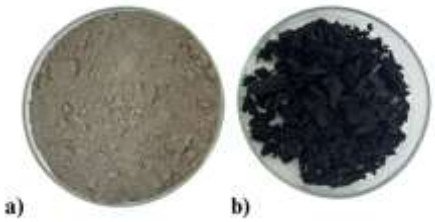

Fig.1. Materials a) Portland cement b) Nanotube matrix

Table 1. Structural properties of SWCNTs

Specification	Unit of Measure	Value	Method of Evaluation
Appearance	-	Black powder	Visual inspection
SWCNT content*	wt.%	99 ± 05	OCSIAI internal method: ash residue
SWCNT length	um	>5	AFM
Specific surface area	m2/g	800 - 1600	Bet method ISO 92772010 (E)
SWCNT outer mean diameter	nm	1.6 ± 0.4	Optical absorption: ISO/TS 10868:2017 (E)
G/D ratio	unit	>40	Raman (532 nm): NIST SP 960-19
Metal impurities (in dry matter) Cr/Fe/Cu/Ni/Zn	ppm	<350/<8000/ <20/<350/<20	OCSIAI IM: ICP-AES
Moisture	wt.%	<5	OCSIA IM: infrared thermogravimetry

Sample Preparation and Testing Program

An overhead mechanical stirrer with an optimized impeller blade configuration capable of achieving a peripheral speed of 7–15 m/s was utilized to ensure adequate mixing. The process was conducted in a flat-bottomed cylindrical mixing container dimensioned to match the stirrer's specifications for enhanced dispersion efficiency and uniformity.

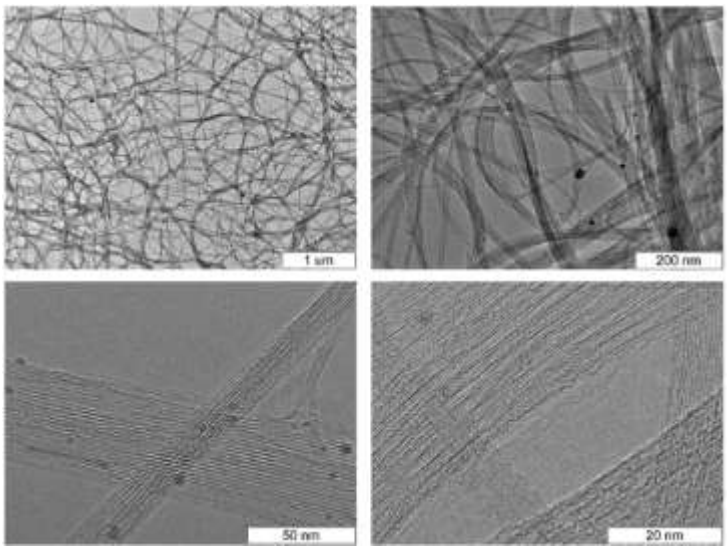

Fig.2. High-resolution TEM images of produced Tuball at different scales. From Predtechenskiy et al. (2022)

The mixing procedure adhered to the two-step protocol, ensuring proper interaction between the stirrer and the container to maximize the efficiency of the mixing process. In Step 1, the initial mix ratio of CNTs matrix to solution (water and cement) was set at 1:49, the total amount of calculated CNTs matrix for mixture used with a corresponding solution of water-to-cement (w/c) ratio of 1. The mixture was stirred for 20 minutes at a peripheral speed of 10 m/s. In Step 2, the remaining cement and water were added to the container and stirred for an additional 5 minutes at the same speed as in Step 1. For control mixtures (no CNTs), water and cement are stirred for 25 minutes in one step. During the preparation of the grout mixtures and subsequent testing, laboratory conditions were controlled, maintaining a relative humidity of 50-65% and a temperature of 24 ± 2°C. The weight-based material proportions of the steps and the testing program are detailed in Table 3. It includes the binder proportions (Portland cement and CNTs matrix), water-to-binder ratios, and the amounts of binder and water used in the cement-based grout mixtures, covering 20 different mix designs.

The water-to-binder (w/b) ratios of 0.5, 0.75, 1, 1.25, and 1.5 were chosen to align with the specific grouting application, such as sealing, compaction, penetration, or injection grout. CNTs, even at low dosages, are highly effective in enhancing the properties of the cementitious matrix, with numerous studies highlighting significant improvements in material performance achieved with minimal CNT concentrations (Chen et al., 2023; Li et al., 2023; Y. Liu et al., 2021; Restuccia et al., 2018). Based on these findings, CNT dosages ranging from 0.05% to 0.30% by weight of the solution were chosen, balancing performance and economic considerations. Accordingly, three CNT dosages—0.05%, 0.10%, and 0.30%—were selected for this study, with the first mixtures for each w/b ratio containing only Portland cement, designated as the control grout for comparison. The naming convention indicates that the second decimal digit '0' in labels such as G10, G20, G30, G40, and G50 signifies that these mixtures contain no CNTs.

Table 2. Mixture proportions and mixing process

Grout ID	Ratios		Weights			Mixing process			
						Step 1*		Step 2	
	w/b	CNT/s (%)	water (gr)	cement (gr)	CNT matrix** (gr)	W (gr)	C (gr)	W (gr)	C (gr)
G10	0.50	0.00	129.51	258.83	0.00	0.00	0.00	129.51	258.83
G11	0.50	0.05	127.05	252.00	1.90	46.67	46.67	80.38	205.33
G12	0.50	0.10	124.67	245.42	3.74	91.59	91.59	33.08	153.83
G13	0.50	0.30	122.39	233.58	11.01	122.39	233.58	0.00	0.00
G20	0.75	0.00	154.41	205.95	0.00	0.00	0.00	154.41	205.95
G21	0.75	0.05	151.68	200.53	1.77	43.36	43.36	108.32	157.17
G22	0.75	0.10	149.04	195.30	3.48	85.22	85.22	63.83	110.09
G23	0.75	0.30	146.50	185.13	10.26	146.50	185.13	0.00	0.00
G30	1.00	0.00	168.07	168.07	0.00	0.00	0.00	168.07	168.07
G31	1.00	0.05	165.29	163.64	1.65	40.50	40.50	124.79	123.14
G32	1.00	0.10	162.60	159.35	3.25	79.67	79.67	82.93	79.67
G33	1.00	0.30	160.00	150.40	9.60	160.00	150.40	0.00	0.00
G40	1.25	0.00	174.96	140.00	0.00	0.00	0.00	174.96	140.00
G41	1.25	0.05	172.25	136.28	1.55	37.98	37.98	134.26	98.29
G42	1.25	0.10	170.92	133.69	3.08	75.38	75.38	95.54	58.31
G43	1.25	0.30	169.62	126.56	9.16	169.62	126.56	0.00	0.00
G50	1.50	0.00	181.82	121.21	0.00	0.00	0.00	181.82	121.21
G51	1.50	0.05	180.45	118.80	1.50	36.84	36.84	143.61	81.95
G52	1.50	0.10	179.10	116.42	2.99	73.13	73.13	105.97	43.28
G53	1.50	0.30	177.78	109.63	8.89	177.78	109.63	0.00	0.00

* CNT Matrix added in Step 1 ** %10 concentrate of CNT

Rheological Testing

The rheological properties of the grout mixtures were measured with a coaxial rotating cylinder rheometer (proRheo R180 Instrument, Germany), which operates on the Searle method. In this setup, the bob rotates while the cup remains stationary, following the Searle principle developed by G.F.C. Searle in 1912 (Barnes et al., 1989). ISO 3219-1 and DIN 53019-1 standards outline the design of concentric cylinder (CC) systems, emphasizing the importance of a narrow, circular gap between the surfaces to ensure a consistent shear rate across the gap. Adherence to these standards is essential when employing the narrow gap configuration. For instance, ISO 3219 specifies that the ratio between the radii of the cup and the bob must not exceed 1.085. For large-gap cylinder measuring systems that do not meet these standards, alternative formulas are applied for shear stress (τ_i) and shear rate ($\dot{\gamma}_i$) (Mezger, 2021):

$$\tau_i = \frac{M}{2\pi L R_i^2}$$

$$\dot{\gamma}_i = \left[\frac{2R_e^2}{(R_e^2 - R_i^2)}\right]\omega$$

where, M denotes the torque, L is the length of the cylindrical section of the bob, R_i is the bob radius, R_e is the cup radius and ω represents the angular velocity.

Two bob sizes (bob I and bob II) were used in testing, with diameters of 30 mm and 24 mm and lengths of 45 mm and 36 mm, respectively. Shear stress measurements were recorded at various shear rates: for w/b = 1.0, w/b = 1.25, and w/b = 1.50, bob I used at shear rates of 4.61 s^{-1}, 55.42 s^{-1}, 106.22 s^{-1}, 157.02 s^{-1}, 207.81 s^{-1}, 258.61 s^{-1}, 309.41 s^{-1}, 360.21 s^{-1}, 411.00 s^{-1}, and 461.81 s^{-1} while for w/b = 0.5 and w/b = 0.75, the bob II used at shear rates of 3.03 s^{-1}, 36.41 s^{-1}, 69.79 s^{-1}, 103.18 s^{-1}, 136.56 s^{-1}, 169.94 s^{-1}, 203.32 s^{-1}, 236.71 s^{-1}, 270.09 s^{-1}, and 303.47 s^{-1}. Tests were conducted in 10 ascending and 10 descending steps, each lasting 15 seconds, with a 30-second rest period between transitions. No pre-shearing was applied to any samples before the rheological measurements.

The flow behavior of fresh concrete is effectively described by flow curves that relate yield stress, shear rate, and plastic viscosity. The Bingham model characterizes yield stress (τ_0) as the minimum force needed to initiate flow, governed by particle interactions and bonds in cementitious materials, and plastic viscosity (μ) as the linear relationship between shear stress and shear rate, influenced by Brownian forces, cement hydration, and viscous interactions. To determine the most suitable rheological model for CNT-enhanced cementitious grouts, five commonly used models—Bingham, Modified Bingham, Herschel-Bulkley, Cross, and Carreau-Yassua—were evaluated, as these are standard for describing non-Newtonian fluids such as grouts and cementitious suspensions (Güllü, 2016; C. Liu et al., 2024; Nazar et al., 2020)

The modified Bingham model addresses limitations of the Bingham model, such as its assumption of constant viscosity limits its applicability to more complex, shear-dependent behaviors by introducing a curvature term (c), allowing for a nonlinear response at higher shear rates and better capturing shear-thinning and shear-thickening behaviors typical of non-Newtonian fluids like cementitious grouts. The Herschel-Bulkley model further generalizes the approach by incorporating a power-law term with a flow behavior index (n) to characterize shear-thinning (n<1) or shear-thickening (n>1) behaviors; it drops to the Bingham model when n=1 and the consistency index (K) becomes viscosity.

The Cross and Carreau-Yasuda models are empirical rheological models that describe non-Newtonian fluids with complex flow behaviors. The Cross model characterizes fluids as power-law fluids over a range of shear rates but transitions to a region of constant viscosity at both low and high shear rates. In contrast, the Carreau-Yasuda model provides a more gradual transition between power-law and constant viscosity regions, offering a better fit for fluids exhibiting complex shear-thinning or shear-thickening behaviors. The formulas for these models are:

$$\tau_B = \tau_0 + \mu\dot{\gamma}$$

$$\tau_{MB} = \tau_0 + \mu\dot{\gamma} + c\dot{\gamma}^2$$

$$\tau_{HB} = \tau_0 + K\dot{\gamma}^n$$

$$\tau_C = \tau_0 + \frac{\tau_\infty - \tau_0}{1 + (\lambda\dot{\gamma})^n}$$

$$\tau_{CY} = \tau_0 + (\tau_\infty - \tau_0)(1 + (\lambda\dot{\gamma})^a)^{\frac{n-1}{a}}$$

where τ_B, τ_{MB}, τ_{HB}, τ_C, τ_{CY} represents the shear stress (Pa) for Bingham, modified Bingham, Herschel-Bulkley, Cross and Cearreau-Yasuda models, respectively. τ_0 is the shear stress at zero shear rate (Pa), representing the stress at rest, μ is the viscosity (Pa.s) and $\dot{\gamma}$ is the shear rate (1/s). c, is the curvature term, K is the consistency index, and n is the flow behavior index indicate shear thickening and shear-thining behaviour. τ_∞ shear stress at infinite shear rate (Pa) representing the asymptotic value at very

high shear rates, λ is the time constant (s), related to the relaxation time and a is the witdth of thansition region between Newtonian and power-law behavior.

Flow curves were generated with rheological models, displaying apparent viscosity and shear stress as functions of shear rate, with data collected for both the ascending and descending phases, but for this study, only the descending data were analyzed, as they were more stable for model fitting (Fig.5)

RESULTS AND DISCUSSION

Figure 4 presents the shear stress-shear rate graphs of grout mixtures for various water-to-binder (w/b) ratios (0.50, 0.75, 1.00, 1.25, and 1.50) and CNT concentrations (0%, 0.05%, 0.10%, and 0.30%). Measurements for G12 and G13 (w/b = 0.5 and CNTs = 0.10%, CNTs = 0.30%, respectively) could not be obtained due to the torque limits of the rheometer used in the rheological test.

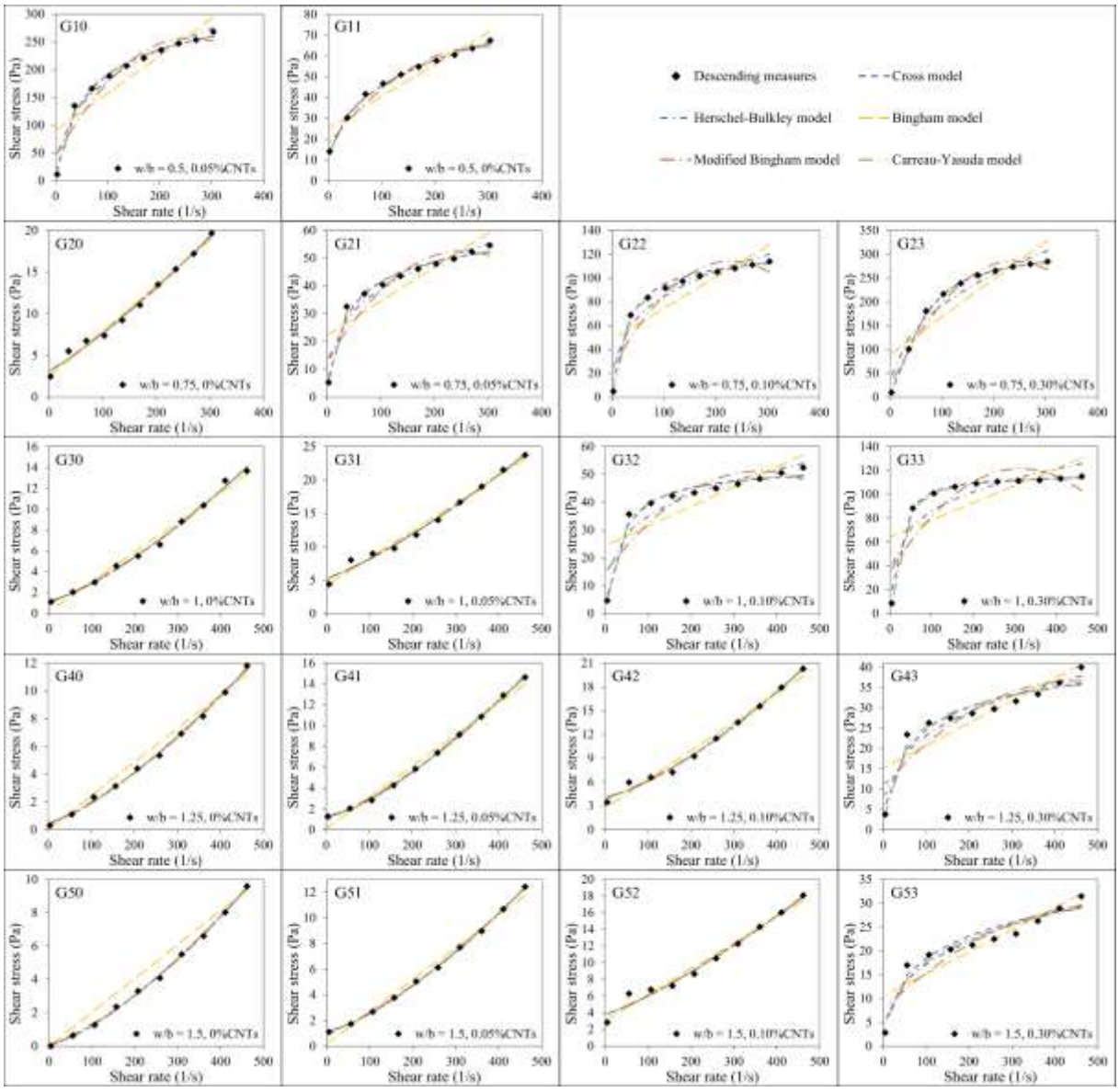

Fig.4. Flow curves of shear stress versus shear rate (viscosity: apparent viscosity).

Statistical measures, such as the Root Mean Square Error (RMSE) and the Coefficient of Determination (R^2), are essential tools for evaluating and comparing the performance of regression models, providing insights into their accuracy and goodness of fit. The RMSE is a widely used metric that quantifies the average magnitude of prediction errors by measuring the differences between predicted and observed values. Lower RMSE values indicate a better fit of the model to the data, signifying more minor prediction errors. Unlike the Mean Absolute Error (MAE), which treats all errors equally, RMSE places

greater emphasis on more significant errors, making it particularly suitable for situations where significant deviations are undesirable—such as selecting the optimal rheological model for the shear stress–shear rate relationship in cementitious grouts. Moreover, RMSE is expressed in the same units as the dependent variable (i.e., shear stress), providing a straightforward and interpretable measure of prediction accuracy. In contrast, the Coefficient of Determination (R^2) is a statistical metric that evaluates the proportion of variance in the dependent variable explained by the independent variable(s) in a regression model. R^2 offers insight into the model's goodness-of-fit, indicating how well the independent variables account for the variability in the dependent variable. R^2 ranges from 0 to 1, with higher values representing better model performance. Since the sample size and number of predictors are consistent across all datasets (10 observations and one predictor, respectively), the use of adjusted R^2 (R^2adj) was deemed unnecessary as there is no variation in the number of predictors or observations. The comparison of rheological models by statistical measures (RMSE and R^2) is given in Table 4.

Whereas RMSE and R^2 assess models' performance based on prediction accuracy and goodness-of-fit, respectively, they do not account for model complexity or the risk of overfitting. To address this limitation, the Akaike Information Criterion (AIC) is a widely used statistical measure that evaluates model performance while balancing goodness-of-fit with the number of parameters in the model. By penalizing excessive complexity, AIC helps identify models that achieve an optimal trade-off between accuracy and simplicity (Akaike, 1973, 1974; Hurvich & Tsai, 1989). Models with lower AIC values are considered to have better overall performance, as they minimize both prediction error and overfitting. AIC differences ($\Delta AIC = AIC_i - AIC_{min}$) are a quick comparison and ranking of candidate models. The model's performance is considered substantial for Δ_i values between 0 and 2, considerably less for values between 5 and 7, and essentially none for values greater than 10 (Anderson & Burnham, 2004). The comparison of rheological model performances by AIC differences is presented in Table 5. The formulas for RMSE, R^2, and, AIC are as follows:

$$RMSE = \left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2\right)^{0.5}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

$$AIC\ (or\ AIC_c) = \begin{cases} n\ln\left(\frac{RSS}{n}\right) + 2k, & \text{when}\ \frac{n}{k} \geq 40 \\ n\ln\left(\frac{RSS}{n}\right) + 2k + \frac{2k(k+1)}{n-k-1}, & \text{when}\ \frac{n}{k} < 40 \end{cases}$$

where y is the observed value for the i-th data point, $\hat{y}$ is the predicted value for the i-th data point, $\bar{y}$ is the mean of all observed values, RSS is the residual sum of squares, n is the total number of observations and k is the number of independent variables.

Table 4. Statistical metrics (SM) of rheological model performances

Grout ID	SM	C	HB	B	MB	CY	Performance Comparison
G10	RMSE	1.051	1.049	5.766	3.104	1.113	HB > C > CY > MB > B
	R^2	0.996	0.996	0.877	0.964	0.995	
G11	RMSE	8.946	15.811	36.335	23.583	6.842	CY > C > HB > MB > B
	R^2	0.986	0.957	0.772	0.904	0.992	
G20	RMSE	0.656	0.607	0.642	0.555	0.719	MB > HB > B > C > CY
	R^2	0.986	0.988	0.987	0.990	0.983	
G21	RMSE	2.114	3.561	7.702	5.650	1.640	CY > C > HB > MB > B
	R^2	0.978	0.938	0.709	0.843	0.987	
G22	RMSE	4.995	10.618	19.911	13.269	0.439	CY > C > HB > MB > B
	R^2	0.976	0.893	0.625	0.834	1.000	
G23	RMSE	2.692	23.321	44.555	17.376	0.910	CY > C > MB > HB > B
	R^2	0.999	0.933	0.756	0.963	1.000	
G30	RMSE	0.374	0.346	0.600	0.349	0.410	HB > MB > C > CY > B
	R^2	0.9928	0.9939	0.9816	0.9938	0.9914	
G31	RMSE	0.790	0.732	0.830	0.672	0.866	MB > HB > C > B > CY
	R^2	0.984	0.987	0.983	0.989	0.981	
G32	RMSE	2.431	4.976	8.810	6.960	2.102	CY > C > HB > MB > B
	R^2	0.969	0.868	0.587	0.742	0.976	
G33	RMSE	4.362	15.863	24.895	17.844	0.669	CY > C > HB > MB > B
	R^2	0.982	0.758	0.404	0.694	1.000	
G40	RMSE	0.237	0.219	0.604	0.162	0.260	MB > HB > C > CY > B
	R^2	0.996	0.997	0.975	0.998	0.995	
G41	RMSE	0.099	0.117	0.598	0.190	0.108	C > CY > HB > MB > B
	R^2	1.000	0.999	0.984	0.998	0.999	
G42	RMSE	0.567	0.525	0.833	0.479	0.622	MB > HB > C > CY > B
	R^2	0.990	0.991	0.978	0.993	0.988	
G43	RMSE	2.800	2.988	5.175	4.698	2.729	CY > C > HB > MB > B
	R^2	0.918	0.907	0.721	0.770	0.922	
G50	RMSE	0.148	0.137	0.803	0.116	0.163	MB > HB > C > CY > B
	R^2	0.998	0.998	0.938	0.999	0.997	
G51	RMSE	0.106	0.098	0.478	0.095	0.116	MB > HB > C > CY > B
	R^2	0.999	0.999	0.985	0.999	0.999	
G52	RMSE	0.809	0.749	0.775	0.692	0.886	MB > HB > B > C > CY
	R^2	0.972	0.976	0.974	0.979	0.966	
G53	RMSE	2.443	2.171	3.572	3.373	2.511	HB > C > CY > MB > B
	R^2	0.904	0.924	0.794	0.816	0.898	

The evaluation of rheological model performance using statistical metrics revealed consistency between the RMSE and R^2 values, with both metrics producing identical rankings of the model's performance. Although these rankings were determined considering the relative performance differences, this does not imply a linear hierarchy in model performance. In the case of G23 grout, the RMSE increase from the first-ranked Carreau-Yasuda (CY) model to the second-ranked Cross (C) model was 195%, while the R^2 decreased by 0.1%. Comparatively, the RMSE increase between the Cross model and the third-ranked Modified Bingham (MB) model was 608%, with a corresponding R^2 reduction of 3.6%. Furthermore, similar performances of specific model pairs (e.g., CY-C and MB-HB) suggest that some models exhibit closely aligned performance. Consequently, based on the best RMSE and R^2 values, the top two models were considered the most accurate in explaining shear stress-shear rate relationships in grout design.

When model complexity, in terms of the number of parameters, was factored into performance comparisons, simpler models like the Bingham model, which showed poorer statistical performance, became more prominent (Table 5). ΔAIC assessments introduced a gradual ranking between the best-performing models and others, mainly aligning with the statistical findings but highlighting the preference for simpler models due to the penalty for increased complexity. This demonstrates how simpler models are favored in AIC-based evaluations.

Table 5. AIC of rheological model performances

Grout ID	Models	RSS	N	Parameters	AIC	ΔAIC	Performance Comparison
	HB	7.70	10	3	13.39	-	
	C	6.63	10	4	20.89	7.51	
G10	MB	67.46	10	3	35.09	21.70	HB > C > MB = CY = B
	CY	6.19	10	5	35.21	21.82	
	B	265.95	10	2	42.81	29.42	
	C	480.22	10	4	63.72	-	
	HB	1749.81	10	3	67.65	3.93	
G11	CY	234.07	10	5	71.53	7.81	C > HB = CY > MB = B
	MB	3892.94	10	3	75.64	11.93	
	B	10561.65	10	2	79.62	15.91	
	B	3.30	10	2	-1.09	-	
	MB	2.16	10	3	0.66	1.75	
G20	HB	2.58	10	3	2.44	3.53	B = MB > HB = C = CY
	C	2.58	10	4	11.45	12.53	
	CY	2.58	10	5	26.46	27.55	
	C	26.81	10	4	34.86	-	
	HB	88.78	10	3	37.84	2.97	
G21	CY	13.45	10	5	42.96	8.10	C > HB = CY > MB = B
	MB	223.45	10	3	47.07	12.20	
	B	474.55	10	2	48.60	13.73	
	CY	0.97	10	5	16.62	-	
	C	149.70	10	4	52.06	35.44	
G22	HB	789.25	10	3	59.69	43.07	CY > C = HB = MB = B
	MB	1232.40	10	3	64.14	47.52	
	B	3171.73	10	2	67.59	50.98	
	CY	4.14	10	5	31.18	-	
	C	43.48	10	4	39.70	8.52	
G23	MB	2113.46	10	3	69.53	38.35	CY > C > MB = HB = B
	HB	3807.13	10	3	75.42	44.24	
	B	15881.15	10	2	83.70	52.52	
	HB	0.84	10	3	-8.77	-	
	MB	0.85	10	3	-8.60	0.17	
G30	B	2.88	10	2	-2.45	6.32	HB = MB > B = C > CY
	C	0.84	10	4	0.23	9.00	
	CY	0.84	10	5	15.24	24.01	
	B	5.51	10	2	4.04	-	
	MB	3.16	10	3	4.48	0.44	
G31	HB	3.75	10	3	6.19	2.15	B = MB > HB = C = CY
	C	3.75	10	4	15.19	11.15	
	CY	3.75	10	5	30.19	26.16	
	C	35.45	10	4	37.65	-	
G32	HB	173.29	10	3	44.52	6.87	C > HB > CY = MB = B
	CY	22.10	10	5	47.93	10.27	

	MB	339.04	10	3	51.24	13.58	
	B	620.90	10	2	51.29	13.63	
	CY	2.24	10	5	25.03	-	
	C	114.18	10	4	49.35	24.32	
G33	HB	1761.45	10	3	67.71	42.68	CY > C = HB = MB = B
	MB	2228.91	10	3	70.07	45.04	
	B	4957.94	10	2	72.06	47.03	
	MB	0.18	10	3	-23.97	-	
	HB	0.34	10	3	-17.95	6.02	
G40	C	0.34	10	4	-8.94	15.03	MB > HB = C = B = CY
	B	2.92	10	2	-2.32	21.64	
	CY	0.34	10	5	6.15	30.11	
	HB	0.10	10	3	-30.44	-	
	C	0.06	10	4	-26.44	4.00	
G41	MB	0.25	10	3	-20.76	9.68	HB > C = MB > CY = B
	CY	0.06	10	5	-11.43	19.01	
	B	2.86	10	2	-2.52	27.92	
	MB	1.61	10	3	-2.27	-	
	HB	1.93	10	3	-0.47	1.80	
G42	B	5.55	10	2	4.10	6.37	MB = HB > B > C = CY
	C	1.93	10	4	8.53	10.80	
	CY	1.94	10	5	23.58	25.85	
	HB	62.51	10	3	34.33	-	
	C	47.04	10	4	40.48	6.16	
G43	B	214.26	10	2	40.65	6.32	HB > C = B = MB > CY
	MB	154.50	10	3	43.38	9.05	
	CY	37.25	"	5	53.15	18.82	
	MB	0.09	10	3	-30.57	-	
	HB	0.13	10	3	-27.32	3.26	
G50	C	0.13	10	4	-18.31	12.26	MB > HB > C = CY = B
	CY	0.13	10	5	-3.19	27.38	
	B	5.16	10	2	3.38	33.96	
	MB	0.06	10	3	-34.57	-	
	HB	0.07	10	3	-34.00	0.57	
G51	C	0.07	10	4	-24.98	9.59	MB = HB > C > CY = B
	CY	0.07	10	5	-9.93	24.64	
	B	1.83	10	2	-7.01	27.56	
	B	4.80	10	2	2.67	-	
	MB	3.35	10	3	5.08	2.41	
G52	HB	3.92	10	3	6.64	3.97	B > MB = HB > C = CY
	C	3.93	10	4	15.65	12.98	
	CY	3.93	10	5	30.65	27.98	
	HB	32.99	10	3	27.94	-	
	B	102.07	10	2	33.23	5.29	
G53	MB	79.66	10	3	36.75	8.81	HB > B = MB = C > CY
	C	35.80	10	4	37.75	9.82	
	CY	31.54	10	5	51.49	23.55	

The statistical metrics and AIC comparisons were based on models calibrated using data up to a shear rate of 500 s^{-1}. However, the parameters derived from these models must also remain valid for higher shear rates to ensure broader applicability. Models that do not follow power-law principles, such as Bingham and Modified Bingham, tend to produce unrealistic results at elevated shear rates. As shown

for G33 in Fig.5, for shear rates of up to 1000 s^{-1}, the outcomes deviated significantly from previous works and general cementitious grout behavior (Dehghani & Aslani, 2022; Güllü et al., 2023; Güllü & Ali Agha, 2021).

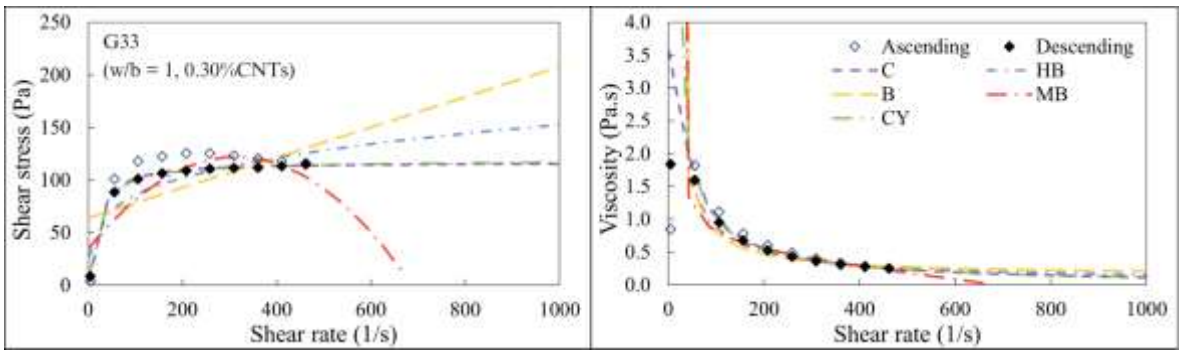

Fig.5. Shear stress – viscosity versus shear rate for G33

Considering statistical metrics (SM), AIC values, and performance at high shear rates, the authors recommend the most suitable models for various water-to-binder (w/b) ratios and CNT additions, as summarized in Table 6. For grouts with high w/b ratios and low CNT additions, the Herschel-Bulkley model exhibited superior performance in prediction accuracy, fitting quality, simplicity, and compatibility with higher shear rates, including those beyond the scope of this study. Conversely, for low w/b ratios and high CNT additions, the Cross model was identified as the most effective, excelling across the same criteria.

Table 6. Summary of rheological models comparison

CNTs / w/b	0%	0.05%	0.10%	0.30%
0.5	SM: HB, C AIC: HB Autors: HB	SM: C, CY AIC: C Autors: C	Autors:C	Autors:C
0.75	SM: HB, MB AIC: MB, B Autors: HB	SM: C, CY AIC: C Autors: C	SM: C, CY AIC: CY Autors: C	SM: C, CY AIC: CY Autors: C
1	SM: HB, MB AIC: HB, MB Autors: HB	SM: HB, MB AIC: MB, B Autors: HB	SM: C, CY AIC: C Autors: C	SM: C, CY AIC: CY Autors: C
1.25	SM: HB, MB AIC: MB Autors: HB	SM: C, CY AIC: HB Autors: HB	SM: HB, MB AIC: HB, MB Autors: HB	SM: C, CY AIC: HB Autors: C
1.5	SM: HB, MB AIC: MB Autors: HB	SM: HB, MB AIC: HB, MB Autors: HB	SM: HB, MB AIC: B Autors: HB	SM: C, CY AIC: HB Autors: C

CONCLUSION

This study investigates the comparative performance of common rheological models (Bingham, Modified Bingham, Herschel-Bulkley, Cross, and Carreau-Yasuda) for cementitious grout mixtures with varying carbon nanotube (CNT) additions. The research analyzes shear stress-shear rate behavior, evaluates model performance using statistical metrics (RMSE, R^2, and ACI), and establishes a ranking to identify the best models for cementitious grouts enhanced with carbon nanotubes.

Based on the findings, the following general conclusions can be drawn:

1) The RMSE and R^2 values consistently ranked the rheological models' predictive accuracy, indicating reliability in the statistical evaluation. Complex models, such as the Carreau-Yasuda (CY) model, stand out in these metrics for low w/b ratios and high CNT additions due to the insensitivity of these metrics to overfitting.

2) Despite poorer performance in statistical metrics, simpler models such as the Bingham model gained prominence in ΔAIC-based evaluations, emphasizing the importance of balancing model complexity and accuracy for practical applications.

3) Models that do not follow power-law principles, such as the Bingham and Modified Bingham models, tend to produce unrealistic results at higher shear rates, limiting their applicability across broader operational ranges.

4) Based on all performance evaluations conducted by the authors, the Herschel-Bulkley model is recommended for high w/b ratios and low CNT additions due to its superior prediction accuracy, simplicity, and compatibility with elevated shear rates. Conversely, the Cross model was identified as the most effective for low w/b ratios and high CNT additions, excelling in the same evaluation criteria.

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MİMARİ TASARIMDA FAZ DEĞİŞTİREN MALZEME KULLANIMI

THE USE OF PHASE CHANGE MATERIAL IN ARCHITECTURAL DESIGN

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ÖZET

Dünya genelindeki enerji tüketiminin %30-40'lık kısmını inşaat sektörü oluşturmaktadır ve bu tüketimin %80-85'i binaların ısıtma ve soğutma ihtiyaçlarında tüketilmektedir. Küresel sıcaklık artışları, kentleşme oranlarındaki yükseliş ve buna paralel olarak enerji talebinin 2050 yılına kadar %50'den fazla artacağı öngörüsü, inşaat sektörünü sürdürülebilirlik açısından kritik bir alan haline getirmektedir. Bu doğrultuda, enerji tüketimini azaltmaya yönelik yaklaşımlar, hem çevresel hem de ekonomik sürdürülebilirlik hedeflerinin temelini oluşturmaktadır. Enerji verimliliği sağlama ve tüketimi optimize etme amacıyla geliştirilen yöntemlerden biri, "ısıl enerji depolama sistemlerinin kullanımı"dır. Isıl enerji depolama sistemleri, enerjinin verimli bir şekilde toplanması ve dönüştürülmesiyle ısıtma ve soğutmada tasarruf sağlamada etkili bir yöntemdir. Faz değiştiren malzemeler (FDM), ısıl enerji depolama sistemlerinde gizli ısıyı depolama kabiliyetiyle dikkat çeken yenilikçi malzemelerdir. FDM, hem iç mekân termal konforunu artırmakta hem de enerji talebini düşürerek çevresel etkileri azaltmaktadır. Bununla birlikte, FDM'lerin sağladığı en önemli avantaj, enerji depolama süreçlerini verimli hale getirmesi ve karbon ayak izini azaltmasıdır. FDM'lerin enerji verimliliği açısından taşıdığı potansiyel, mimarlık ve yapı malzemeleri alanında giderek artan bir ilgi görmektedir. Özellikle, sürdürülebilirlik ve enerji tasarrufu hedeflerine olan katkıları, FDM'lerin tasarım süreçlerinde kullanılmasını önemli hale getirmektedir. Ancak, mevcut literatür incelendiğinde, FDM uygulamalarının sağlamış olduğu enerji tasarrufu ve ekonomik avantajların çok sayıda araştırmanın odağı olmasına rağmen, FDM'lerin bir mimari tasarım öğesi olarak değerlendirilmesine yönelik araştırmaların oldukça sınırlı bir kapsamda ele alındığı tespit edilmiştir. Özellikle, bu malzemelerin pratik uygulamalarda üretim ve kullanım olanaklarını araştıran girişimlerin olmaması dikkate değerdir. Bu bağlamda, bu araştırmada sınırlı literatür genişletilerek, FDM'lerin mimari tasarımdaki potansiyel kullanım alanları daha kapsamlı bir şekilde incelenmektedir. FDM'lerin mimarlıkta pratik uygulamaları ve karşılaştırmalı malzeme özellikleri incelenmiş, ayrıca gelecekte mimarlıkta yaygın bir şekilde kullanılma potansiyeli üzerine çıkarımlar yapılmıştır. Bu araştırmanın, FDM'lerin mimari tasarımlarda kullanımı için teorik ve pratik katkılar sunması hedeflenmektedir. Bu doğrultuda, FDM'lerin mimari tasarımlarda kullanımının yaygınlaşması, sürdürülebilir yapıların inşasına önemli bir katkı sağlayarak, enerji verimliliği ve çevresel sürdürülebilirlik hedeflerine ulaşılmasında kritik bir rol oynayacaktır.

Anahtar Kelimeler: Faz Değiştiren Malzeme, Yenilikçi Malzeme, Mimari Tasarım

ABSTRACT

The construction sector accounts for 30-40% of global energy consumption, with 80-85% of this consumption used for heating and cooling buildings. Global temperature increases, rising urbanization rates, and the projected increase in energy demand by over 50% by 2050 make the construction sector a critical area for sustainability efforts. Approaches to reducing energy consumption form the foundation of both environmental and economic sustainability goals. One method developed to achieve energy efficiency and optimize consumption is the use of thermal energy storage systems. These systems

effectively store and transform energy, providing savings in heating and cooling. Phase change materials (PCM) stand out as innovative materials in thermal energy storage systems due to their ability to store latent heat. PCM enhance indoor thermal comfort while reducing energy demand, thus mitigating environmental impacts. The most significant advantage of PCM lies in their ability to make energy storage processes more efficient and reduce carbon footprints. Their potential for improving energy efficiency is attracting increasing attention in architecture and building materials. Specifically, their contributions to sustainability and energy savings goals make the integration of PCM into design processes particularly important. However, a review of the existing literature reveals that, despite numerous studies focusing on the energy-saving and economic benefits of PCM applications, research addressing their evaluation as an architectural design element remains relatively limited. Notably, there is a lack of initiatives exploring the production and application possibilities of these materials in practical contexts. Within this scope, this research aims to expand the limited body of literature by examining the potential uses of PCM in architectural design more comprehensively. The study investigates the practical applications and comparative material properties of PCM, along with drawing conclusions about their potential for widespread use in future architectural projects. This research aims to provide both theoretical and practical contributions to the use of PCM in architectural designs. In this context, the widespread use of PCM in architectural design is expected to significantly contribute to the construction of sustainable buildings, playing a critical role in achieving energy efficiency and environmental sustainability goals.

Keywords: Phase Change Material, Innovative Material, Architectural Design

GİRİŞ

İnşaat sektörü, dünya genelinde yaşanan enerji tüketiminin %30-40'ından sorumlu olup (Yılmazoğlu, 2010) bu oran içinde ısıtma ve soğutmada harcanan enerji tüketimi %80-85 gibi önemli bir paya sahiptir (Konuklu ve Paksoy, 2011). Artan küresel sıcaklıklar, kentleşme oranlarındaki yükseliş ve buna bağlı olarak enerjiye olan talebin 2050 yılına kadar %50'nin üzerine çıkacağı öngörülmektedir (Alam ve diğ., 2019). 21. yüzyıl, enerji tüketimi ve kaynak yönetimi açısından kritik öneme sahip olmakla birlikte, iklim değişikliği, artan sera gazı emisyonları ve kaynakların etkin kullanımı gibi küresel ölçekli zorluklarla da karşı karşıyadır (Fereidoni ve diğ., 2023). Bu bağlamda, enerji tüketiminin azaltılmasına yönelik stratejiler hem çevresel hem de ekonomik sürdürülebilirlik hedeflerinin merkezinde yer almaktadır.

Enerji verimliliği sağlama ve tüketimi optimize etme amacıyla geliştirilen yöntemlerden biri, pasif sistemler olarak adlandırılan iklimlendirme yaklaşımlarıdır. Buna ek olarak, yenilikçi malzemeler ve enerji depolama teknikleri bu hedefe ulaşmada önemli bir rol oynamaktadır (Beltran ve Martinez-Gomez, 2019). "Isıl enerji depolama sistemleri", enerjiyi uygun şekilde toplama ve dönüştürme yeteneği ile ısıtma ve soğutma süreçlerinde tasarruf sağlamanın etkili bir yöntemi olarak dikkat çekmektedir. Faz değiştiren malzemeler (FDM), gizli ısı depolama özellikleri sayesinde ısıl enerji depolama sistemlerinde etkili bir çözüm sunan yenilikçi malzemelerdir. Bu malzemeler, iç mekân konfor koşullarını iyileştirirken aynı zamanda enerji talebini düşürerek çevresel etkilerin azalmasına katkı sağlamaktadır (Casini, 2014). FDM'ler, sıvı ve katı fazları arasındaki geçiş sırasında ısı enerjisini depolayarak sıcaklığını sabit tutar. Gündüz artan çevre sıcaklığı ve güneş radyasyonu etkisiyle eriyerek ısıyı bünyesinde depolar ve iç ortam sıcaklığının artışını engeller. Gece ise çevre sıcaklığı düştüğünde depoladığı ısıyı ortama geri salarak katılaşır ve iç mekânda ısıl konforu korur (Mohseni ve diğ., 2019), (Chan, 2011).

FDM'lerin yüksek enerji depolama avantajı, inşaat sektöründen diğer endüstrilere kadar geniş bir alanda enerji verimliliği ve sürdürülebilirlik hedeflerine ulaşmada kritik bir öneme sahiptir. Örneğin, tekstil endüstrisinde, termal konfor sağlayan giysilerde FDM kullanımı giderek artmaktadır. Ayrıca, elektrikli araçların bataryalarında ısı yönetimini optimize etmek için FDM'ler kullanılmakta, böylece batarya performansı ve ömrü artırılmaktadır (Sharma ve diğ., 2009). Gıda sektöründe, sıcaklık kontrolü gerektiren taşımacılık ve depolama süreçlerinde FDM'ler etkili bir çözüm sunmaktadır (Baetens ve diğ., 2010). Sağlık sektöründe ise, ilaç taşımacılığı ve sıcaklık kontrollü saklama alanlarında kullanım

örnekleri bulunmaktadır. Bu uygulamalar, FDM'lerin geniş bir kullanım alanına sahip olduğunu ve enerji verimliliğine yönelik önemli katkılar sunduğunu göstermektedir.

FDM'lerin farklı endüstrilerdeki uygulamaları, bu malzemelerin mimarlık ve yapı malzemeleri alanında da sürdürülebilirlik ve enerji verimliliği sağlama potansiyeliyle artan bir ilgi odağı haline gelmesini sağlamıştır. Ancak, mevcut literatür incelendiğinde, FDM uygulamalarının sağlamış olduğu enerji tasarrufu ve ekonomik avantajların çok sayıda araştırmanın odağı olmasına rağmen, FDM'lerin mimari tasarım süreçlerindeki entegrasyonunu ve pratik uygulamalarını ele alan araştırmaların sınırlı olduğu tespit edilmiştir. Bu bağlamda, bu araştırmanın temel amacı, FDM'lerin mimarlık ve yapı malzemeleri alanındaki potansiyel kullanım alanlarını kapsamlı bir şekilde incelemektir. Özellikle, FDM'lerin sürdürülebilirlik ve enerji tasarrufu hedeflerine sağladığı katkılar doğrultusunda, bu malzemelerin bir mimari tasarım öğesi olarak değerlendirilmesine yönelik teorik ve pratik bir çerçeve sunulması hedeflenmektedir.

YÖNTEM

Bu araştırmada, FDM'lerin mimari tasarımdaki uygulama potansiyellerini ve kullanım avantajlarını analiz etmek için kapsamlı bir yöntem izlenmiştir. Öncelikle, literatür taraması ile FDM'lerin termal özellikleri, enerji verimliliği üzerindeki etkileri ve mevcut uygulamaları incelenmiştir. Ayrıca, örnek çalışmalar üzerinden FDM'lerin farklı mimari bağlamlarda nasıl kullanılabileceği değerlendirilmiş ve bu malzemelerin pratik uygulamalardaki başarıları incelenmiştir.

Yapılan incelemelere istinaden, FDM'lerin gelecekteki potansiyel kullanım alanları üzerine derinlemesine bir inceleme yapılmıştır. FDM'lerin mimari tasarımlarda daha geniş bir şekilde entegrasyonunun sağlanması için gerekli stratejiler tartışılmış ve bu malzemelerin sürdürülebilir yapı projelerinde nasıl önemli bir yer tutabileceği ele alınmıştır. Gelecekteki uygulamaları doğrultusunda, FDM'lerin çevresel sürdürülebilirlik ve enerji verimliliği hedeflerine katkı sağlama potansiyeli vurgulanmış ve bu malzemelerin geniş ölçekte uygulanabilirliğine dair önerilerde bulunulmuştur.

BULGULAR

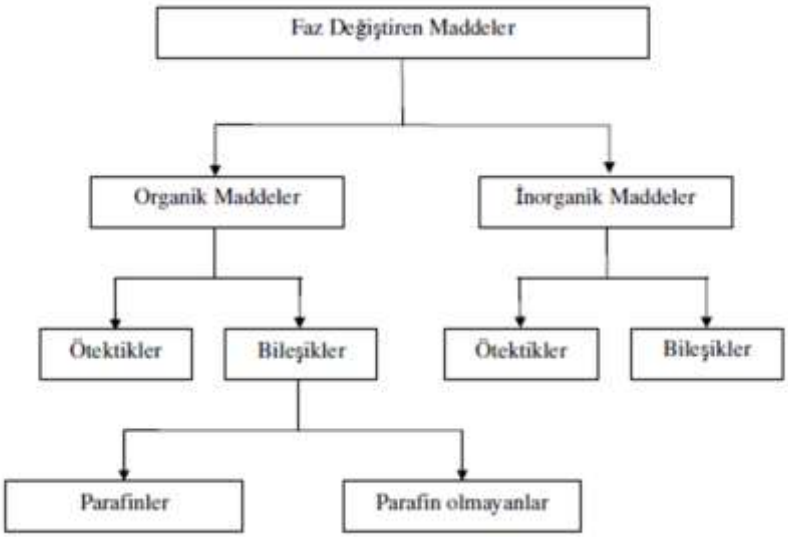
FDM Tanımı

FDM'ler, ısıl enerjiyi gizli ısı şeklinde depolayan malzemelerdir. Gizli ısı, bir maddenin faz değişimi sırasında çevresinden aldığı veya verdiği ısı olarak tanımlanabilir. FDM'ler, faz geçişleri sırasında sabit sıcaklıkta gerçekleşen ısıl depolama süreçleri sunarak, ısı enerjisinin etkin bir şekilde depolanmasını ve geri kazanılmasını sağlarlar. Bu özellikleri sayesinde, ısınma ve soğutma uygulamalarında enerji verimliliğini artırmak amacıyla kullanılmakta olup, enerji tasarrufu sağlayan çözümler geliştirilmesinde önemli bir rol oynamaktadır (Konuklu ve Paksoy, 2011).

FDM'lerin Sınıflandırılması

Isı enerjisi depolaması için kulanılan FDM'ler organik, inorganik ve ötektik olarak sınıflandırılmaktadır (Mazman, 2006). Şekil 1'de FDM çeşitleri sınıflandırılmıştır.

Şekil 1. Faz Değiştiren Malzemelerin Sınıflandırılması (Basal, 2007)



Organik FDM'ler, uzun vadeli ısıl kararlılığa sahip olup, katı fazda kristalleşme eğilimi gösterirler. Bu malzemeler, parafin ve parafin içermeyen organik bileşikler olarak iki ana gruba ayrılabilir. Parafin içermeyen türler arasında yağ asitleri ve polietilen glikol (PEG) gibi bileşikler yer almaktadır. Parafinlerin kimyasal formülü genellikle C_nH_{2n+2} şeklinde olan düz zincirli hidrokarbonlar olup, karbon zincirinin uzunluğu arttıkça erime sıcaklıkları ve entalpi değerleri de yükselmektedir (Mert ve diğ., 2018).

İnorganik FDM'ler, dört ana gruba ayrılmaktadır: tuzlar, tuz hidratları, metaller ve alaşımlar. Tuz hidratları, sodyum asetat trihidrat, kalsiyum klorür hekzahidrat, sodyum sülfat dekahidrat, sodyum tiyosülfat pentahidrat ve baryum hidroksit oktahidrat gibi bileşikler örnek olarak verilebilir. Bu tür tuz hidratları, düşük maliyetli olmaları nedeniyle özellikle araştırma ve geliştirme çalışmalarında tercih edilmektedir (Verma ve Singal, 2008).

Ötektik karışımlar, en az iki farklı atom veya molekülün birleşimiyle meydana gelmektedir. Bu malzemeler, sabit bir sıcaklıkta katılaşırken bir reaksiyon geçirir ve bu süreçte sıvı haldeki malzeme, iki ayrı katı faza dönüşür (Mert ve diğ., 2018). Farklı FDM türlerinin avantaj ve dezavantajları Tablo 1' de gösterilmektedir.

Tablo 1. Organik, İnorganik ve Ötektik FDM'lerin Avantaj ve Dezavantajları (Koşan, 2018)

FDM Türü	Avantajlar	Dezavantajlar
Organik	• İyi ısıl kararlılık • Aşırı soğuma olmadan donma • Düşük buhar basıncı • Özgün çekirdekleşme özelliği • Uyumlu eriyebilme • Düşük hacim değişikliği • Geleneksel yapı malzemeleri ile uyumluluk • Geniş çalışma sıcaklığı	• Sıvı FDM'nin sızması • Düşük termal iletkenlik • Yanıcılık
İnorganik	• Yüksek hacimli gizli depolama kapasitesi • Yangına karşı dayanımlı • Düzgün faz değişimi • Yüksek termal ısıl iletkenlik	• Aşırı soğumaya eğilimli • Ayrışma • Uyumlu eriyememe • Yüksek hacim değişiklikleri • Metal ile korozif olma • Tekrarlanan fazlarda faz ayrılma
Ötektik	• Keskin, net erime noktaları • Özellikler isteğe bağlı değişebilir	• Yüksek maliyetli • Termofiziksel özellikleri sınırlı

FDM'lerin Yapı Malzemelerine Entegrasyonu

FDM'ler yapı malzemelerine, doğrudan birleştirme, daldırma ve kapsülleme yöntemleriyle entegre edilmektedir. Doğrudan birleştirme yönteminde, sıvı veya toz haldeki FDM, yapı malzemesiyle karıştırılmaktadır. Bu yöntem, düşük ekipman gereksinimi nedeniyle ekonomik olmasına rağmen homojen bir karışım sağlanamayabilir ve erimiş haldeki FDM malzemeden dışarı sızabilir. Daldırma yönteminde ergimiş FDM, yapı malzemesinin gözeneklerine nüfuz etmesi için malzemenin içine daldırılır; sonrasında malzeme soğutularak gözenekler FDM ile dolar. Bu yöntem, her tür yapı malzemesine kolayca uygulanabilir ve önemli bir avantaj sunar. Kapsülleme yöntemi ise, FDM'nin olumsuz etkilerden korunmasını sağlamak amacıyla tercih edilir. Bu yöntem, FDM'nin mikrokapsülleme veya makrokapsülleme yöntemleriyle yapı malzemesine entegre edilmesini sağlar. Mikrokapsüllemede FDM parçacıkları, yapı malzemesiyle uyumlu polimerik filmlerle kaplanırken, makrokapsülleme yönteminde FDM, tüp, torba veya panel gibi kapsüllere yerleştirilir (Şekil 2) (Tokuç, 2013).

Şekil 2. Kapsülleme Örnekleri (soldan sağa): Mikroenkapsülasyon (PureTemp LLC), ve Makroenkapsülasyon Toplar (Global-E-Systems), Torbalar (Rubitherm Technologies GmbH)

Mimari Tasarımda FDM Uygulamaları

FDM, genellikle mikroenkapsüle FDM halinde geleneksel yapı malzemelerine uygulanmaktadır. Bu malzemelerin uzun ömürlü olması nedeniyle, mikroenkapsüle FDM'nin stabilitesi ve yapı malzemesiyle uyumu önemlidir. İlk Ar-Ge çalışmaları 1980'lere dayanmakta olup, 2000'li yıllarda yeniden hız kazanmıştır. Bu dönemde BASF, Micronal adı altında mikroenkapsüle FDM'yi piyasaya sürmüş, alçıpan ve sıvaya FDM entegrasyonunu sağlamıştır. Daha sonra, beton ve kili entegre etme çalışmalarına başlanmıştır. Ticari olarak piyasada bulunan başlıca ürünler, Knauf'un Comfortboard alçıpanı ve Lehmorange'ın kil esaslı panolarıdır. Bu ürünler, 10 yıldan uzun bir süredir çeşitli binalarda kullanılmaktadır (Harald ve diğ., 2022).

Nottingham Üniversitesi'ndeki Mark Group Eco House projesi (Şekil 3), BASF'nin mikroenkapsüle FDM içeren Comfortboard alçıpanın (Şekil 4) enerji verimliliği üzerindeki etkilerini değerlendiren önemli bir örnektir. Micronal, Knauf tarafından üretilen Comfortboard alçıpanında kullanılmış olup, enerji verimli konut teknolojilerinin performansını değerlendirmek için tasarlanmış bir projede yer almaktadır. Evde, güneş alan bölgede, standart alçıpan ve Micronal FDM içeren Comfortboard olmak üzere iki farklı alçıpan kullanılmıştır. FDM'ler, gizli ısı prensibiyle çalışarak ortam sıcaklığını dengelemektedir. Sıcaklık yükseldiğinde, FDM ısıyı emer; sıcaklık düştüğünde ise bu ısıyı geri verir. Bu özellik, Comfortboard'un iç mekanlarda sıcaklık dalgalanmalarını azaltmasını sağlamaktadır. Nottingham Üniversitesi, standart alçıpan ve Comfortboard arasında yüzey ısı akışını sürekli izleyerek bilimsel bir karşılaştırma yürütmektedir (BASF, 2013). Proje, Micronal'in konut uygulamalarındaki performansını gerçek yaşam koşullarında değerlendirmek için önemli bir fırsat sunmaktadır. Bu doğrultuda, proje, FDM'lerin konut tasarımında kullanımını teşvik eden teorik ve pratik bilgiler sağlamaktadır.

Şekil 3. Mark Group Eco House Projesi

Şekil 4. BASF Micronal FDM (BASF, 2013)

2009 yılında, Charles Sturt Üniversitesi'nin Albury'deki Thurgoona Kampüsü (Şekil 5), beton zeminlerinde FDM'lerin kullanıldığı dünyadaki ilk proje olarak tanımlanmıştır. Bu yenilikçi uygulama, FDM'lerin alçıpan tavanlara da entegre edilmesiyle desteklenmiştir. Bu özellikler, kampüsün Avustralya Yeşil Bina Konseyi tarafından "altı yeşil yıldız derecesi" ve "dünya lideri" statüsü ile ödüllendirilmesini sağlamıştır (McLaren, 2015).

Şekil 5. Charles Sturt Üniversitesi'nin Albury'deki Thurgoona Kampüsünde FDM Entegre Edilmiş Yapı Kabuğu (McLaren, 2015)

Diğer bir kimya devi DuPont, Energain (Şekil 6) adlı ürününü tanıtarak bu alanda yerini almıştır. Energain, %60 parafin esaslı FDM ve %40 etilen kopolimeri karışımından ürettiği malzemeyi 100 µm kalınlığında iki alüminyum levha arasında sıkıştırarak yaklaşık 5 mm kalınlığında bir panel haline getirmiştir. Bu paneller, alçıpanın arkasına yerleştirilen bölme duvarları ve tavanlarda kullanıma uygundur. DuPont, klima bulunan binalarda Energain panellerinin, maliyetleri ortalama %35 oranında azaltabileceğini ve kışın ısınma faturalarını %15'e kadar düşürebileceğini savunmaktadır. Ayrıca, yapılan malzeme analizlerine göre, geleneksel betonun %17 oranında enerji depolama kapasitesine sahip olduğu beton hacmiyle aynı hacimdeki FDM esaslı bu paneller, çok daha yüksek ısı depolama kapasiteleriyle hafif strüktürlerin termal kütle eksikliğini gidermektedir (DuPont), (McLaren, 2015).

Şekil 6. DuPont, Energain Ürünü Tavan Uygulaması (McLaren, 2015)

Phase Change Energy Solutions firması, BASF Micronal ve DuPont Energain'den farklı olarak, parafin veya sert paneller kullanmadan BioPCM (Şekil 7a) üretmektedir. Bu malzeme, soya, palmiye ve hindistancevizi yağı üretiminden elde edilen atık maddelerle hazırlanır ve nano ölçekli silika parçacıkları içeren bir kalınlaştırıcı ile karıştırılır. Sonuç olarak, esnek plastik filmler içinde saklanan bir jel elde edilir. BioPCM, yeni yapılara kolayca entegre edilebileceği gibi, mevcut yapılarda da daha sonra uygulanma olanağına sahiptir. Victoria'daki "9 Yıldızlı NatHERS Dereceli" bir konut projesinde (Şekil 7b), BioPCM kullanılarak enerji verimliliği sağlanmıştır. Projede, ısının ikinci kata yükselmesi

nedeniyle sıcaklık kontrolü sağlanamayan durumlar için BioPCM, termal kütle etkisi yaratacak şekilde duvar bileşenlerine entegre edilmiştir. Bu malzeme ısının yükselmesiyle eriyerek ekstra ısıyı emmektedir, böylelikle odanın sıcaklığının 24°C'den daha fazla yükselmesini engellemektedir (McLaren, 2015).

Şekil 7. (a) Phase Change Energy Solutions, BioPCM; (b) Victoria'daki 9 Yıldızlı NatHERS Dereceli bir Konut Projesi (McLaren, 2015)

(a) 

(b) 

İsviçreli GlassX firmasının Crystal ürünü (Şekil 8), FDM'lerin daha ilginç bir kullanımını sunmaktadır. Crystal, dört katmanlı bir cam pencere sistemidir ve iki cam arasına yerleştirilen saydam bir tuz-hidrat FDM içermektedir. Bu cam panel, beton kadar enerji depolama kapasitesine sahip olup, FDM'in katı fazda görünür ışığın %28'ini, sıvı fazda ise %45'ini iletebilmektedir. Bu özellik, yüksek termal kütleye sahip yapı kabuğunun aynı zamanda güneş ışığını geçirmesine olanak tanımaktadır (GlassX AG). GlassX'in Crystal ürünü, FDM'lerin yenilikçi bir kullanımını sunarak, binalarda enerji verimliliğini artırırken aynı zamanda doğal ışık geçişini optimize eder.

Şekil 8. GlassX, Crystal Ürünü Uygulaması (GlassX AG)

Tate Access Floors firması, zeminlerde FDM kullanımıyla farklı bir yaklaşım benimsemektedir. EcoCore panelleri (Şekil 9), yükseltilmiş döşeme sistemlerinde kullanılarak ofislerin kablolama ve klima gibi altyapı sistemlerinin döşeme altına gizlenmesini sağlamaktadır. Bu paneller, binanın bol güneş ışığına maruz kaldığı yönlerde döşeme kaplama malzemesi olarak kullanıldığında, içerdiği FDM'ler ısıyı emer ve ofise giren sıcaklığı kontrol eder. Tate tarafından yapılan testler, bu sistemin tipik beton zeminlere kıyasla klima talebini %17,7 oranında azaltabileceğini göstermektedir (McLaren, 2015).

Şekil 9. EcoCore Panelleri Uygulaması (McLaren, 2015)

Bir başka uygulama örneği olan "Smart is Green" konut projesi (Şekil 10a), Hamburg'daki Uluslararası Yapı Sergisi (IBA) kapsamında yer almış ve birinci ödül kazanarak uygulamaya geçirilmiştir. Bu projede, 1000 m^2'yi geçmeyen alanda bağımsız bir konut inşa edilmiştir. Tasarımda, çevresel ve sosyal değişimlere uyum sağlamak amacıyla FDM perdeleri (Şekil 10b) kullanılmıştır. Bu perdeler, güneşten alınan ısının depolanmasını ve gece serbest bırakılmasını sağlayarak, iç mekân sıcaklığını dengelemektedir. FDM malzemesi, fazla ısının merkezi bir enerji depolama sistemi olarak kullanılmaktadır. Ev, yenilenebilir enerji kaynaklarına dayalı merkeziyetsiz tedarik stratejileriyle, enerji verimliliği ve sürdürülebilirlik sağlamaktadır (Zillerplus).

Şekil 10. (a) "Smart is Green" Konut Projesi; (b) Projede Uygulanan FDM Perdeleri (Zillerplus)

(a)  (b) 

FDM Standartları

FDM'lerin Performans Değerlendirmesi İçin Standartlar

FDM'lerin en temel özelliklerinden biri olan ısı depolama kapasitesinin sıcaklıkla olan ilişkisi, kalorimetrik yöntemler kullanılarak ölçülmektedir. Bu amaçla, farklı ölçüm yöntemlerini kapsayan çeşitli standartlar geliştirilmiştir. Diferansiyel taramalı kalorimetreler (DSC) için bir ölçüm standardı, IEA Güneş Isıtma ve Soğutma/Enerji Depolama Yoluyla Enerji Koruma programının "Compact Thermal Energy Storage: Material Development for System Integration" başlıklı Görev 42/Ek 24 çalışması kapsamında geliştirilmiştir (Gschwander ve diğ., 2015).

Isı akış ölçer cihazı (HFM) için ise, ASTM C1784-20 standardı oluşturulmuştur. Bu standart, "Standard Test Method for Using a Heat Flow Meter Apparatus for Measuring Thermal Storage Properties of Phase Change Materials and Products" (ASTM C1784-20, 2020) olarak FDM'lerin ısı depolama kapasitelerinin belirlenmesi amacıyla geliştirilmiştir.

RAL FDM Kalite ve Test Spesifikasyonları (RAL-GZ 896), FDM'lerle ilgili geniş kapsamlı bir çerçeve sunmaktadır. Bu standart, FDM'lerin yalnızca sıcaklıkla değişen ısı depolama kapasitelerinin belirlenmesini değil, aynı zamanda çevrim stabilitesinin değerlendirilmesini de içermektedir. RAL-GZ

896, kalite yönetiminde hem üretici öz-denetimlerini hem de bağımsız denetçiler tarafından gerçekleştirilen periyodik dış denetimleri içeren sofistike bir izleme sistemine sahiptir. Bu süreçten başarıyla geçen ürünler, "RAL PCM Kalite İşareti" ile ödüllendirilmektedir. İlk olarak 2006 yılında geliştirilen bu kalite spesifikasyonları, düzenli olarak güncellenmekte ve en son teknolojik gelişmelere uyarlanarak güncel haliyle RAL PCM Kalite Derneği'nin web sitesinde yayımlanmaktadır (https://www.pcm-ral.org/pcm/en/pcm/certified-products/).

Soğuk zincir sektörünün ticari önemi, taşınan malzemelerin miktarı ve yüksek değeri göz önüne alındığında, bu sektörün kendi test standartlarına sahip olması beklenen bir durumdur. Bu alandaki bilinen standartlardan biri, Uluslararası Güvenli Taşıma Derneği (ISTA) (https://ista.org/) tarafından geliştirilen STD-7E standardıdır. Bu standart, "Testing Standard for Thermal Transport Packaging Used in Parcel Delivery System Shipment" olarak, soğuk zincir taşımacılığında kullanılan ambalajların performansını değerlendirmek için uygulanmaktadır (USAID).

FDM'lerin Uygulamaları İçin Standartlar

FDM uygulamaları için en eski standart, 1993 yılından itibaren ilk baskısı yapılan ASHRAE Soğuk Termal Depolama Tasarım Kılavuzu olarak bilinmektedir (ASHRAE, 2019). Bu kılavuz, soğuk termal enerji depolama sistemlerinin tasarımı, modellemesi, maliyeti ve devreye alınması konusunda kapsamlı bilgiler sunmaktadır.

Daha güncel bir tasarım kılavuzu ise, VDI 2164 "PCM energy storage systems in building services" (VDI 2164, 2016) kılavuzudur. Bu kılavuz, FDM'nin teknik bina ekipmanlarında uygulanmasının temellerini belirlemektedir. Ayrıca, pasif yüzey ısıtma ve soğutma sistemleri (örneğin bina malzemeleri ve bileşenleri), aktif yüzey ısıtma ve soğutma sistemleri (soğutma tavanları vb.), soğutma için dağıtılmış taze hava sistemleri ve ısıtma ve soğutma için merkezi taze hava sistemleri gibi çeşitli uygulama alanlarını ele almaktadır.

Hollanda'da ise benzer bir kılavuz bulunmakta olup, bu kılavuz, Hollanda ISSO Yayını 111 "Phase Change Materials (PCM)" olarak bilinmektedir. Ancak, şu anda yalnızca Flemenkçe olarak mevcut olduğundan, bu kılavuz hakkında detaylı bilgi bulunmamaktadır.

SONUÇ ve ÖNERİLER

Araştırmanın bulgularından çıkarılan sonuçlar aşağıdaki gibidir:

- FDM'lerin ilk Ar-Ge çalışmaları 1980'lerden itibaren başlamıştır. Bu malzemeler mimari tasarımda şu şekillerde kullanılmıştır:

1. Duvarlar: FDM'lerin ısı depolama özellikleri sayesinde duvarlar, gün içerisinde fazla ısıyı bünyesinde depolamakta ve geceleri bünyesinde depoladığı bu ısıyı salarak iç mekânda ısıl konfor koşullarının sürdürülmesini sağlamaktadır.

2. Döşemeler: FDM'ler, döşemelerde, özellikle sıcaklık değişimlerinin fazla olduğu yerlerde kullanılarak ısının dengelemesine ve enerji verimliliğini artırmaya yardımcı olur.

3. Çatılar: Çatı sistemlerinde FDM'ler, ısının yapıda daha verimli bir şekilde dağıtılmasına yardımcı olmak için kullanılır.

4. Pencereler ve Cam Sistemleri: FDM'ler, pencerelerde ve cam sistemlerinde, güneş ışığını içeriye yönlendirerek veya fazla ısının dışarıya çıkmasını engelleyerek iç mekânın sıcaklık dengesini iyileştirmek için kullanılır.

5. Cephe Sistemleri: FDM'ler, binaların dış cephelerinde, dış ortamla olan ısıl etkileşimini düzenleyerek binaların enerji tüketimini optimize etmek için kullanılır.

- Mimari tasarımda FDM uygulanan örnekler, FDM kullanımının, hem enerji verimliliğini artıran hem de yeşil bina sertifikasyon süreçlerinde avantaj sağlayan bir çözüm sunabileceğini açıkça göstermektedir. FDM teknolojisi, hafif yapıların ısıl kütle eksikliğini gidererek, enerji verimliliğini sağlayan önemli bir çözüm sunmaktadır. Aynı zamanda FDM'lerin iç tasarımda tekstil ürünü olarak kullanılması, iç mekân ısı yönetiminde yenilikçi bir çözüm sunmaktadır. Bu kullanım, büyük cam cephelerin bulunduğu binalarda sıcaklık dalgalanmalarını azaltarak termal konforu artırmaktadır. Bu

bağlamda, FDM'lerin geniş bir yelpazede mimari ve mühendislik uygulamalarına entegrasyonu, enerji tasarrufu ve çevresel sürdürülebilirlik hedeflerine ulaşılmasına katkı sağlamaktadır.

- FDM'lerin çevre dostu özellikleri ve enerji verimliliğine katkıları nedeniyle daha fazla nihai kullanıcı, bu malzemeleri kullanma konusunda farkındalık kazanmıştır. Ancak, geleneksel yapı malzemelerinin tamamen FDM ile değiştirilmesi kolay değildir. Çünkü geleneksel malzemelerin birçok ulusal ve uluslararası standardı vardır ve dünya çapında yaygın olarak kabul edilmektedir. FDM ürünlerinin yaygın bir şekilde kabul edilen bir ürün haline gelmesi zaman alabilir. Bu doğrultuda FDM'ler için mevcut standartlara ilave olarak uygun standartların oluşturulması konusunda daha çok ilerleme kaydedilmesi gerekmektedir. Uygun bir standardizasyon ile, FDM teknolojisinin inşaat sektöründeki kabulü yaygınlaşacaktır.

- Türkiye'de FDM'lerin pratik uygulamalarda üretim ve kullanım olanakları sınırlıdır. Bu bağlamda, FDM'lerin ticari ölçekli üretimine başlanması gerekmektedir. İnşaat sektöründen diğer endüstrilere kadar tüm paydaşlar, FDM'lerden uygun inşaat uygulamalarını belirlemek için işbirliği yapmalıdır. Binaların inşasında kullanılacak FDM'ler resmi olarak onaylanmalıdır. Teknik belgeler bir araya getirilerek "Mimari Tasarımda FDM Kullanımı" için bir ulusal standart hazırlanması yönünde yoğun çaba sarf edilmelidir.

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BETON KARIŞIM ORANI HESAPLAMA: MAKİNE ÖĞRENMESİ MODELLERİ İLE YENİLİKÇİ YAKLAŞIMLAR

CONCRETE MIX DESIGN: INNOVATIVE APPROACHES WITH MACHINE LEARNING MODELS

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ÖZET

Beton, inşaat sektörünün temel yapı malzemelerinden biridir ve dayanıklılığı, işlenebilirliği ve maliyet verimliliği, doğru karışım oranlarına bağlıdır. Geleneksel yöntemlerle beton karışım oranlarını belirlemek, deneyim ve deneme yanılma süreçlerine dayalıdır, bu da zaman alıcı ve maliyetli olabilir. Bu çalışmada, beton karışım oranlarını daha hızlı ve doğru bir şekilde hesaplamak için makine öğrenmesi (ML) modellerinin kullanımını incelemekteyiz. Makine öğrenmesi, büyük veri setlerini analiz edebilme ve karmaşık ilişkileri öğrenme kapasitesi sayesinde, beton karışım oranlarının optimize edilmesinde güçlü bir araç olarak öne çıkmaktadır.

Çalışmanın amacı, betonun bileşenleri olan çimento, kum, agrega ve suyun oranlarını tahmin edebilen bir makine öğrenmesi modeli geliştirmektir. Bu model, betonun dayanıklılığını, işlenebilirliğini ve maliyet etkinliğini en iyi şekilde sağlayacak karışım oranlarını belirlemek için tasarlanmıştır. Veri setleri, geçmiş beton üretim süreçlerinden elde edilen parametreler ve dayanım testleri kullanılarak oluşturulmuştur. Modelin eğitilmesinde, doğrusal regresyon, karar ağaçları ve yapay sinir ağları gibi farklı makine öğrenmesi algoritmaları değerlendirilmiştir. Ayrıca, modelin performansını değerlendirmek için doğruluk ve hata oranı gibi kriterler kullanılmıştır.

Sonuçlar, makine öğrenmesi tabanlı yaklaşımın, geleneksel yöntemlere kıyasla daha hızlı bir tasarım süreci sunduğunu göstermektedir. Model, geliştirilirken gerçek dünya uygulamalarından elde edilen verileri de dikkate alarak daha verimli ve ekonomik çözümler sunmaktadır. Bu, inşaat sektöründe hem maliyetleri düşürmeye hem de kaliteyi artırmaya yardımcı olabilir.

Bu çalışma, beton karışım oranlarının hesaplanmasında makine öğrenmesi yöntemlerinin potansiyelini keşfetmekte ve bu alandaki daha ileri araştırmalar için bir temel oluşturmaktadır. Geliştirilen model, inşaat sektöründe daha sürdürülebilir ve verimli beton üretim süreçlerine katkı sağlayacak potansiyele sahiptir. Gelecekte, modelin daha geniş veri setleri ve farklı beton türleriyle test edilerek daha da geliştirilmesi planlanmaktadır.

Anahtar kelimeler: Makine öğrenmesi, beton, Gauss süreç regresyonu, destek vektör makineleri.

ABSTRACT

Concrete is one of the basic building materials of the construction industry and its durability, workability and cost-efficiency depend on the correct mix proportions. Determining concrete mix proportions with traditional methods relies on experience and trial and error processes, which can be time consuming and costly. In this study, we investigate the use of machine learning (ML) models to calculate concrete mix proportions more quickly and accurately. ML has emerged as a powerful tool for optimizing concrete mix proportions due to its capacity to analyze large data sets and learn complex relationships.

The aim of the study is to develop a machine-learning model that can predict the proportions of cement, sand, aggregate and water as components of concrete. This model is designed to determine the mix proportions that will provide the best durability, workability and cost-effectiveness of concrete. The data sets were created using parameters obtained from past concrete production processes and strength tests. Different machine learning algorithms such as linear regression, decision trees and artificial neural

networks were evaluated to train the model. Furthermore, criteria such as accuracy and error rate were used to evaluate the performance of the model.

The results show that the machine learning-based approach offers a faster design process compared to traditional methods. The model offers more efficient and economical solutions by taking into account data from real-world applications during development. This can help to both reduce costs and improve quality in the construction industry.

This study explores the potential of machine learning methods in the calculation of concrete mix proportions and lays a foundation for further research in this field. The developed model has the potential to contribute to more sustainable and efficient concrete production processes in the construction industry. In the future, it is planned to further develop the model by testing it with larger data sets and different concrete types.

Keywords: Machine learning, concrete, Gaussian process regression, support vector machines.

GİRİŞ

Makine öğrenmesi, beton karışım oranlarının optimize edilmesinde çeşitli yöntemler ve teknikler sunarak inşaat sektöründe önemli bir yenilik sağlamaktadır. Aşağıda bu süreçte kullanılan başlıca yaklaşımlar üç şekilde özetlemek mümkündür. Bunlardan ilki tahmine dayalı modellemedir. Bu teknikte makine öğrenmesi, beton karışım oranlarını optimize etmek için tahmine dayalı modelleme tekniklerini kullanır. Bu yöntem, geçmiş verilere dayanarak gelecekteki performansları tahmin etme imkanı sunar. Örneğin, derin öğrenme algoritmaları, betonun dayanıklılığını etkileyen çeşitli bileşenlerin etkileşimlerini modelleyerek daha doğru karışım önerileri sunabilir (Acikgenc Ulas, 2022; URL-1, n.d.).

Çok amaçlı optimizasyon tekniklerinde maliyet, çevresel etki ve performans gibi farklı hedeflerin bir arada değerlendirilmesi sağlanır. Bu sayede, en uygun beton karışım oranları belirlenebilirken, aynı zamanda sürdürülebilirlik hedeflerine de ulaşılabilir (Açıkgenç Ulaş, 2023). Son teknik olan veri entegrasyonu ve eksik veri yönetiminde ise beton karışım tasarımında kullanılan verilerin farklı kaynaklardan entegrasyonu kritik bir öneme sahiptir. Makine öğrenmesi uygulamaları, eksik verilerin tahmin edilmesi için atama teknikleri ve eksik özelliklere tolerans gösteren modeller geliştirmektedir. Bu sayede daha güvenilir sonuçlar elde edilir (Açıkgenç Ulaş, 2023; Altay et al., 2021).

Bu çalışmada, beton karışım tasarımı sürecine makine öğrenmesi metotlarını dahil etmenin avantajlarını tartışmıştır. Makine öğrenmesi metotlarının, geleneksel yöntemler ile yapılan beton üretim sürecini kısaltacağı açıktır. Geleneksel yöntemler ile yapılan beton karışım tasarımında (Standard, 2016) istenilen özelliklerde betonun üretilebilmesi için çok sayıda deneme-yanılma karışımı ve/veya numunesi üretilmektedir. Bu durum hem üretim maliyetini hem de süreçte sarf edilen zaman ve iş gücü ihtiyacını arttırmaktadır. Makine öğrenmesi metotları bu sürece olumlu katkı sağlayarak zaman, iş gücü ve maliyetlerden tasarruf sağlayabilir. Ayrıca makine öğrenmesi metotları ile oluşturulan modellerin başarısının ölçülebilir oluşu da geleneksel yöntemlere göre başka bir avantaj sağlamaktadır.

Bu çalışmada ayrıca Gauss Süreç Regresyonu metodu ile beton bileşimi ve işlenebilirlik özelliği kullanarak betonun basınç dayanımını tahmin eden bir model örnek olarak sunulmuştur. Modelin eğitim ve tahmin sonuçlarının başarısı ölçülerek Bulgular bölümünde incelenmiştir.

BETON ÜRETİMİ ALANINDA KULLANILAN MAKİNE ÖĞRENMESİ MODELLERİ

Bu bölümde beton karışım oranlarının hesaplanmasında en çok kullanılan metotlar açıklanmıştır.

Yapay Sinir Ağları (YSA)

Bu alanda kullanılan en yaygın uygulama örneklerinden biri Yapay Sinir Ağları (YSA)'dır. YSA modelleri, betonun fiziksel ve mekanik özelliklerini tahmin etmek için kullanılır. Farklı beton türleri için işlenebilirlik testleri ve basınç dayanımını tahmin etmede oldukça başarılıdır. YSA, genelde beton bileşenlerinin özelliklerini girdi olarak alarak çıkışta dayanıklılık değerlerini tahmin eder (Atici, 2011; Behnood & Golafshani, 2018; Bilim et al., 2009; Naderpour et al., 2018; Pazouki et al., 2021; Prasad et al., 2009; İ. B. Topçu & Sarıdemir, 2008; Uddin et al., 2017). Ayrıca YSA'nın, giriş parametrelerinin çıkış parametresi üzerindeki etkisini de ölçebildiği de gösterilmiştir (Acikgenc Ulas, 2022). YSA, çok

katmanlı yapısı sayesinde karmaşık verileri işleyebilir ve tahminlerde bulunabilir (Açıkgenç Ulaş, 2023). YSA'nın yüksek doğruluk oranları ile çalışması, bu yöntemi popüler hale getirmiştir.

Gauss Süreç Regresyonu (GSR)

Gauss Süreç Regresyonu (GSR), beton karışımının basınç dayanımını tahmin etmek için kullanılan bir yöntemdir. Bu model, belirsizlik tahmini yapabilme özelliği ile öne çıkar ve karmaşık verileri işleyerek güvenilir sonuçlar sunar (Açıkgenç Ulaş, 2023).

Doğrusal olmayan çok değişkenli regresyon ve sınıflandırma problemleri, sıklıkla çok yönlü ve etkili bir makine öğrenme tekniği olan GSR kullanılarak çözülmektedir. GSR'nin temel faydası, sonuçlarına belirsizlik ölçütleri uygulanabildiği için parametrik olmayan küçük veri kümelerinde doğru tahminler üretebilmesidir (Korkmaz et al., 2022; Snelson & Ghahramani, 2007).

Destek Vektör Makineleri (DVM)

Destek Vektör Makineleri (DVM), beton bileşenlerinin özelliklerini tahmin etmekte kullanılan bir diğer makine öğrenmesi modelidir. Bu model, doğrusal olmayan ilişkileri de modelleyebilme yeteneği sayesinde betonun performansını etkileyen faktörleri daha iyi analiz eder (Açıkgenç Ulaş, 2023; Altay et al., 2021).

K-En Yakın Komşu (KNN) Algoritması

KNN algoritması, beton bileşenlerinin değişimi ile basınç dayanımı arasındaki ilişkiyi araştırmak için kullanılmaktadır. Bu yöntemle, farklı karışım oranlarının etkileri analiz edilerek en uygun formülasyonlar belirlenir (Altay et al., 2021; Kazak Çerçevik & Kayhan, 2021).

BULGULAR VE TARTIŞMA

Bu çalışmada GSR ile beton bileşimi ve işlenebilirlik özelliği kullanarak betonun basınç dayanımını tahmin eden bir model, örnek olarak sunulmuştur. Modelin eğitim ve tahmin sonuçlarının başarısı ölçülerek bu bölümünde incelenmiştir.

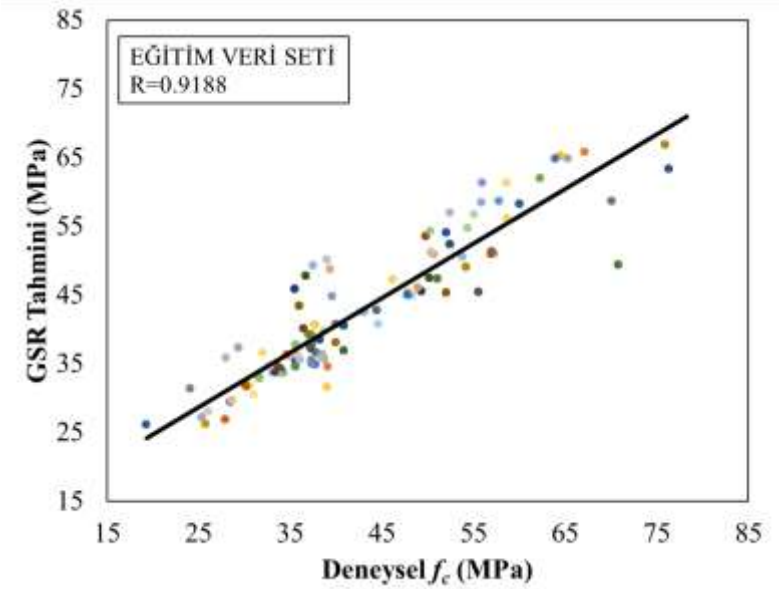
Modelin eğitimi ve testleri için literatürden elde edilen kapsamlı bir veri seti kullanılmıştır (Alyamaç et al., 2017; Alyousef et al., 2018; Belaidi et al., 2012; Boukhelkhal et al., 2016; Gesoğlu et al., 2012; Hameed et al., 2012; Sadek et al., 2016; Tennich et al., 2015; I. B. Topçu et al., 2009; Uysal et al., 2012; Uysal, 2018; Valdez et al., 2010). Toplamda 118 farklı beton karışımından oluşan bu veri setinin istatiksel özellikleri Tablo 1'de görülmektedir. Tablo 1'de modelin giriş ve çıkışı da belirtilmiştir. Buna göre, çimento, su, agrega, kimyasal katkı ve mineral katkı miktarı (kg/m^3) ile betonun taze haldeki çökme-yayılma test sonucu (cm) modelin girişlerini oluşturmaktadır. Modelin çıkışı ise 28 günlük beton basınç dayanımıdır (f_c) (MPa).

Tablo 1. Veri Setinin İstatiksel Özellikleri

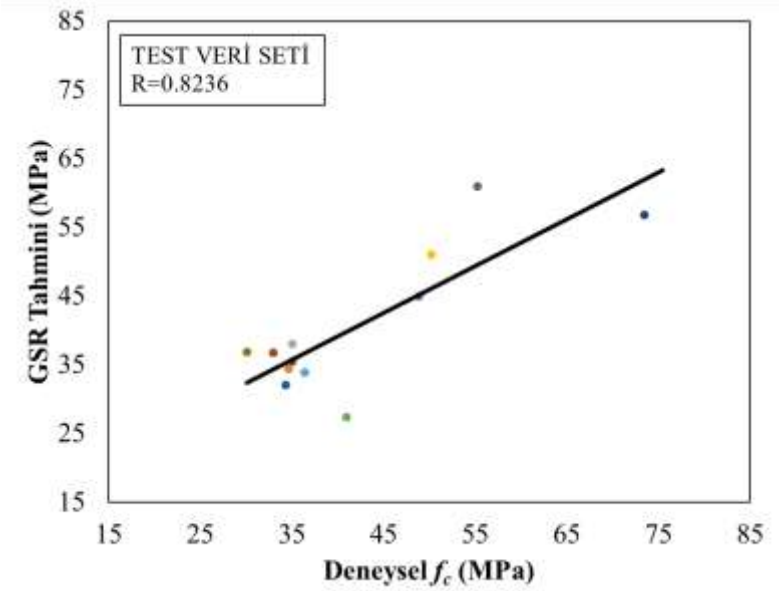
	GİRİŞLER						ÇIKIŞ
	Çimento (kg/m^3)	Su (kg/m^3)	Agrega (kg/m^3)	Kimyasal Katkı (kg/m^3)	Mineral Katkı (kg/m^3)	Çökme-Yayılma (cm)	f_c (MPa)
Maksimum	550	441	1911	15.8	500	81.5	76.28
Minimum	250	165	1305.572	0	0	2	19.3
Ort.	388.47	196.74	1648.4	7.01	122.27	61.06	42.95
Std. Sapma	74.29	31.67	96.17	3.05	94.17	18.37	12.10

Geliştirilen GSR modelinin amacı, Beton bileşiminden ve hedeflenen çökme yayılma değerinden betonun basınç dayanımını tahmin edebilmektir. GSR modeli, literatürde yayınlanmış çalışmalardan toplanan 118 adet deneysel veri kullanılarak geliştirilmiştir. Bu çalışmalardan rastgele seçilen 106 veri

ilk olarak modeli eğitmek için kullanılmıştır. Ardından, 12 rastgele veri de GSR modelini test etmek için bir kenarda tutulmuştur. Geliştirilen modelin eğitim ve test verilerindeki çıktıları ve bu sonuçlar ile deneysel veriler arasındaki doğrusal korelasyonlar Şekil 1 ve 2'de gösterilmiştir. Eğitim ve test veri kümelerindeki bu korelasyonlar (R) sırasıyla 0,9188 ve 0,8236'dır (Şekil 1-2). Tahmin edilen ve deneysel veriler arasındaki bu en iyi korelasyonlar, geliştirilen GSR modelinin yüksek doğruluğunu göstermektedir. Eğitim aşamasında yüksek doğrulukta çıktılar üreten GSR, test veri kümeleriyle de yüksek korelasyonlu sonuçlar üretmiştir.



Şekil 1. Deneysel eğitim verileri ile GSR tahminlerinin karşılaştırılması



Şekil 2. Deneysel test verileri ile GSR tahminlerinin karşılaştırılması

YENİLİKÇİ YAKLAŞIMLAR

Çok Amaçlı Optimizasyon Teknikleri

Beton karışım oranlarını optimize etmek için çok amaçlı optimizasyon teknikleri kullanılmaktadır. Bu teknikler, maliyet, çevresel etki ve performans gibi farklı hedeflerin bir arada değerlendirilmesini sağlar (URL-1, n.d.).

Veri Entegrasyonu ve Eksik Veri Yönetimi

Beton karışım tasarımında kullanılan verilerin farklı kaynaklardan entegrasyonu önemlidir. Makine öğrenmesi uygulamaları, eksik veri tahmini için atama teknikleri ve eksik özelliklere tolerans gösteren modeller geliştirmektedir (Açıkgenç Ulaş, 2023; URL-1, n.d.).

Doğal Dil İşleme (NLP)

Literatürden veri toplamak için doğal dil işleme teknikleri kullanılmaktadır. Bu yöntemle, beton bileşenleri ve performansları hakkında bilgi toplanarak daha doğru karışım tasarımları yapılabilmektedir (URL-1, n.d.).

SONUÇ

Makine öğrenmesi uygulamaları, beton karışım oranlarının hesaplanmasında yenilikçi yaklaşımlar sunarak inşaat sektöründe önemli gelişmelere yol açmaktadır. GSR, DVM ve YSA gibi modellerin yanı sıra çok amaçlı optimizasyon ve veri entegrasyonu gibi yenilikçi teknikler, daha sürdürülebilir ve ekonomik beton üretimini mümkün kılmaktadır. Bu gelişmeler, hem çevresel etkilerin azaltılması hem de maliyetlerin düşürülmesi açısından büyük önem taşımaktadır.

Makine öğrenmesi yöntemleri, beton karışım oranlarının optimize edilmesinde önemli bir rol oynamaktadır. Tahmine dayalı modelleme, çok amaçlı optimizasyon teknikleri ve veri entegrasyonu gibi yaklaşımlar sayesinde inşaat sektöründe daha sürdürülebilir ve ekonomik çözümler geliştirilmesi mümkün hale gelmektedir. Bu teknolojilerin entegrasyonu, hem maliyetleri düşürmekte hem de çevresel etkileri azaltmaktadır.

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SİSMİK DAYANIKLILIK İÇİN HAFİF POLİMER CEPHE UYGULAMARI

APPLICATIONS OF LIGHTWEIGHT POLYMER FACADES FOR SEISMIC RESILIENCE

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ABSTRACT

The selection of façade materials is a critical decision made in the early stages of design, shaping both the aesthetic and functional aspects of a building. This process requires consideration of multidimensional performance criteria such as appearance, user comfort, lighting, indoor air quality, ventilation, structural load capacity, and compatibility with building systems. Furthermore, it is crucial to account for the region's climatic conditions, contextual requirements, and user needs, which determine the priority performance expectations.

In seismic regions, lightweight polymer-based materials stand out for their ability to reduce structural loads and provide flexibility, offering significant advantages for structural safety. These materials resist damage through their elastic behavior, making them a viable alternative to brittle materials such as glass. Their energy-absorbing properties enable them to mitigate vibrations and impacts, contributing to the protection of non-structural components. However, while their use in façades often focuses on aesthetics, energy efficiency, and sustainable architectural applications, research on their application in seismic zones remains limited. This gap underscores the necessity of addressing their potential in such contexts, positioning it as a crucial focus of this study.

In this study, the technological advancements in polymer materials and their impact on building façades are examined, alongside their application potential in seismic-active regions. Case studies conducted in earthquake-prone countries are analyzed in detail, evaluating the effectiveness of existing applications and potential areas for development. These evaluations highlight the positive effects of polymer-based materials on seismic resilience and the opportunities they present for future applications in improving structural safety and performance.

Keywords: Building façades, Lightweight materials, Polymer-based materials, Earthquake-resistant design, Seismic risk mitigation, Technological advancements in materials

INTRODUCTION

Earthquakes are considered one of the most destructive natural disasters, often leading to substantial loss of life, damage to infrastructure, and serious economic repercussions for the communities impacted (AlKhaldi, 2024). According to the U.S. Resiliency Council damage to buildings is the primary cause of death, injury, and property loss from earthquakes (U.S. Resiliency Council). The damaging effects of earthquakes can be greatly reduced by thoroughly understanding seismic impacts and taking proactive steps in construction. This includes using modern building standards, retrofitting and strengthening existing structures, and planning urban development to consider seismic risks. These strategies work together to improve the resilience of buildings and lessen the chances of severe damage (Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, 2019). Türkiye, situated between three major tectonic plates and compressed by the Arabian and African plates, is one of the most seismically active countries in the world, with the North Anatolian Fault contributing significantly to frequent earthquakes, which impact the lifespan of buildings in the region (Cambaz et al., 2021; Duman et al., 2018). Seismic events in the area, especially in older structures not built to modern earthquake-resistant standards, often result in serious structural damage and deterioration. The use of inferior materials and outdated construction methods in these buildings makes them increasingly susceptible to seismic forces

over time. The catastrophic earthquake measuring (Mw) 7.8 hit Türkiye and Syria on February 6, 2023, destroyed a wide range of buildings, and resulted in the tragic loss of thousands of lives (NASA Earth Observatory). This catastrophe highlighted the urgent need for earthquake-resistant building designs in high-risk regions, highlighting the critical importance of addressing seismic resilience in urban planning and construction methods.

The seismic resilience of a building largely depends on the materials used and the structural system chosen. These factors are first established by the architect and then fine-tuned by the structural engineer, who considers feasibility, reinforcement, element sizes, and cost efficiency. Effective collaboration between architects and engineers is crucial to align these components, ensuring the building can effectively withstand seismic forces (Tuna, 2000; Ersoy, 1999). Although the main seismic performance of a building relies on its primary load-bearing system, facades, being the outermost layer, are especially susceptible to damage during seismic events. Just like load-bearing structures, facades need to be able to endure forces caused by earthquakes. Thus, it is essential to ensure the structural integrity of facades to maintain the overall safety of the building during an earthquake. While current standards usually categorize them as non-structural elements, a facade's failure can present a serious risk (Filiatrault et al., 2021). Facades must withstand earthquake-induced forces to mitigate significant risks, such as falling debris that can lead to severe injuries and block access or escape routes, potentially hindering rescue efforts and emergency services.

Recent seismic events in Turkey have highlighted the inadequate earthquake resistance of many reinforced concrete residential buildings, prompting the investigation of various strengthening strategies. A major drawback of these methods is that they often require residents to evacuate the buildings during the structural work. In contrast, external strengthening techniques allow for the reinforcement of buildings without the need for evacuation. By adding structural elements to the outside, the original facade of the building can be preserved, minimizing the need for extensive renovations. This approach is especially beneficial for structures in seismic areas, where internal modifications can be difficult or disruptive. However, it is crucial to acknowledge that most reinforcement techniques still require evacuation, which poses a significant challenge, as it necessitates temporary housing for the residents (Toker & Unay, 2006).

Figure 1. Examples of damages of buildings in the 6th February 2023 Türkiye earthquake (URL1, URL2, URL3)

Earthquake-Induced Damages

The design and detailing of both structural elements, like walls, columns, and floors, as well as non-structural components, such as partition walls and facades, are essential in shaping how a structure responds during an earthquake. These elements greatly affect the building’s overall performance, including its capacity to endure seismic forces and its susceptibility to damage. The interaction between these components is crucial in determining the building's resilience to earthquakes and its chances of sustaining damage before a collapse occurs (Bachmann, 2003). Building collapses during earthquakes often occur due to structural weaknesses that arise when load-bearing elements, like walls, are removed from upper floors and replaced with columns on the ground floor. This change creates a soft ground floor, or soft story, which is particularly vulnerable to seismic forces. In these situations, the cyclic movements between the ground and the upper sections of the building, along with insufficient lateral resistance on the ground floor, can lead to significant damage to the columns (Dhabre & Dhamge, 2019). Uneven distribution of mass and stiffness in buildings can also lead to structural instability, and stress concentrations in specific areas increasing the likelihood of cracking or failure (Khanal & Chaulagain, 2020).

Recent technological advancements in seismic-resisting structural systems are changing the way buildings are designed. However, it is essential to protect the entire building system, which includes both structural and non-structural elements, to ensure resilience during earthquakes. Proper detailing, reinforcement, and anchoring of openings and facades significantly improve seismic performance and stability. A notable study on the 1994 Northridge earthquake found that around 75% of the 66,000 damaged buildings had problems with non-structural components, highlighting the need to address these vulnerabilities in addition to structural issues (Charleson, 2008). Non-structural components such as walls, ceilings, cladding, curtain walls, glass panels, and rooftop equipment can become dangerous during earthquakes, as they may detach, shatter, or collapse, posing threats to both the building's stability and the safety of its occupants. These elements can turn hazardous, jeopardizing not only the integrity of the structure but also the safety of its occupants. This underscores the importance of properly designing, detailing, and anchoring non-structural components, which is just as vital as having a well-designed primary structural framework to ensure safety and functionality during and after an earthquake.

Research Aim & Objectives

This research aims to explore the performance of polymers in seismic zones, particularly focusing on the non-structural components of buildings and facades, as well as their durability and adaptability in earthquake-prone environments. By evaluating the resilience of polymer materials under seismic stress, the study intends to assess their effectiveness in maintaining both architectural and structural integrity. Additionally, the research will investigate design flexibility and the possibilities for retrofitting with polymer facades, offering insights through detailed case studies from various seismic regions. The case studies will highlight different approaches and innovations in polymer facade design, providing valuable inspiration for enhancing safety and sustainability in Türkiye.

ESSENTIAL REQUIREMENTS FOR FACADE SYSTEMS

Facade design and performance is a complex and interdisciplinary field that combines architectural aesthetics with engineering principles to tackle issues of functionality, sustainability, and environmental responsiveness. The facade acts not only as a visual and structural component that shapes a building's identity but also impacts its design, intended use, and the arrangement of services within. In this context, both active and passive design techniques—such as the use of advanced materials and technologies or the optimization of the facade's orientation and geometry—play a crucial role in striking a balance between form and function. This relationship between design and performance makes facades a vital subject in the exploration of resilient building practices (Rupal et al., 2020).

The main roles of building facades are crucial for maintaining structural integrity, improving energy efficiency, and ensuring comfort in the built environment. These roles include shaping the building's aesthetic identity, preventing water from entering, reducing air leakage, managing the flow of light and heat (both through radiation and conduction), minimizing noise from outside, and addressing the impact of thermal bridges. Beyond these primary functions, facades also fulfill secondary roles, such as accommodating movements within the structure due to wind, earthquakes, and creep, as well as handling thermal expansion and contraction. Additional secondary functions involve controlling moisture movement, providing fire resistance, and ensuring durability against weather conditions to prevent issues like streaking, oxidation, or spalling (Moghtadernejad & Mirza, 2014; Lapidus et al., 2023; Schittich, 2006).

Aesthetic considerations are frequently neglected in the design of buildings in Türkiye. Even though structures are built according to strict regulations and on plots of nearly the same size, irregularities still exist in the urban landscape. As a result, it is difficult to claim that buildings across the country present a unified and harmonious look. Although many buildings share similar characteristics, their fragmented and inconsistent appearance continues to prevail in the overall cityscape (Toker & Unay, 2006). This disjointed and inconsistent architectural style not only disturbs the visual unity of urban areas but also obstructs the creation of cohesive urban identities and livable environments. Given the challenges posed by global warming and climate change, these shortcomings highlight the pressing need to focus on energy-efficient and sustainable building practices that harmonize aesthetic appeal with functional objectives. Simultaneously, the devastating effects of earthquakes on structures and their occupants, caused by ongoing tectonic movements, highlight the equal importance of designing earthquake-

resistant buildings. Sustainable building design should go beyond just adding green elements or cosmetic environmental features; it should prioritize long-term functionality and durability, ensuring that these structures can endure for generations (Dabija, 2021).

Quake-Proof Facade

When designing facades that can withstand earthquakes, several important factors need to be taken into account, such as flexibility, material durability, anchorage systems, joint details, and ongoing maintenance (Massey, 1992). Flexibility is an essential factor; the facade should be able to absorb seismic shocks without collapsing or cracking. This can be accomplished by utilizing materials, which can bend and reshape under stress without breaking. Material durability is vital, as the facade must withstand the forces generated during an earthquake, necessitating the use of strong and robust materials. Furthermore, connection systems are crucial for ensuring that the facade remains securely attached to the building during seismic events. Proper anchoring, using metal ties or bolts, is necessary to prevent the facade from detaching or falling, and regular maintenance is key to preserving the integrity of these systems (Ortega Heras et al., 2015). The design of joints between facade panels is another significant consideration; these joints must accommodate movement without cracking or separating during an earthquake. Employing flexible joint materials, such as neoprene or silicone, along with proper sealing and maintenance, is essential for achieving this. (Hareer, 2007) and (Abtahi, 2017) concentrated on creating façade systems that feature energy-dissipating connections aimed at reducing the effects of earthquakes. These façades include devices or materials capable of absorbing seismic energy, like viscoelastic dampers, friction dampers, or base isolators, which are integrated into the structure of the façade to improve the building's overall ability to withstand seismic events. Lastly, routine maintenance and inspection of facades are critical for ensuring ongoing earthquake safety. Regular checks and repairs help maintain the structural integrity of the facade, ensuring it remains functional and safe during seismic events. (Baird et al., 2011; Building Seismic Safety Council for the Federal Emergency Management Agency, 2004).

To tackle the challenges in facade design, it's crucial to first identify the problems with material and application selections that have resulted in notable seismic vulnerabilities. The 2011 Christchurch earthquake highlighted that many facades, especially those with lightweight materials like glass, did not comply with seismic safety standards, creating life-threatening hazards from falling debris. Although heavier claddings fared better, they still posed serious risks of failure (Baird et al., 2011). Likewise, traditional facades during the Bam (2003) and Kermanshah (2017) earthquakes exhibited considerable vulnerabilities, with brick and stone facades experiencing extensive damage that was difficult to repair (Ghatte, 2021). To address these issues, several damage-reducing solutions can be employed in facade systems to improve seismic performance, as shown in Figure 1. In contrast, modern facades utilizing flexible materials and advanced anchoring methods demonstrated enhanced seismic performance and facilitated easier repairs.

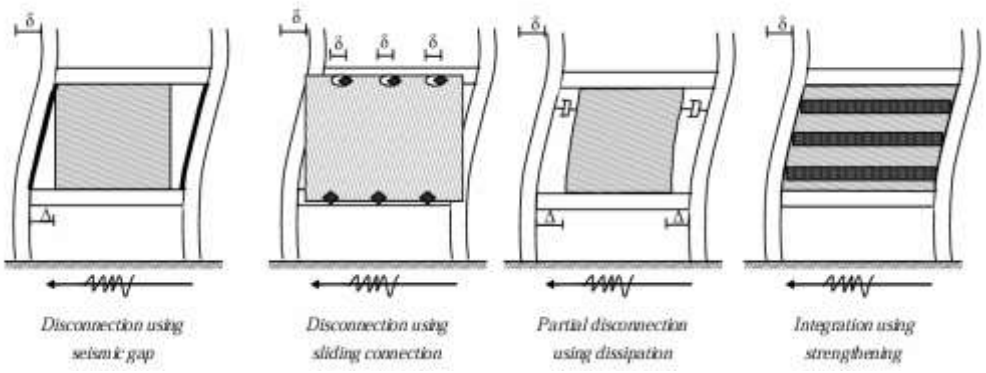

Figure 1. Focusing on Reducing Earthquake Damage to Facade Systems (Baird et al., 2011)

FIXING 'HEAVY' FACADES IN SEISMIC ZONES: THE ROLE OF POLYMER MATERIALS

Polymer materials have rapidly become a widely utilized component within the construction industry due to their versatile applications and growing demand (Tamošaitienė et al., 2024). These materials give

architects more flexibility and creativity in their designs, allowing for the creation of unique facade systems and structural components. Plastics are high-molecular-weight polymers that combine the transparency of glass with the workability of wood. Different types of plastics have various properties, but they generally share characteristics such as low thermal conductivity, high tensile strength, and resistance to water and chemicals. However, they can become brittle in very cold conditions and may lose their strength when exposed to high temperatures (Hegger et al., 2012).

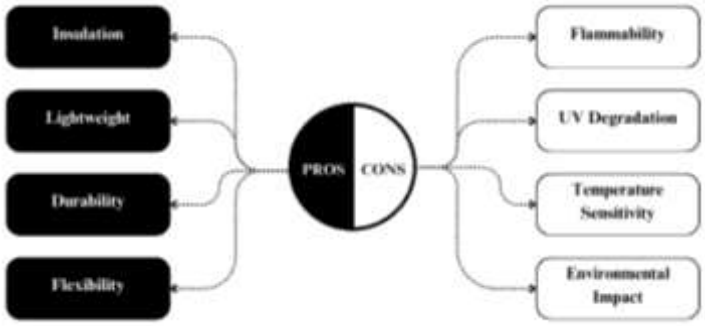

Figure 2. Advantages and Disadvantages of Polymer Materials in Construction

Plastics are materials made up of large molecules called polymers, which can be created synthetically or significantly altered when sourced from natural materials (Strong, 2006). While they have many benefits, their vulnerability to UV radiation can be reduced by using additives like carbon black or flame retardants, which improve their durability and overall performance (Aydın, 2004). Plastic examples and their applications are outlined in the table below, showcasing their distinct properties and roles in construction.

Table 1. Properities and applications of Polymer Materials in Facade Systems

Polymeric Materials	Key Properties	Applications in Facades	References
PMMA/ATH (Mineral-Acrylic Panels)	Composite material (80% ATH, 20% PMMA), strong, weather-resistant, thermal-sensitive. Decreased strength at high temperatures.	Transparent panels, glazing, light-diffusing elements	(Byrdy & Kołaczkowski, 2015)
Polyvinyl Chloride (PVC)	Durable, cost-effective, resistant to moisture, low UV resistance, health risks and environmental impact, challenges in recycling.	Window frames, decorative cladding, panels, solar shading	(Ajayi & Gasu, 2014; Petrović & Hamer, 2018; Health and Environment Alliance, 2023)
High-density polyethylene (HDPE) and low-density polyethylene (LDPE)	Low Wear Resistance, Ease of Mechanical Processing, High Impact Resistance Durability, Rigidity, Harder texture.	Protective Coatings and Membranes, Cladding Panels,Recycled Facade Components	(Habibi et al., 2020; Wani et al., 2020)
Fiber-Reinforced Polymers (FRP)	High strength-to-weight ratio, ductility, lightweight, excellent weather resistance,	Facade Reinforcement, Panels for Curtain Walls, Glazing Façade Modules, Cladding Panels	(Scott & Beck, 2016; Gattesco et al., 2015; Almusallam & Al-Salloum, 2007; Bedon, 2016)

	high durability, higher initial cost,		
Polypropylene (PP)	Durability, Flexibility, Lightweight, Dimensional Stability, Low Moisture Absorption, Good Insulation, Flammability, UV degradation.	Cladding Panels, Wall Insulation	(Tamošaitienė et al., 2024)
Polycarbonate (PC)	High impact resistance, transparency, heat flux distribution.	Glazing systems, panels, curved facade cladding panels	(Moretti et al., 2014)
Ethylene Tetrafluoroethylene (ETFE)	Lightweight, highly transparent, strong,UV-resistant, self-cleaning, recyclable.	Cushion systems, large-scale glazing, curtain wall glazing, double skin façade.	(LeCuyer, 2008; Nahar et al., 2023)
Polymer Concrete	High mechanical strength, short curing period, wear resistance, weather resistance, waterproofing, insulation performance.	Used in prefabricated walls, hydraulic structures.	(Seco et al., 2020; Agavriloaie et al., 2012; Kulshreshtha et al., 2017)
Textile	Low Weight, Reduced Structural Load Durability and Long Lifespan, Flexibility.	Architectural shading, membrane claddings, tension membrance, sliding and fixed panels, nesting, kinetic systems.	(Procaccini et al., 2023; Paech, 2016)

When evaluating polymeric materials for seismic regions, it's crucial to assess how they perform under stress and varying environmental conditions. PMMA/ATH panels are known for their transparency and durability, but they may lose strength at higher temperatures, which can limit their effectiveness in areas facing both seismic and thermal challenges. While PVC is a cost-effective option, it has limited UV resistance and potential environmental issues, necessitating careful long-term management. On the other hand, HDPE and LDPE stand out for their durability and impact resistance, providing flexibility and long-term resilience, although they encounter challenges with recycling.

FRP and ETFE materials are commonly utilized in seismic regions due to their high strength-to-weight ratio and excellent weather resistance. Their ductility enables them to absorb and dissipate energy effectively, improving seismic performance. Likewise, PP is durable, flexible, and lightweight, making it suitable for seismic applications, with good insulation and flammability resistance. Polymer Concrete and textile materials, such as tensile fabrics, also offer high mechanical strength and adaptability to dynamic movements, making them effective for low-maintenance seismic solutions.

While plastics provide significant benefits like being lightweight, flexible, and affordable, glass continues to be a favored choice in façade construction because of its unmatched clarity and visual attractiveness. Plastics, being lightweight and highly transparent, can be used as an alternative to glass. Comparing these two materials offers important insights into their unique functions in architecture, especially in areas prone to seismic activity. Table 2 compares glass and polymer materials based on

parameters related to seismic activity. This analysis emphasizes the impact of material properties on their performance and appropriateness in regions prone to earthquakes.

Table 2. Comparison of Glass and Polymeric Materials in Seismic Applications

Material	Weight (kg/m^2)	Energy Absorption Capacity (Damping)	Brittleness	Modulus of Elasticity (GPa)	Life span (years)	Long-Term Cost (Lifetime)
Glass	Higher	Lower	Higher	Higher	Higher	Higher
Polymeric Materials	Lower	Higher	Lower	Moderate/ Lower	Moderate/ Lower	Moderate

Glass, being significantly heavier, contributes more to structural loads, whereas polymers are much lighter, reducing the overall dead load of a building (Chowdhury et al., 2022). In terms of rigidity, glass has a high modulus of elasticity, making it more rigid, while polymers are more flexible, allowing them to absorb greater deformation and better withstand dynamic forces. (Bestech Australia, 2019). This flexibility means that polymers tend to deform or crack under stress rather than shatter, as is common with glass (Dutton, 2016). This flexibility also leads to polymers deforming or cracking rather than shattering, offering better safety during an earthquake. Additionally, polymers have higher energy absorption capacity (damping), making them more capable of reducing vibrations and enhancing the building's performance in seismic events (Zhou et al., 2018). Additionally, polymers are generally more cost-effective for lightweight applications, and ETFE has emerged as a cost-effective alternative to traditional glazing solutions (Durston & Robinson, 2016). Over time, glass has a longer lifespan, especially with treatments like tempering (Babitharani et al., 2019), but polymers, though more susceptible to UV degradation, have seen improvements in durability due to advanced coatings and treatments, allowing them to last longer (Lu et al., 2018).

Polymer Façade Case Studies

The selected case studies in this research highlight the integration of façade design with seismic resilience, emphasizing how the use of plastic-based materials plays a pivotal role. These examples demonstrate how polymer-based materials not only improve seismic performance but also maintain architectural integrity and aesthetic appeal, transforming seismic zones into opportunities for innovative and durable façade solutions. Seismic façade design involves a complex interaction of visual, practical, and structural considerations shaped by engineering and materials research.

Table 3. Selected Case Studies (URL4, URL5, URL6, URL7, URL8, URL9)

Case study 1 Name: Komatsu Seiren Fabric Laboratory Location: Ishikawa, Japan Polymer Material Used: Thermoplastic Carbon Fiber Composite	Case study 2 Name: SFMOMA Expansion Location: San Francisco, USA Polymer Material Used: FRP Panels	Case study 3 Name: La Miroiterie Location: Lausanne, Switzerland Polymer Material Used: PTFE Glass and ETFE cushions
		
Case study 4 Name: Bima Microlibrary Location: Bandung, Indonesia Polymer Material Used: Polypropylene	Case study 5 Name: Sogokagu Design Lab Location: Ishikawa, Japan Polymer Material Used: ETFE Panels	Case study 6 Name: Pola Ginza Location: Tokyo, Japan Polymer Material Used: Acrylic Panels
		

The Komatsu Seiten office building in Ishikawa, Japan, designed by architect Kengo Kuma, showcases a creative use of CFRP for both seismic protection and aesthetic appeal. Situated in a region prone to earthquakes, the building's structure was reinforced with CABKOMA strand rods, a lightweight and high-tensile material specifically created for this project. These rods were installed externally to link the roof to the foundation and internally as a mesh reinforcement, providing a dual-layered approach to seismic resistance. With a tensile strength five times greater than that of steel and weighing only one-fifth as much, CABKOMA strand rods present an efficient, cost-effective, and visually attractive option for retrofitting older buildings and enhancing new ones. Their resistance to rust, flexibility, and ease of installation add to their practicality. The building combines these functional advantages with visual appeal, as the rods are designed as architectural features that are illuminated to create a striking visual effect (Gardiner, 2015a).

While the other chosen case studies emphasize various advantages for seismic areas, they do not explicitly provide detailed information about seismic testing or adherence to specific performance standards. These examples mainly illustrate creative uses of materials and façade design strategies, providing insights into their potential for withstanding seismic events. The SFMOMA expansion features a striking façade made up of over 700 uniquely shaped FRP panels, covering around 7,800 m²

of a 10-story building. The lightweight and strong FRP material provides seismic benefits by reducing the overall mass of the façade, which in turn lowers inertial forces during earthquakes. The panels are attached to a curtain wall system, allowing for flexibility and adaptability to movement while preserving structural integrity. This project stands out as one of the largest architectural uses of FRP composites, highlighting the material's potential in seismic areas where lightweight, durable, and fire-resistant solutions are essential for both aesthetic appeal and resilience against seismic stresses (JEC Group, 2018).

The Miroiterie Flon Lausanne project in Switzerland highlights the use of cutting-edge façade technologies, featuring ETFE membranes and PTFE-coated glass fabrics. These materials provide distinct advantages for seismic façade applications due to their lightweight nature—about 1/40th the weight of glass—and their capacity to minimize breakage risk during seismic events. The ETFE membrane boasts remarkable translucency (up to 95%) and self-cleaning chemical composition, ensuring durability with minimal upkeep. Additionally, its flame-retardant characteristics and adherence to international safety standards further bolster its reliability (Cremers, 2009).

The Bima Microlibrary showcases a creative approach to materials and structural techniques that meet both functional and aesthetic requirements while also incorporating passive environmental controls. In terms of its seismic façade application, the design incorporates steel columns and beams into the existing stage structure, creating a solid foundation for the elevated library. The façade's use of recycled plastic ice cream buckets boosts its seismic resilience by providing a lightweight yet sturdy infill material. Furthermore, the floating volume design enables the library to serve as both a shelter and an engaging architectural element, minimizing seismic risk through its flexible and cohesive structural system (Ichioka, 2019).

Kengo Kuma's design for the Sogokagu Design Lab features a facade made from a polymer-based application, with a steel structure enveloped in polyurethane foam and a multilayered material resembling animal hide. This combination creates a flexible yet robust exterior that enhances thermal insulation and boosts seismic resilience. The incorporation of ETFE film and transparent PVC further fortifies the facade's capacity to endure seismic forces while preserving its structural integrity. Additionally, the use of recycled materials, like plastic bottles, promotes sustainability and durability, making the facade effective in terms of seismic performance (Yanılmaz & Eyüboğlu, 2023).

The Pola Ginza Building features a striking double-skinned facade that combines thermal, optical, and airflow functions. It consists of curved acrylic shutters that can be individually controlled and are equipped with LED lighting, enhancing both aesthetics and energy efficiency. These shutters are engineered to handle structural movements and stresses, ensuring the building's resilience during seismic events. With individual control mechanisms, the facade can flexibly respond to different seismic forces while maintaining its overall stability and durability.

CONCLUSION

This research has examined how polymers can improve the seismic performance of buildings, particularly in non-structural components/ facade systems. Earthquakes remain a significant threat, with damage to buildings being a major contributor to casualties and economic losses. Recent seismic incidents in Türkiye have highlighted the weaknesses of reinforced concrete structures, creating a demand for innovative and adaptable solutions. Case studies have shown that polymer materials, like CFRP and other polymer composites, not only provide structural reinforcement but also allow for design flexibility. These materials boost durability, enhance structural integrity, and provide greater resistance to seismic forces. Moreover, polymers are lightweight, resistant to corrosion, and can be seamlessly incorporated into both new and existing structures, making them perfect for retrofitting and reinforcing older buildings. By using polymer-based solutions, the retrofitting process causes minimal disruption to the buildings, while also offering a sustainable way to enhance seismic resilience. Rapid and irregular urbanization, especially during the 1950s and 1960s, led to the construction of many buildings in Turkey without following modern safety and seismic standards. Consequently, thousands of these structures, particularly in high-risk seismic areas, urgently need structural strengthening to enhance their seismic performance while maintaining functionality. This strategy is increasingly favored for improving the resilience of older buildings, contributing to safer and more sustainable built environments.

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EFFECT OF CALCINATION TEMPERATURE AND DURATION ON THE COMPRESSIVE STRENGTH AND WATER RESISTANCE OF VOLCANIC ASH-BASED GEOPOLYMER MORTARS

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ABSTRACT

Geopolymer binders, considered a viable alternative to Portland cement, stand out for their environmentally friendly nature and superior mechanical properties. In geopolymers, artificial pozzolans can be used as powdered binders, as well as natural materials such as pumice, perlite, and volcanic ash. The use of natural pozzolans emerges as a promising alternative in terms of sustainability and eco-friendly practices. Among natural pozzolans, volcanic ashes have garnered significant attention in recent years as aluminosilicate sources for geopolymer binder production. Studies on volcanic ash-based geopolymer mortars and concretes indicate that while they achieve adequate strength levels, they lack sufficient durability against water exposure. This study investigates the effect of calcination on the resistance of volcanic ash-based geopolymer mortars to water exposure. In this regard, the strength and water resistance of volcanic ash-based geopolymer mortars produced with volcanic ashes calcined at different temperatures (600, 750, and 900 °C) and durations (1, 2, and 4 hours) were evaluated. The results revealed that calcination had no significant positive effect on the strength or water resistance properties of volcanic ash-based geopolymer mortars. However, calcination at 900 °C for 1 hour slightly improved the strength and provided limited enhancement in residual compressive strength after water exposure.

Keywords: Geopolymer, Volcanic ash, Water resistance, Calcination

INTRODUCTION

Concrete is the most widely used construction material globally. However, Portland cement, which constitutes the binding matrix of concrete, has significant adverse environmental impacts. Geopolymer binders, recognized as an environmentally friendly alternative with a lower environmental footprint compared to Portland cement, have gained increasing attention [1]. These binders also exhibit notable resistance to fire and acids [2, 3]. Reactive materials such as fly ash, metakaolin, and ground granulated blast furnace slag have been widely used as powder binders in geopolymers over the past years. However, to promote the development of sustainable construction materials, the use of natural materials like pumice, perlite, and volcanic ash as aluminosilicate sources for geopolymer mortars and concretes has been increasingly encouraged in recent years [4].

The use of natural pozzolans presents a promising alternative to artificial pozzolans in terms of sustainability and eco-friendly applications [5]. While studies on using natural pozzolans such as pumice and perlite in geopolymer mortars and concretes exist, there has been a notable rise in research focusing on volcanic ashes as aluminosilicate sources for geopolymer binder production. These studies have demonstrated that volcanic ash-based geopolymer mortars and concretes can achieve sufficient strength when activated with appropriate alkali activators and subjected to adequate curing conditions [6]. However, they also reveal that volcanic ash-based geopolymers often lack sufficient durability against water exposure.

Lemougna et al. [7] immersed geopolymers produced with various volcanic ashes in water and observed strength losses of up to 89% in the saturated samples after 24 hours. Additionally, it was reported that

re-curing the water-soaked samples could significantly recover the lost strength. Some studies [8-10] have further shown that samples can crack and disintegrate within a few days of immersion in water.

To improve the strength and durability of volcanic ash-based geopolymers, certain reactive materials can be partially substituted for volcanic ash [11]. Moreover, studies suggest that pre-treatment methods such as mechanical activation, alkali fusion, and calcination can enhance the strength and durability of volcanic ash-based geopolymers [12]. Calcination involves heating the binder powders (e.g., volcanic ash) at temperatures between 600 °C and 1000 °C for several hours, resulting in the breakdown of crystalline phases and their transformation into amorphous or semi-amorphous structures [13, 14]. These amorphous materials exhibit higher reactivity, which is expected to improve the strength and durability of geopolymers produced with calcined volcanic ashes.

Research on the use of calcined volcanic ashes as powder binders in geopolymers is limited. Furthermore, while existing studies focus on the effects of calcination on the mechanical properties of geopolymers, their impact on water resistance remains unexplored. This study investigates the effects of calcination on the compressive strength and water resistance of volcanic ash-based geopolymer mortars. For this purpose, volcanic ashes calcined at different temperatures (600, 750, and 900 °C) and durations (1, 2, and 4 hours) were used to produce volcanic ash-based geopolymer mortars. The water resistance of the produced mortars was evaluated by measuring their compressive strength in dry and saturated surface-dry conditions.

MATERIALS AND METHODS

Materials

The volcanic ash used in this study was sourced from the Gölcük region of Isparta, Türkiye. This binder material had previously been used by Yeğin [15] in the production of geopolymer concrete. The particle size distribution, X-ray diffraction (XRD) pattern, and scanning electron microscopy (SEM) image of the volcanic ash used in the geopolymer mortar samples are presented in Figures 1, 2, and 3, respectively. Additionally, the chemical composition of the volcanic ash, determined using the X-ray fluorescence (XRF) method, is provided in Table 1.

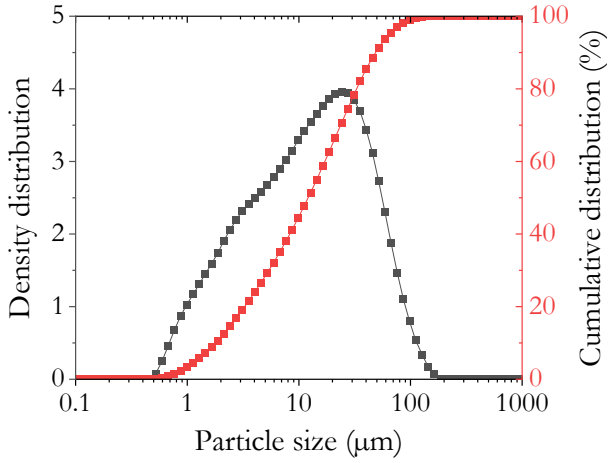

Figure 1. Particle size distribution of the volcanic ash.

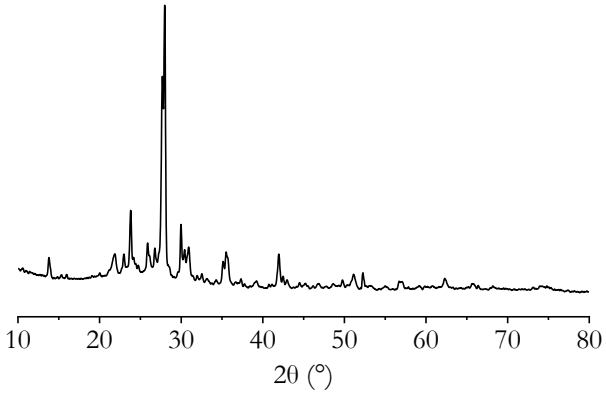

Figure 2. XRD pattern of the volcanic ash.

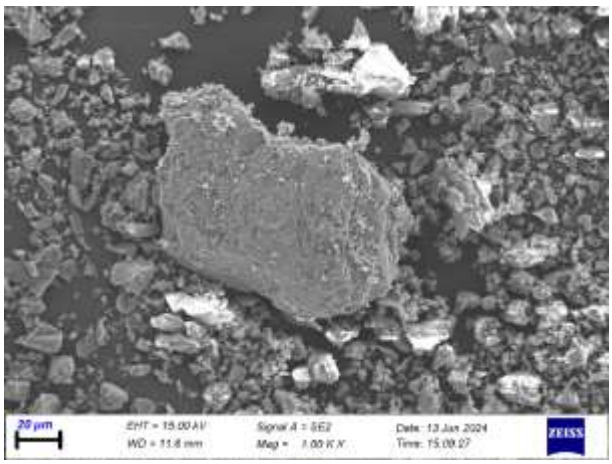

Figure 3. SEM micrograph of the volcanic ash.

Table 1. Chemical composition of the volcanic ash.

Oxides	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	Na_2O	K_2O	SO_3	LOI
Wt.(%)	4.1	2.1	16.5	3.8	59.0	4.8	5.3	-	2.6

LOI: Loss on ignition

The alkali activator used in the study was a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. The sodium silicate solution (SiO_2/Na_2O = 2.04 by weight, with 24.50% SiO_2 content by weight) was mixed with a 10 M sodium hydroxide solution (98% purity) in a weight ratio of 2.5.

CEN standard sand conforming to TS EN 196-1 [16] was used as the fine aggregate in the production of geopolymer mortars.

Deionized water was used to prepare the sodium hydroxide solution, while tap water from the municipal water supply was used to evaluate the water resistance of the geopolymer mortars.

Calcination

Volcanic ash was calcined at three different temperatures and three different durations. The calcination temperatures were 600 °C, 750 °C, and 900 °C, while the durations were 1, 2, and 4 hours. The temperature of the furnace used for calcination was increased at a rate of 10 °C/min until the target temperature was reached, and this temperature was maintained for the specified duration. After the calcination process, the furnace was turned off, and its door was left open for 30 minutes. The material was then removed from the furnace and left to cool under laboratory conditions. Once cooled to ambient

temperature, the calcined volcanic ash was packaged. In this manner, nine different calcined volcanic ashes were prepared.

Sample Preparation

The geopolymer mortar mixtures were prepared using a manual cement mixer conforming to TS EN 196-1 [16]. The dry materials, including the powder binder and sand, were mixed first, followed by the addition of the pre-prepared alkali activator solution. Mixing continued until a homogenous fresh geopolymer mortar was achieved. The fresh mortar was then poured into 40 mm × 40 mm × 40 mm plastic cube molds in two layers, with each layer compacted using a jolting table for 60 drops. After leveling the surfaces, the molds were sealed and cured at 75 °C for 48 hours and then at 90 °C for 24 hours. After curing, the samples were demolded and stored in open laboratory conditions until the testing day.

A total of 10 geopolymer mortar mixtures were prepared: one using raw volcanic ash and nine using the calcined volcanic ashes. Since the calcination process did not significantly alter the water demand of the volcanic ash, the same mix proportions were used for all mixtures, as presented in Table 2.

Table 2. Mix proportions (g).

Sodium hydroxide solution	Sodium silicate solution	Volcanic ash	Standard sand
111.9	279.6	675	1350

Experimental Methods

The 28-day compressive strengths of the geopolymer mortar samples were determined using a 20 kN capacity automatic cement compression machine, in accordance with TS EN 196-1 [16].

To evaluate water resistance, the samples were submerged in water on the 28th day and left for 72 hours. After this period, the samples were removed from the water, and surface water was wiped off. The compressive strength of the saturated surface-dry samples (wet strength) was then determined.

FINDINGS

It was observed that the volcanic ash turned brown after calcination. Furthermore, with increased calcination temperature and duration, the volcanic ash exhibited darker shades of brown. To maintain brevity, not all combinations of calcination temperature and duration are visually presented in this study; only one representative example is provided (Figure 4).

Figure 4. Visual representation of raw and calcined volcanic ash.

The 28-day compressive strength of the geopolymer mortar produced with raw volcanic ash was measured as 50.1 MPa. Figure 5 illustrates the 28-day compressive strengths of geopolymer mortars

prepared using volcanic ash calcined at different temperatures and durations. As shown in the figure, except for the geopolymer mortar produced with volcanic ash calcined at 900 °C for 1 hour, all other calcined ashes resulted in compressive strengths lower than the 50.1 MPa of the raw ash-based mortar. However, the compressive strength of the mortar with volcanic ash calcined at 900 °C for 1 hour reached 56.1 MPa. This indicates that the strength of geopolymers based on volcanic ash from the Gölcük region can be slightly improved with this specific calcination condition. Additionally, it was observed that the strength tends to increase with longer calcination durations at 750 °C. Therefore, investigating the effects of calcination on strength at temperatures between 750 °C and 900 °C could be valuable.

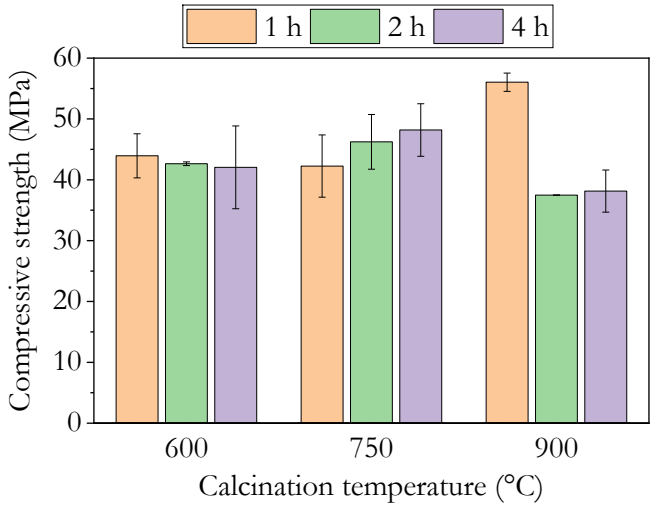

Figure 5. Compressive strengths of geopolymer mortars at different calcination conditions.

The compressive strength of the raw volcanic ash-based geopolymer mortar in saturated surface-dry condition was measured as 6.8 MPa. This indicates an 86.6% loss in strength compared to its dry state. On the other hand, Figure 6 presents the compressive strengths of geopolymer mortars with volcanic ash calcined under various conditions in saturated surface-dry condition, along with the corresponding strength losses. As observed, all geopolymer mortars with calcined ash experienced slightly higher strength losses than the raw volcanic ash-based geopolymer. However, in terms of residual compressive strength, the geopolymer mortar prepared with volcanic ash calcined at 900 °C for 1 hour showed a slightly higher residual strength of 7.0 MPa compared to the raw volcanic ash-based mortar.

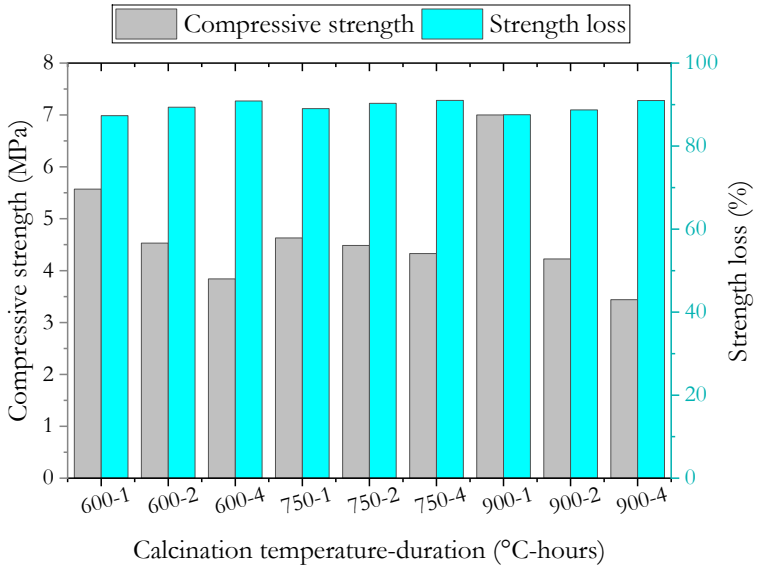

Figure 6. Compressive strengths and strength losses of geopolymer mortars in saturated surface-dry condition.

CONCLUSION

In this study, the compressive strengths of geopolymer mortars produced with volcanic ash calcined at different temperatures (600, 750, and 900 °C) and durations (1, 2, and 4 hours) were measured under both dry and wet (saturated surface-dry) conditions and compared to those of mortars with raw volcanic ash. The calcination process did not have a beneficial effect on the dry or wet compressive strengths of geopolymer mortars for the volcanic ash used in this study. However, the mortar prepared with volcanic ash calcined at 900 °C for 1 hour exhibited higher compressive strengths in both dry and wet conditions compared to those of the raw volcanic ash-based mortar. Future studies could explore the effects of calcination temperatures between 750 °C and 900 °C on the alkali activation of volcanic ashes.

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MİMARİ MEKANIN ÜRETİMİNDE ÇELİK VE CAMIN BİR ARADA KULLANIMININ ÖRNEKLER ÜZERİNDEN İNCELENMESİ

EXAMINATION OF THE COMBINED USE OF STEEL AND GLASS IN THE PRODUCTION OF ARCHITECTURAL SPACE THROUGH EXAMPLES

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ÖZET

Bu çalışma, çelik ve cam malzemelerinin mimarideki gelişimini ve bu malzemelerin birlikte kullanımının modern yapılar üzerindeki etkilerini incelemektedir. Endüstri Devrimi ile çelik ve camın mimarideki kullanımı hız kazanmış, bu malzemelerin estetik ve işlevsellik açısından sağladığı avantajlar, mimarinin yeni bir dil geliştirmesine olanak tanımıştır. Çelik, güçlü ve esnek yapısıyla büyük açıklıkların geçilmesini sağlar, cam ise doğal ışık geçirgenliği ve şeffaflık özellikleri ile mekanları daha ferah ve geniş hale getirir. Bu iki malzeme, özellikle modern yüksek yapıların temel yapı taşları haline gelmiştir.

Çelik ve camın entegrasyonu, çağdaş mimarinin simgelerinden olan yapıları, hem yapısal hem de estetik açıdan güçlendirmiştir. **Crystal Palace** (1851), çelik ve camın ilk büyük entegrasyon örneklerinden biri olarak mimarlıkta bir devrim yaratmış ve modern yapılar için bir temel oluşturmuştur. Günümüzde ise, enerji verimliliği sağlayan cam sistemleri ve çevre dostu çelik üretim teknikleri, bu malzemelerin sürdürülebilirlik açısından önemli bir rol oynamasına katkıda bulunmaktadır. Ayrıca, çelik ve camın mimarideki rolü, sadece fiziksel yapılarla sınırlı kalmayıp, gelecekteki şehir projelerinde sürdürülebilir, enerji üretme kapasitesine sahip ve çevre dostu çözümler sunmayı vaat etmektedir.

Bu bağlamda, çalışma, çelik ve camın mimarideki tarihsel gelişiminden başlayarak, bu malzemelerin gelecekteki potansiyellerini ve olası kullanım alanlarını araştırmaktadır. Gelecekte, çelik ve camın entegrasyonu ile tasarlanan yapılar, daha verimli ve çevre dostu çözümler sunarak, şehirleşme ve sürdürülebilirlik bağlamında önemli bir rol oynamayı sürdürecektir. Bu malzemelerin kullanımı, özellikle gezegen dışı yaşam alanları ve tamamen otonom şehirlerin inşasında temel bir yapı taşı olabilir.

Anahtar Kelimeler: Mimari Mekan, Çelik Malzeme, Cam Malzeme, Çelik ve Cam Mimarlığı

ABSTRACT

This study examines the development of steel and glass materials in architecture and the impact of their combined use on modern structures. With the Industrial Revolution, the use of steel and glass in architecture gained momentum, offering advantages in both aesthetics and functionality, enabling the development of a new architectural language. Steel, with its strong and flexible structure, allows for large spans, while glass enhances spatial openness and light transmission. These materials have become the foundation of modern high-rise buildings.

The integration of steel and glass has strengthened iconic structures, both structurally and aesthetically. The **Crystal Palace** (1851), as one of the first major integrations of steel and glass, revolutionized architecture and laid the foundation for modern buildings. Today, energy-efficient glass systems and eco-friendly steel production methods play a crucial role in sustainability. Furthermore, the role of steel and glass in architecture extends beyond physical structures and promises sustainable, energy-producing, and environmentally friendly solutions in future urban projects.

This study explores the historical development of steel and glass in architecture, analyzing their potential future uses and contributions. The integration of these materials in future buildings will continue to

provide more efficient and sustainable solutions, playing a significant role in urbanization and sustainability. The use of these materials may become a key factor in the construction of extraterrestrial habitats and fully autonomous cities.

Key words: Architectural Space, Steel Material, Glass Material, Steel and Glass Architecture.

GİRİŞ

Mimari mekanın üretiminde yeni işlevsel, teknolojik ve estetik eğilimler, geniş açıklıklı bina ihtiyacı, çok katlı yüksek bina yapma isteği karşısında taş, tuğla ve ahşap gibi geleneksel yapı malzemelerinin kullanımı sınırlı düzeyde kalmıştır. Demir ve betonun yapıda kullanılmaya başlamasıyla ilerleyen mimari mekan anlayışı, Endüstri devrimi sonrası değişen üretim biçimleri ve gelişen teknoloji ile birlikte yapılarda çelik ve camın da kullanımının üst düzeye çıkmasıyla devam etmiştir. Özellikle çelik ve cam en çok gelişim ve değişim gösteren yapı malzemesi olmuştur.

Yapılarda çelik malzeme sayesinde büyük açıklıklar geçilmiş ve asansörün kullanımının yaygınlaşmaya başlaması ile birlikte yapılan çok katlı yapılar, çelik malzeme sayesinde betonarmeye göre daha küçük kesitli taşıyıcılar elde edilmiştir. Hafif bir malzeme olan çelik yapılardaki temel maliyetini düşürmüş, ayrıca yapılardaki kullanım esnekliği mimari mekanların daha özgür ve özgün olmasına olanak sağlamıştır.

Aynı zamanda gelişen teknolojiye uyum sağlayan cam, özellikle cam fırın teknolojisindeki gelişmeler ile birlikte yapılabilen seri üretimler sayesinde, yüksek kalitede, büyük ebatlarda ve ekonomik bir yapı malzemesi olarak yapılarda kullanılabilirliğini arttırmıştır. Bu gelişim özellikle çelik taşıyıcı sistemin sağladığı geniş açıklıkların cam malzeme ile kapatılmasında etkin rol oynamıştır.

Çelik ve camın bir arada kullanımı, mimarlıkta sadece teknik bir yenilik olarak kalmamış, aynı zamanda bir tasarım dili haline gelmiştir. Crystal Palace (1851) ve Eiffel Kulesi (1889) gibi yapılar, bu malzemelerin mimarlıkta kullanımına öncülük etmiş, sonraki dönemlerde modern mimarlığın temelini oluşturmuştur. 20. yüzyılda, Ludwig Mies van der Rohe gibi modernist mimarlar, çelik ve camın sadeliğini estetik bir prensip olarak benimsemiş ve bu malzemeleri minimalizmle birleştirerek ikonik yapılar tasarlamıştır.

Günümüzde çelik ve cam, mimaride yalnızca estetik ve işlevsellik açısından değil, aynı zamanda sürdürülebilirlik hedefleri doğrultusunda da önemli bir rol oynamaktadır. Enerji verimliliğini artıran cam paneller ve çevre dostu çelik üretim teknikleri, bu malzemeleri çağdaş mimarlığın vazgeçilmez unsurları haline getirmiştir. Çelik ve cam, modern mimaride mekanların sınırlarını kaldırarak kullanıcıyla çevre arasında bir bütünlük sağlar. Şeffaflık ve dayanıklılık özellikleriyle bu iki malzeme, yalnızca yapının fiziksel bir unsuru değil, aynı zamanda mimaride bir ifade aracı olarak kullanılır.

Gelişen çelik ve cam malzeme teknolojileri ve binalarda bütüncül performans için mimariyi etkileyen yapısal tasarım bileşenlerinin mimari tasarım ile entegre olmasını sağlayan bilgi teknolojileri sayesinde özellikle son yıllarda mimari mekanın üretiminde nitelikli ve özgün yorumlarla "Çelik ve Cam Mimarisi" kavramı ortaya çıkmıştır. Bu mimari anlayış, beklentileri karşılayacak düzeyde farklı mimari mekan tasarımı ve üretimine olanak sağlamıştır. Çelik malzemenin binalarda sağladığı strüktürel avantaj ile cam malzemenin özellikle cephede oluşturduğu mimari estetik anlayış ile hem estetik hem de sağlam binalar elde edilmiştir. Çelik ve cam mimarisinde, strüktür elemanı olarak çelik malzeme kullanılarak doğadan ayrılan ve yükselen bina, cephede cam kullanımı ile birlikte şeffaflaşarak tekrar doğayla bütünleşmektedir.

Bu çalışmada, çelik ve camın tarihsel süreçteki gelişimi ve mimarlık pratiğine etkileri ele alınmıştır. Ayrıca, bu malzemelerin entegre kullanımıyla tasarlanan ikonik yapılardan örnekler verilerek, çelik ve cam mimarisinin estetik, işlevsellik ve sürdürülebilirlik bağlamındaki katkıları değerlendirilmiştir. Bunun yanı sıra, gelecekte çelik ve cam malzemelerinin mimarlık pratiğinde üstleneceği roller ve bu malzemelerle inşa edilecek yapıların potansiyel gelişimleri üzerine hipotezler sunulmuştur. Çalışma, bu bağlamda, modern mimarlığın sadece bugünkü değil, aynı zamanda gelecekteki yönelimlerine ışık tutmayı amaçlamaktadır.

ARAŞTIRMA VE BULGULAR

Mimari Mekan

Mekan, insanın doğal çevreden ayrılarak belirli bir işlev için şekillendirdiği özel bir alan olarak mimarlığın temel unsurudur. Mimari mekan, duvarlar, tavanlar, sütunlar ve benzeri fiziksel bileşenlerle tanımlanırken, estetik ve işlevselliği bir araya getirerek özgün yapılar oluşturur. Bu bileşenler, mekanın fiziksel sınırlarını belirlemekle kalmaz, aynı zamanda kullanıcı deneyimini ve mekanı algılama biçimini de şekillendirir. Renk, doku, ışık ve havalandırma gibi unsurlar, mekanın atmosferini ve kullanım özelliklerini derinleştirirken, şeffaf malzemelerle doğayla bütünleşme sağlanabilir. Mekan üretimi, bu fiziksel ve deneyimsel unsurların bir bütün olarak ele alınmasıyla gerçekleşir ve her bir eleman mekanın estetiğine ve işlevine katkıda bulunur.

Tarih boyunca mimari mekan anlayışı, toplumların inançları, kültürel dinamikleri ve teknolojik yenilikler doğrultusunda şekillenmiştir. Antik dönemlerden itibaren taş ve kerpiç gibi doğal malzemelerle yapılan anıtsal yapılar, mimarinin işlevsel olduğu kadar ideolojik bir araç haline gelmesini sağlamıştır. Mısır ve Yunan tapınakları gibi yapılar, dinsel inançları ve toplumsal kimlikleri yansıtırken, Roma döneminde teknik yeniliklerle konfor odaklı yapılar inşa edilmiştir. Rönesans ile birlikte insan merkezli mekan anlayışı gelişmiş, Endüstri Devrimi sonrası ise çelik, cam ve beton gibi malzemelerle yapılan dayanıklı ve işlevsel yapılar modern mimarinin temelini oluşturmuştur. Bu süreçte mimari, yalnızca bir barınma aracı olmaktan çıkarak estetik, teknik ve toplumsal bir ifade biçimine dönüşmüştür.

Mimari Mekanda Çelik Malzeme Kullanımı

Demir ve karbonun belirli oranlarda bir araya gelmesiyle oluşan bir alaşım olan çelik malzeme, tarih boyunca yapılarda kullanılmış olmasına rağmen, yapısal özelliklerinin tam anlamıyla keşfedilmesi ve modern anlamda kullanımının yaygınlaşması Endüstri Devrimi sonrasında gerçekleşmiştir. Öncesinde "Demir Yapı" olarak nitelendirilen yapılar özellikle 1930'lu yıllarda kaynak teknolojisinin gelişmesiyle birlikte oluşturulan çelik konstrüksiyon neticesinde "Çelik Yapı" şeklinde nitelendirilmeye başlanmıştır. Mimarlıkta dökme demirden çeliğe geçiş, yapı malzemeleri ve strüktür anlayışında devrim yaratarak mekan kavramını kökten değiştirmiştir. Geleneksel olarak sınırları belirli, kapalı mekanlar inşa etme yaklaşımı, yerini giderek daha açık, akışkan ve kesintisiz mekan deneyimlerine bırakmaktadır.

Gelişen teknoloji ile birlikte, dökme demirden çelik üretimine geçiş aşamasında her bir çelik üretim yöntemi, kendi döneminin ihtiyaçlarına yanıt vererek mimaride önemli dönüşümler sağlamıştır. Bessemer Yöntemi, seri ve ucuz çelik üretimi ile gökdelenlerin inşasını mümkün kılmıştır. Thomas Yöntemi, fosforlu demir cevherini işleyerek Avrupa'da sanayi yapılarında kullanılmıştır. Siemens-Martin Yöntemi, kaliteli çelikle geniş köprüler inşa edilmesine olanak tanımıştır. Linz-Donawitz Yöntemi, savaş sonrası hızlı çelik üretimiyle modern yapıları desteklemiştir. Heroult Yöntemi ise geri dönüştürülen çelikle sürdürülebilir yapılar için öncü olmuştur.

Şekil 1.1. Eiffel Kulesi (URL-1)

Endüstri Devrimi ile birlikte çeliğin yapı sektöründe kullanımı hızla artmıştır. İlk başta demir malzemesi ile başlayan süreç, Bessemer yöntemi gibi yeniliklerle düşük maliyetli çelik üretimini mümkün kılmıştır. Bu gelişme, köprüler, demiryolları ve gökdelenler gibi büyük ölçekli projelerde çeliğin yaygın kullanımını sağlamıştır. Çelik malzemesi, modern mimaride yüksek dayanıklılık, esneklik ve geniş açıklıklar sunarak mimarların daha cesur ve yaratıcı tasarımlar yapmasına olanak tanımıştır. Böylece, mimaride estetik ve fonksiyonel bir devrim gerçekleşmiştir.

Mimari Mekanda Cam Malzeme Kullanımı

Cam malzeme ise, temel olarak toprak kökenli bileşenlerden elde edilen, yüksek ısıda şekillendirilebilen, sert, kırılgan ve şeffaf bir malzemedir. Isıya karşı dayanıklı olan bu malzeme, formunu koruyarak farklı kalıplara dökülebilir ve istenilen şekli alabilir. Camın saydamlığı, onu ışığı geçiren, ancak aynı zamanda iç mekanları dış etkenlerden koruyan ideal bir yapı elemanı yapar. Mimaride hem estetik hem de işlevsel çözümler sunan cam, farklı projelerde yenilikçi tasarımlara olanak tanır.

5000 yıllık geçmişiyle en eski yapı malzemelerinden olan cam malzemenin üretiminde önemli bir dönüm noktası, üfleme tekniğinde kullanılan piponun keşfidir. M.Ö. 200'lerde Suriye'de cam pencereler üretilmeye başlanmış, ardından Roma İmparatorluğu aracılığıyla Avrupa'ya yayılmıştır. Romalılar M.S. 1. yüzyılda döküm yöntemiyle düz cam üretmiş ve camı villalarda kullanmışlardır. Sanayi Devrimi ile cam üretim teknolojileri hız kazanmış, 1687'de "Plate Glass" yöntemi ile büyük cam levhalar üretilmeye başlanmıştır. Bu teknik, modern mimaride cam kullanımını yaygınlaştırmıştır.

Bessemer'in cam üretimiyle ilgili katkıları, özellikle cam presleme yönteminin geliştirilmesi, çelik üretimindeki buluşlarından esinlenmiştir. 1856'da çelik üretiminde devrim yaratan Bessemer süreci ile elde ettiği başarı, cam üretiminde de verimlilik artışını sağlayan tekniklerin temellerini atmıştır. Bu gelişme, cam endüstrisinin modernleşmesine büyük katkı sağlamış ve üretim süreçlerinin hızlanmasında önemli bir rol oynamıştır. Bu bağlamda, Bessemer'in cam endüstrisine yaptığı katkılar, aslında çelik üretimindeki yeniliklerin başka sektörlere nasıl etki edebileceğinin güzel bir örneğidir.

1952 yılında Alistair Pilkington'un camı sıvı kalay üzerinde yüzdürmeye başlaması ile seri cam üretimine geçilmiştir. 19. Yy'da cam üretimi Siemens kardeşlerin rejeneratör fırını, cam havuzu ve Beriwez'in cam soğutma fırını, cam üretiminde devrim niteliğindeki yenilikler sunarak sanayileşmenin önemli bir parçası olmuştur. Bu teknolojiler, cam üretimini hızlandırmış ve maliyetleri düşürmüştür. Böylece, cam daha geniş kitlelere ulaşabilir hale gelmiş, kalitesi artmış ve estetik ile fonksiyonel kullanım alanları genişlemiştir. Özellikle inşaat ve mimaride büyük cam cepheler, vitrinler, pencereler

ile mobilya sektöründe yaygın olarak kullanılmasına olanak sağlamıştır. Cam teknolojisindeki bu evrim, hem estetik hem de işlevsellik açısından mimari projelerde yeni ufuklar açacaktır.

Camın mimarideki rolü, estetik ve fonksiyonellik açısından oldukça önemli bir yere sahiptir. Cam, yüksek ışık geçirgenliği ile doğal ışığı iç mekanlara yönlendirirken, dış dünya ile olan etkileşimi güçlendirir. Şeffaf yapısı sayesinde, yapılar çevreleriyle bütünleşerek iç mekan algısını zenginleştirir. Farklı renk ve dokulardaki cam tasarımları, mimarların estetik algısını genişletmekte ve yapının kimliğini belirginleştirmektedir. Ayrıca, günümüzde geliştirilen yüzey kaplamalı, temperli, tapakalı ve enerji verimli cam türleri, iç mekan konforunu artırarak enerji performansını iyileştirmektedir. Bu özellikleriyle cam, modern mimarinin vazgeçilmez bir parçası haline gelmiştir.

Barselona'nın ikonik yapılarından biri olan ve 2005 yılında tamamlanan Torre Agbar (Şekil 1.2.), mimari yüzey kaplama camlarının başarılı bir örneğini temsil eder. Jean Nouvel tarafından doğal ışık, sürdürülebilirlik ilkesi kapsamında tasarlanan bu yapı, hem görsel estetik hem de fonksiyonellik açısından dikkat çekmektedir. İç mekana doğal ışığın girmesini sağlayan pencereler, havalandırma işlevinin yanı sıra enerji depolama işlevini de yürütmektedir. Bunun yanı sıra, iç mekanın en etkili şekilde aydınlatılması için fotoelektrik cam paneller tercih edilmiştir. Bu fotoelektrik paneller, gece saatlerinde iç mekan aydınlatmasıyla birlikte renkli bir ışık yansıması oluşturarak binaya dinamik bir görsellik kazandırır; bu etki, binanın LED aydınlatma sistemi ile entegre bir şekilde çalışarak dış cephede göz alıcı bir ışık oyunu yaratır.

a)  b) 

Şekil 1.2. a) Torre Agbar (URL-2) **b)** Torre Agbar Cephe Detayı (URL-2)

21. yüzyıl yapılarında cam kaplama teknolojileri, enerji verimliliği ve iklim kontrolüne yönelik önemli roller üstlenmektedir. Gelişen teknolojiler, binaların dış cephe tasarımlarını değiştirerek daha etkili enerji yönetimi ve doğal ışık kullanımı olanakları sunmaktadır. Bu doğrultuda cam kaplamalarda öncelikli hedefler; ısı kayıplarını azaltmak, güneş ışığını en verimli şekilde yönlendirmek, güneş ısısını kontrol altında tutmak ve doğal ışığı maksimum düzeyde kullanmaktır. Isı kaybının önlenmesi ve doğal ışık elde etme sorunları büyük ölçüde çözülmüşken, ışığın yönlendirilmesi ve güneş ısısı kontrolü alanlarında hâlâ geliştirme çalışmaları devam etmektedir. Bu gelişmeler, gelecekte cam kaplama teknolojilerinin binaların sürdürülebilirlik ve işlevsellik standartlarını daha da yükseltmesine olanak sağlayacaktır.

Cam kaplamalarının gelecekteki işlevleri, enerji verimliliği sağlamanın ötesine geçerek, enerji üretimi açısından da önem kazanacaktır. Şu anda dış cephe elemanı olarak, dış ortamın değişken koşulları ile iç ortamın sabit ihtiyaçları arasında enerji akışını düzenleyici bir rol üstlenen cam kaplamalar, teknolojik gelişmelerle birlikte ısı, ışık ve elektrik enerjisi üretebilen birer enerji kaynağı haline dönüşecektir. Bu dönüşüm, cam kaplamalarının sürdürülebilir mimarideki rolünü daha da güçlendirecektir.Cam teknolojilerindeki ilerlemeler, bina cephelerini yalnızca bir enerji kontrol aracı olmaktan çıkarıp, aynı

zamanda enerji üretebilen ve güneş ışığını yönlendirebilen dinamik sistemlere dönüştürmüştür. Çevre dostu yaklaşımlar ve yeni mimari eğilimler, gelecekte cam kaplama sistemlerinde yenilikçi fırsatlar yaratacaktır. Dinamik cepheler, doğal ışık ve havalandırmayı bütüncül bir tasarım anlayışıyla ele alarak, iç mekanları doğal ışıkla aydınlatmayı hedeflemektedir. Bu sistemler, enerji maliyetlerini düşürmenin yanı sıra bina değerini artırarak kullanıcıya yüksek konfor sunacak şekilde tasarlanacaktır.

Mimari Mekanda Çelik ve Cam Malzemenin Bir Arada Kullanımı

Çelik ve cam, modern mimarinin yapı taşları arasında önemli bir yer edinmiştir. Her iki malzemenin de birbirini tamamlayan özellikleri, çağdaş mimarlıkta estetik ve işlevselliği bir araya getiren yapılar oluşturulmasına olanak tanımıştır.

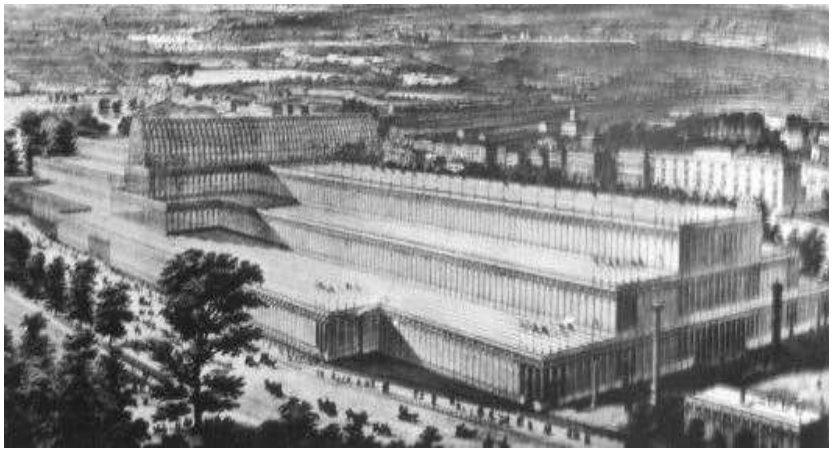
Çelik, 19. yüzyılda sanayi devrimiyle birlikte mimaride kullanılmaya başlanmıştır. Güçlü, dayanıklı ve esnek yapısı sayesinde büyük açıklıkların geçilmesine ve yüksek binaların inşa edilmesine imkan tanır. Özellikle gökdelenlerin ve geniş açıklıklı köprülerin yapımında çeliğin kullanımı, mimarların yeni formlar yaratmasına olanak sağlamıştır. Cam malzeme ise tarih boyunca dekoratif amaçlarla kullanılmış olsa da, 20. yüzyılın başlarında geniş yüzeyler halinde kullanılabilir hale gelmesiyle mimaride devrim yaratmıştır. Camın şeffaf yapısı, mekanların doğal ışıkla aydınlatılmasını sağlar, bu da iç mekanları daha geniş ve ferah gösterir.

Çelik ve camın birlikte kullanımının yarattığı **Yapısal Yenilikler**, mimariye sadece görsel zenginlik kazandırmakla kalmaz, aynı zamanda **Sürdürülebilirlik** açısından da önemli katkılar sağlar. Çelik ve cam, **Yapısal Dayanıklılık** ile **Şeffaflık** arasında denge kurarak mekan tasarımında büyük **Esneklik** ve **Estetik Çeşitlilik** sağlar. Özellikle geniş açıklıklar, doğal ışık kullanımı ve enerji verimliliği gibi avantajlarla, modern yapıların **Mekansal Etkileşim** sağlamasında öncü unsurları haline gelmiştir.

Çelik ve camın bir arada kullanımı, modern mimaride estetik ve fonksiyonellik sunarken, bazı dezavantajlar da doğurur. Camın ısı yalıtımı zayıf olduğu için enerji verimliliğini olumsuz etkiler ve ek ısıtma veya soğutma gereksinimleri doğurur. Ayrıca, camın kırılma riski ve dış etkenlere karşı hassasiyeti güvenlik ve bakım açısından zorluklar yaratabilir. Yüksek maliyetler ve ses yalıtımı eksiklikleri de önemli dezavantajlar arasında yer alır. Bu zorluklar, tasarım aşamasında dikkate alınıp, uygun çözümlerle minimize edilmelidir.

Çelik ve Cam Malzemenin Bir Arada Kullanım Örnekleri

Çelik ve camın bir arada kullanımı, ilk olarak dünya çapındaki Expo (Dünya Fuarı) organizasyonları aracılığıyla sergilenmiştir. Özellikle Joseph Paxton'ın tasarladığı Crystal Palace bu kombinasyonun öncülerindendir. Crystal Palace, Londra'daki ilk Dünya Fuarı için tamamen çelik ve cam kullanılarak, yarattığı büyük açıklıklar ve şeffaf mekanlarla modern mimariye öncülük etmiştir. Bu yapı, mimari tasarımda çelik iskelet sistemlerinin ve geniş cam yüzeylerin nasıl yenilikçi çözümler sunduğunu göstermiştir. Galerie des Machines, Paris'teki sergiye ait büyük çelik kemerler ve cam yüzeylerle geniş açıklıklar sunan bir yapıdır. Bu yapı geniş mekanlar yaratmada çeliğin dayanıklılığı ve camın şeffaflığını birleştirerek mimarlık alanında yeni bir estetik anlayışın oluşmasına olanak tanımıştır.



Şekil 1.3. Kristal Saray (Kohlmaier ve Sartory, 1986)

EXPO 1929 Barselona Pavyonu, çelik ve camın minimal tasarımla birleştiği estetik bir örnek olarak öne çıkar. EXPO 2000 Hollanda Pavyonu doğa dostu tasarımıyla çelik konstrüksiyon ve cam cephelerin çevreye duyarlı bir şekilde birleştirirken, EXPO 2010 Çin Pavyonu geleneksel ve modern unsurları harmanlar. Expo 2020 Dubai'deki Alif Mobility Pavyonu ise, çelik ve camın modern mimaride sürdürülebilirlik, işlevsellik ve estetikle nasıl birleştiğini gösteren ikonik yapılardır.

Şekil 1.4. Alif - The Mobility Pavilion (URL-3)

20. yüzyıldan itibaren çelik ve cam, cesurca kullanılan malzemeler haline gelmiş ve mimaride yeni bir ifade biçimi oluşturmuştur. Yüksek yapılar, bu iki malzemenin uyumlu birleşimiyle tasarlanmış ve dönemin simgesi olmuştur. Peter Behrens'in tasarladığı **AEG Türbin Fabrikası,** çelik ve camın birleşimiyle modern endüstriyel mimarinin simgesi haline gelmiştir. Beton cephesi, yapının görsel etkisini artırırken, çelik ve cam strüktürle birlikte işlevsellik sunar. Behrens, estetik ve işlevselliği birleştirerek, modern endüstriyel mimarinin temelini atmıştır. Mies van der Rohe'nin tasarladığı **Seagram Binası**, minimalist ve şık bir modern mimari örneğidir. Çelik ve camdan yapılan dış cephesiyle dikkat çekerken, bronz malzemelerle zenginleştirilmiştir. Bina, "az çoktur" felsefesinin izlerini taşır ve döşemeden tavana kadar uzanan cam pencerelerle çağdaş mimarinin sade estetiğini vurgular.

Şekil 1.5. Seagram Building (URL-4)

Renzo Piano ve Richard Rogers tarafından tasarlanan **Pompidou Sanat Merkezi**, dışa dönük çelik ve cam malzemeleriyle dikkat çeker. Modern High Tech mimarlığının öncüsü olan bu yapı, işlevsel geniş iç mekanları ve renkli borularla dikkat çeker. Yapı, geleneksel Paris mimarisinden farklı olarak cesur bir estetikle, teknolojiyi ve yapısal sistemleri açıkça sergileyerek mimarlık dünyasında önemli bir dönüm noktası oluşturmuştur. Norman Foster tarafından tasarlanan **Reichstag Kubbesi**, cam ve çeliğin

şeffaflık ve açıklık simgesi olarak birleşimini sunar. Döner rampa sayesinde ziyaretçiler parlamento salonunu gözlemleyebilir, bu tasarımın demokrasiye olan vurgusunu pekiştirir. Çelik yapısının sağlamlığı ve camın doğal ışığı içeri alması, yapının görsel ve yapısal dengeyi kurmasına olanak tanır.

Şekil 1.6. Resichtag Kubbesi (URL-5)

Norman Foster'ın tasarımıyla yükselen **Hearst Kulesi**, çelik diagrid yapısı ve düşük enerji tüketimli camlarıyla dikkat çeker. Dış cephesi, binaya estetik bir zarafet katarken, aynı zamanda iç mekanda doğal ışık kullanımı sağlar. Çelik malzeme kullanımı, binanın hem ekonomik hem de estetik yönden verimli olmasını sağlar. Dubai'deki **Burç Halife**, çelik ve betonarmeden oluşan bir yapı ile 828 metreye kadar yükselir. Çelik yapı, binanın stabilitesini sağlar, cam ise yapıyı görsel olarak hafif gösterir. Camın kullanımı, yapının modern tasarımını ve çevresine entegre olmasını güçlendirir. **Aldar HQ**, Abu Dabi'deki dünyadaki ilk dairesel gökdelen olup, cam ve çelik diagrid kullanımıyla dikkat çeker. Cam cepheler, iç mekanlara maksimum doğal ışık sağlarken güneş ışığını azaltarak enerji verimliliği sunar. Çelik iskelet, binanın karmaşık geometrisine olanak tanır. Renzo Piano'nun tasarladığı **The Shard**, cam cephelerle Londra'nın siluetine şeffaflık kazandırırken, çelik yapılar ise binanın sağlamlığını artırır. Geometrik form ve cam kullanımı sayesinde zarif bir yapı ortaya çıkmıştır. Bu tasarım, şehre yeni bir görsel kimlik kazandıran önemli bir mimari eser olarak öne çıkar.

Şekil 1.7. The Shard (URL-6)

Teknosfer Binası, mimar James Law tarafından tasarlanmış ve sürdürülebilir mimariyi teknolojiyle birleştirmeyi amaçlayan bir konsept projedir. Henüz inşa edilmemiş olan bu tasarım, küre biçimli formuyla, Dünya'nın doğal geometrisinden ilham alarak çevre dostu bir yaşam alanı yaratmayı hedefler. Dubai'deki Jebel Ali Serbest Bölgesi için önerilen proje, enerji üretimi, su geri dönüşümü ve doğal ışık kullanımı gibi çevresel sürdürülebilirlik uygulamalarıyla dikkat çeker. Teknosfer, yalnızca bir bina değil, aynı zamanda kendi kendine yetebilen bir yaşam alanı vizyonunu temsil eder.

Şekil 1.8. Teknosfer Binası Projesi (URL-7)

Çelik ve camın mimarlıkta birlikte kullanımı, estetik ve işlevsellik arasındaki dengeyi yeniden tanımlamış, modern ve yenilikçi yapıların tasarımında dönüştürücü bir rol üstlenmiştir. Crystal Palace gibi öncü yapılardan Teknosfer gibi vizyoner projelere kadar uzanan bu süreç, mimarlık tarihinde bir dönüm noktası yaratmıştır. Çelik, dayanıklılığı ve strüktürel gücüyle geniş açıklıklar ve cesur formlar

yaratırken, camın şeffaflığı ve ışık geçirgenliği, mekanları çevreyle bütünleştirerek estetik bir hafiflik kazandırmıştır. Bu birliktelik, çağdaş mimarinin sınırlarını genişleten bir tasarım anlayışı sunmaktadır.

TARTIŞMA VE SONUÇ

Gelişen çelik ve cam malzeme teknolojileri, son yıllarda mimari mekanların üretiminde nitelikli ve özgün yaklaşımların ortaya çıkmasına olanak tanımıştır. Bu süreçte, binaların bütüncül performansını artıran yapısal tasarım bileşenlerinin mimari tasarım ile entegre olmasını sağlayan bilgi teknolojilerinin etkisi büyüktür. **"Çelik ve Cam Mimarisi"** kavramı, bu entegrasyonun bir sonucu olarak karşımıza çıkmakta ve mimarların çeşitli beklentileri karşılayacak düzeyde farklı tasarım ve üretim olanakları sunmaktadır.

Bu mimari anlayışta, çelik strüktürel elemanlar kullanılarak inşa edilen binalar, doğadan ayrılan ve yükseklik kazanan formlar sunarken, cephede kullanılan cam ile şeffaflaşarak çevre ile yeniden bütünleşmektedir. Böylece, doğal ışık iç mekanlara yönlendirilirken, dış mekanla olan ilişki de güçlendirilir. Sonuç olarak, çelik ve cam mimarisi, çağdaş mimarlığın estetik ve işlevsellik arayışına yenilikçi çözümler sunmakta ve mimari tasarımda yeni ufuklar açmaktadır.Çelik ve camın bir arada kullanımı, mimarlıkta sadece görsel çekiciliği artırmakla kalmaz, aynı zamanda sürdürülebilirlik hedeflerine de katkı sağlamaktadır. Camın doğal ışık geçirgenliği, enerji tüketimini azaltarak yapının enerji verimliliğini artırır. Çelik yapısal elemanlar, daha az malzeme kullanarak güçlü ve dayanıklı yapılar oluşturulmasına olanak tanır; bu da çevre dostu bir yaklaşımın benimsenmesine katkıda bulunur. Dolayısıyla, çelik ve camın birlikte kullanımı, modern mimaride estetik, işlevsellik ve sürdürülebilirlik arasında bir denge kurar.

Çelik ve camın bir arada kullanımı, akıllı bina tasarımlarında estetik ve fonksiyonelliği birleştirirken enerji verimliliğini artırmada da önemli bir rol oynar. Çelik, dayanıklılığı ve taşıyıcı gücüyle geniş açıklıklara ve yenilikçi formlara olanak tanırken, cam, doğal ışık geçirgenliği ve şeffaflık özellikleriyle modern mimaride vazgeçilmez bir malzeme olarak öne çıkar. Bu iki malzemenin uyumlu entegrasyonu, akıllı binaların enerji tüketimini azaltma, sürdürülebilirliği destekleme ve kullanıcı konforunu artırma hedeflerini başarılı bir şekilde gerçekleştirmesine katkı sağlar.

Akıllı binalarda çelik strüktürler, yüksek yapısal dayanım sağlayarak geniş alanların oluşturulmasına ve binanın tasarım esnekliğinin artırılmasına imkan tanır. Bunun yanında cam yüzeyler, güneş ışığını iç mekanlara yönlendirerek doğal aydınlatmayı artırır ve enerji tasarrufuna katkı sağlar. Özellikle çift cam, fotokromik veya elektrokromik cam gibi teknolojiler kullanıldığında, güneşin ısı ve ışık etkisi kontrol edilerek ısıtma ve soğutma yükleri azaltılabilir.

Bu tür yapılarda çelik ve cam, yenilenebilir enerji kaynaklarıyla entegre edilebilen mimari çözümler sunar. Örneğin, cam cephe sistemlerinde yer alan fotovoltaik paneller, güneş enerjisini elektrik enerjisine dönüştürerek binanın enerji ihtiyacını karşılamaya katkıda bulunur. Çelik ise, bu tür enerji sistemlerinin montajı ve dayanımı için ideal bir altyapı sağlar. Böylece çelik ve camın birlikte kullanımı, hem estetik hem de sürdürülebilirlik açısından akıllı bina konseptinin temel unsurlarından biri haline gelir. Bu kombinasyon, aynı zamanda uzun vadede bina maliyetlerini düşürerek enerji etkin bir yapı modeli sunar. Modern mühendislik ve mimari tekniklerin sunduğu bu olanaklar, çelik ve camı, akıllı bina tasarımlarında vazgeçilmez bir ikili yapmaktadır.

Cam ve çelik, mimaride uzun zamandır kullanılan dayanıklı ve estetik malzemelerdir. Ancak gelecekte, bu malzemelerin teknolojik gelişmelerle birlikte dönüşerek sadece yapıların değil, tüm şehirlerin inşasında önemli bir rol oynaması beklenmektedir. Özellikle çevresel sürdürülebilirlik, enerji verimliliği ve dayanıklılık konularında çığır açan yenilikler, cam ve çeliğin bu potansiyelini artırmaktadır.

Geleceğin Perspektifi

Cam, saydamlık ve estetik özelliklerinin ötesinde, gelecekte aktif bir bileşen haline gelebilir. Örneğin, **akıllı cam teknolojisi**, ışık geçirgenliğini kontrol edebilme, iç mekan sıcaklığını düzenleme ve güneş ışığını elektriğe çevirme gibi özelliklerle enerji verimliliğini artıracaktır. Bu tür camlar, yalnızca enerji tasarrufu sağlamakla kalmayacak, aynı zamanda kendi enerjisini üreten şehirlerin temel taşlarından biri olacaktır. Ayrıca **şeffaf güneş panelleri**, tüm bina cephelerini birer enerji üretim ünitesine dönüştürme potansiyeline sahiptir. Bu gelişmeler, modern şehirlerin enerji ihtiyaçlarını azaltırken çevre dostu çözümler sunar.

Çelik ise gelecekte daha hafif, daha dayanıklı ve çevresel açıdan sürdürülebilir bir malzeme olarak öne çıkacaktır. **Kendi kendini onaran çelik**, yapılardaki hasarların minimize edilmesine yardımcı olarak bakım maliyetlerini düşürecek ve özellikle zorlu ortam koşullarında uzun ömürlü yapılar oluşturacaktır. Ayrıca, çelik üretiminde karbon salımını azaltmayı hedefleyen **karbon nötr üretim yöntemleri**, sürdürülebilirlik hedeflerine ulaşmada kritik rol oynayacaktır. Bu yenilikler, büyük ölçekli projelerde çeliğin çevresel etkisini azaltırken daha ekonomik çözümler sunar.

Teknosfer gibi projeler, bu dönüşen malzemelerin kullanımıyla sadece bireysel yapılar değil, kendi kendine yetebilen koloni şehirlerin prototipleri olarak görülebilir. Bu yapılar, enerji üreten cam ve sürdürülebilir çelik kombinasyonlarıyla, su geri dönüşümünden atık yönetimine kadar otonom sistemler barındırabilir. Özellikle **dikey şehirler**, yoğun nüfuslu bölgelerde yerden tasarruf sağlayarak geniş toplulukları barındırabilir ve kaynakların daha etkin kullanımını mümkün kılar. Bu tür yapılar ayrıca, **gezegen dışı koloniler** için ideal bir başlangıç noktasıdır. Cam ve çeliğin hafif, dayanıklı ve sürdürülebilir özellikleri, Ay ya da Mars gibi gezegenlerde yaşam alanlarının oluşturulmasına katkı sağlayabilir.

Bu malzemelerin teknolojik gelişmelerle evrimi, Teknosfer gibi projelerden başlayarak tamamen otonom şehirlerin inşasına yol açabilir. Enerji üreten ve çevreye duyarlı yapılar, küresel ölçekte **kaynak krizlerine çözüm** sunabilir, **iklim değişikliğiyle mücadelede** önemli bir rol oynayabilir ve **dünya dışı yaşam alanlarının** temelini oluşturabilir. Cam ve çelik, yalnızca bir bina malzemesi olmanın ötesine geçerek, geleceğin şehirlerini ve yaşam alanlarını şekillendirecek birer araç haline gelecektir.

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USING RECYCLED PLASTIC PELLETS AS FINE AGGREGATE IN CEMENT MORTARS FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT

Plastic, one of the most impactful innovations of the 20th century, has become a significant environmental challenge due to its extensive use and prolonged degradation periods. Globally, approximately 6.5 billion tons of plastic waste are generated annually, underscoring the urgent need for sustainable waste management practices. In the construction industry, the integration of recycled materials into concrete presents a viable strategy for addressing this issue. Recycled plastic pellets may have potential as a substitute for fine aggregates, enabling the development of lightweight and environmentally friendly concrete solutions. This study investigates the use of recycled plastic pellets sourced from Turkish recycling facilities as a substitute for fine aggregates in cement mortar, with replacement levels of 5%, 10%, 25%, 35%, and 50%. Additionally, the effects of using fly ash and ground granulated blast furnace slag (GGBFS) as supplementary cementitious materials (SCMs) in varying proportions were examined. The modified mortar's fresh and hardened properties, including workability and mechanical performance, were evaluated. The results demonstrate that processability improves with increasing levels of recycled plastic up to 50%; however, beyond this threshold, the specimens exhibit inadequate load-bearing capacity. Notably, mixtures with up to 35% recycled plastic achieved compressive strengths exceeding 10 MPa after seven days. Moreover, the use of fly ash and GGBFS as cement replacements, up to a combined total of 50%, enhanced long-term strength due to their pozzolanic properties, particularly beyond 28 days. These findings underscore the feasibility of integrating recycled plastic pellets and SCMs into cement-based materials, providing a sustainable approach to waste management while supporting the development of lightweight and environmentally friendly construction materials.

Keywords: Recycled plastics, cement mortar, mechanical performance, fresh properties

THE IMPORTANCE OF NUTRITION AND EMOTIONAL INTELLIGENCE IN MODULATING NEUROPHYSIOLOGICAL RESPONSES TO PSYCHOLOGICAL TRAUMA: THE ROLE OF BIOLOGICAL MARKERS IN STRESS ADAPTATION AND THE PREVENTION OF NEUROTIC DISORDERS

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ABSTRACT

Psychological trauma can significantly alter neurophysiological responses, leading to chronic stress and the development of neurotic disorders. This paper explores the pivotal roles of nutrition and emotional intelligence in modulating these responses. Proper nutritional interventions can influence neurochemical pathways, supporting brain plasticity and reducing the risk of maladaptive stress responses. Similarly, emotional intelligence, encompassing self-awareness and stress management skills, facilitates psychological resilience and adaptive coping mechanisms. The integration of biological markers, such as cortisol levels, inflammatory cytokines, and neurotrophic factors, provides a comprehensive understanding of the stress adaptation process. These markers serve as valuable tools in evaluating the effectiveness of interventions aimed at preventing neurotic disorders. This review highlights the synergistic impact of nutrition and emotional intelligence on neurophysiological regulation, emphasizing their potential as preventive and therapeutic strategies in trauma-related mental health challenges.

Keywords: Nutrition, emotional intelligence, psychological trauma, stress adaptation, neurotic disorders.

INVESTIGATION ON THE ELECTRICAL AND PHOTOCATALYTIC PROPERTIES OF T-STANAGRAPHENE AND SnC-GRAPHENE

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ABSTRACT

Photocatalysis, an advanced technique that converts solar energy into chemical energy, can address environmental issues and energy scarcity. 2D-materials, with their unique two-dimensional structure and large surface area, have significant potential for photocatalysis due to their flexible composition, transforming solar energy with exceptional efficiency. We performed a computational study in this paper, which suggests that two-dimensional stanagraphene will eventually be produced. Using density functional theory (DFT) calculations performed in the wien2k code, the stability dynamical, photocatalytic, electronic, and optical properties of two monolayer types of stana-graphene (t-SnC and g-SnC) have been investigated. These monolayers are a semiconductor with indirect band gaps (between Γ & $\mathbb{N}$ vectors) and direct for t-SnC and g-SnC, according to electronic property research. This research also demonstrated that stanagraphene absorbs visible solar light. In addition, the charge density of stanagraphene was evaluated to establish the charge density distribution between atoms. Another significant advancement is that the photocatalytic activity of these compounds shows that t-stanagraphene is a suitable photocatalysis material.

Keywords: Stanagraphene; photocatalysis; DFT; electronic band gap; semiconductor and electrical conductivity.

STUDY ON COMPRESSIVE STRENGTH OF QUARRY DUST AS FINE AGGREGATE IN CONCRETE

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ABSTRACT

According to the research, one way to boost the amount of quarry dust produced by quarries is to employ it in place of fine aggregate. Quarry dust substitute can lessen the need for landfill and address the issue of a shortage of natural sand. Affordable sand is not a good choice for fine aggregate in concrete, so other sources of material must be investigated. Quarry dust not only serves as a cost-effective substitute for sand, but it also serves as an alternative material. Even the weight of dumping crusher dust in one location pollutes the ecosystem. The conclusion drawn from the practical investigations findings is that quarry dust can be employed as a fine aggregate substitute. It has been discovered that substituting 40% of the fine aggregate with quarry dust results in stronger concrete than regular concrete, with the strength decreasing after 50%.

Keywords: Dust, Landfill, Investigation, Strength, Regular concrete.

1. Introduction

The concentrated substance known as quarry dust, which is produced as a by product of crushing, is used as aggregates for concrete, particularly fine aggregates. When rock is broken into different sizes for quarrying purposes, a dust known as quarry dust is produced, which is then disposed of as waste. Consequently, it turns into a waste item and pollutes the air. As a result, using quarry dust in construction projects will lower costs, save money on building materials, and ensure that natural resources are managed responsibly. There is pressure on the majority of emerging nations to substitute some of the fine aggregate in concrete with another material, either completely or partially, while maintaining the same level of quality.

The science of working with materials and gadgets at the atomic and molecular level is known as nanotechnology. Concrete's strength, durability, and other qualities can be enhanced by the application of nanotechnology to cement. Adding nanoparticles to concrete enhances its strength, durability, and shrinkage by reducing empty space. Materials including carbon nanotubes, titanium dioxide, and silica are frequently used to create nanoparticles. Innovative, sustainable, and more robust constructions can result from the use of nanotechnology in cement. High compressive and tensile strengths, good workability, less need for additives, lower costs per building site, and a decreased risk of silicosis are some advantages of Nano concrete.

Because of its possible uses and advantages, quarry dust—a byproduct of the crushing of stones—has drawn interest from the building sector. The need for building materials has grown as a result of the acceleration of urbanization and infrastructure development, which has prompted a quest for sustainable alternatives. The fine particles produced when stones are crushed make up quarry dust. Its granular texture is akin to that of sand since it usually contains silica, alumina, and iron oxide. Quarry dust's viability as a building material is influenced by its physical characteristics, including moisture content, specific gravity, and particle size distribution. Its angular design helps increase bonding in asphalt and concrete applications, while its fineness can make concrete mixes easier to deal with.

Inadequate quarry site management can result in habitat destruction and landscape deterioration, while dust produced during quarrying can contribute to air pollution.

The usage of quarry dust has drawbacks despite its advantages. Depending on where it comes from, quarry dust's characteristics might vary, which can impact how well it works in concrete and other uses. Furthermore, there are worries about the possible health hazards of breathing in fine dust particles, which calls for appropriate management and mitigation techniques in building procedures. Furthermore, regional differences in the legal frameworks controlling the use of quarry dust in building may have an effect on its uptake. Guidelines for its safe and efficient usage must be established through ongoing research and standardization initiatives.

In the building sector, quarry dust is a useful resource that provides a sustainable substitute for conventional materials. Its uses in the manufacturing of asphalt, cement, and concrete improve material qualities while also aiding in environmental preservation. Although there are obstacles to overcome, using quarry dust in construction is a viable way to meet the rising demand for environmentally friendly building materials. To maximize its benefits and reduce its negative effects on the environment, more research and prudent management are essential.

In the construction business, quarry dust has been used for a variety of purposes, including aggregates, bricks, tiles, building materials, and materials for developing roads. Because quarry dust can produce airborne particles during handling and processing, handling it could be hazardous to one's health if necessary precautions are not taken. Quarry dust can have different qualities depending on where it comes from, therefore it can be difficult to grade and maintain consistency in it.

Quarry dust is a multipurpose substance that is frequently used in building projects as a more affordable option to sand. It has several advantages, but handling and using it correctly can offer some difficulties.

Quarry dust is a cost-effective substitute for sand in construction projects since it is frequently less-expensive.
It lessens the quantity of waste produced by quarrying operations by using quarry dust. Quarry dust can improve the workability of concrete mixes when it is blended and graded correctly. The current study focuses on the effects of varying sand replacement percentages with quarry dust on concrete's characteristics. The purpose of this study is to evaluate the effects of adding quarry dust to regular concrete and to determine how quickly compressive strength develops.

2. Literature review

Citra R (2019) et al. paper showed every blend showed enhanced filling and passing capabilities along with good workability. According to the workability test findings, those fall within the parameters outlined in the EFNARC recommendations.

While quarry dust serves as a filler material, silica fume's fineness was crucial in enhancing SCC's flow ability characteristics. Therefore, the improved workability qualities of SCC are demonstrated by the presence of silica fume. Comparing the mixes S05Q05 and S7.5Q05 to the standard concrete CC, a 1% and 3.3% increase in compressive strength was noted. It was discovered that S7.5Q05 had a 4.04% higher percentage gain in tensile strength than CC. The S7.5Q10 was found to have a 3.5% somewhat higher percentage of flexural strength than the CC.

Jagadeesh P (2019) et al. Quarry dust, a by-product of crushed stone, is substituted as a fine aggregate in this study at 20%, 30%, 40%, and 50% substitution. By testing the sample cube, the compressive strength of the concrete is ascertained while fine material is substituted. The sample's characteristics, including its moisture content, fineness modulus, and specific gravity, are ascertained. Because quarry dust is a waste product from quarries, it is a good substitute for regular sand and is also quite temperate. Because of its superior retaining qualities, the quarry dust exhibits higher quality.

Gedela K (2023) et al. The performance of an alkali-activated binder based on sugarcane bagasse ash and quarry dust as a substitute fine aggregate is evaluated in this study. As activators, NaOH and Na2SiO3 were employed. To assess the curing effect, alkali-activated specimens based on sugarcane bagasse ash were exposed to both ambient and heat curing. Five different alkali-activated concrete compositions were cast using varying amounts of quarry dust: 0, 10, 20, 30, 40, and 50%. Additionally,

for quarry dust aggregates that employed alkali-activated binder, the impact of using sugarcane bagasse ash as a precursor (10, 20, and 30% SCBA as a replacement of the GGBS) was assessed. According to the study, the ideal amount of quarry dust to replace river sand is 20%. When compared to the control specimens, the 30% bagasse ash–20% quarry dust heat-cured alkali-activated specimens' compressive strength is reduced by 35.1%. Compared to the heat-cured specimens, the specimens based on ambient-cured sugarcane bagasse ash and quarry dust demonstrated superior strength. Although the alkali-activated specimens based on bagasse ash and slag have a lower compressive strength than the control specimens, the resulting strength is still significantly higher than the minimum strength needed for a number of structural applications.

Shyam prakash K (2017) et al. Used quarry dust to replace natural fine aggregate results in the consumption of the created dust, reduces the need for land fill space, and addresses the issue of natural sand scarcity. The low cost of sand as a fine aggregate provides justification for looking for an alternative material. Additionally, it results in the saddle dumping the crusher dust in one location, which pollutes the environment. By substituting quarry dust for sand, the chemical analysis, specific gravity, sieve analysis, and compressive strength are determined for different percentages and grades of concrete.

Kaish A (2022) et al. The purpose of this study was to examine how the strength characteristics of regular concrete were affected when various industrial waste materials were used in partial replacement of fine aggregate. Utilizing some industrial waste can have many advantages for the building sector in terms of cost-effectiveness and sustainability of natural resources. However, little research has been done on the use of industrial waste to replace fine aggregate in concrete of normal strength, particularly when it comes to using alum sludge from water treatment plants. In this investigation, oven-dried alum sludge was utilized in place of fine aggregate (river sand). To determine the precise impact of oven-dried alum sludge on concrete, quarry dust and limestone dust were also used as non-reactive industrial waste materials. After being crushed to reduce their particle size, all of the materials were employed in varying quantities (5, 10, and 15%) to substitute fine aggregate. The trials' findings demonstrate that adding industrial waste material increased the concrete's density, flexural, compressive, and splitting tensile strengths. Also, the results indicate that the best replacement content of fine aggregate with industrial waste was 10% for oven-dried alum sludge and 15% for quarry and limestone dust, which enhanced all of the strength characteristics examined in this study. All of the industrial waste used as fine aggregate in this study has been shown to be an effective filler material by enhancing the strength characteristics of normal strength concrete and filling internal voids. After being crushed to reduce their particle size, all of the materials were employed in varying quantities (5, 10, and 15%) to substitute fine aggregate. The trials' findings demonstrate that adding industrial waste material increased the concrete's density, flexural, compressive, and splitting tensile strengths. Also, the results indicate that the best replacement content of fine aggregate with industrial waste was 10% for oven-dried alum sludge and 15% for quarry and limestone dust, which enhanced all of the strength characteristics examined in this study. All of the industrial waste used as fine aggregate in this study has been shown to be an effective filler material by enhancing the strength characteristics of normal strength concrete and filling internal voids.

Shyam Prakash k (2016) et al. The study's emphasis on the idea of substituting quarry dust for natural fine aggregate may increase the amount of quarry dust produced by quarries. The issue of natural sand scarcity can be resolved and the need for land fill is decreased by substituting quarry dust. Sand is not a suitable fine aggregate for concrete due to its low cost, which is why it is necessary to look for an alternate material. Quarry dust is a very inexpensive alternative material that meets the requirements for replacing sand. The study's emphasis on the idea of substituting quarry dust for natural fine aggregate may increase the amount of quarry dust produced by quarries. The issue of natural sand scarcity can be resolved and the need for land fill is decreased by substituting quarry dust. Sand is not a suitable fine aggregate for concrete due to its low cost, which is why it is necessary to look for an alternate material. Quarry dust is a very inexpensive alternative material that meets the requirements for replacing sand.

3. Methodology

Crushers produce quarry dust when they work on quarries. Quarry dust was acquired from quarries in the vicinity. The purpose of the current studies is to examine the effects of partially replacing quarry

dust with sand in concrete. The strength properties of the samples that were gathered from the surrounding area were examined and contrasted. Each set of three cubes in the software consists of cube specimens that are cast and tested. Standard 150 mm *150 mm *150 mm cubes were used to cast the cubes. For the mix, specific gravities of 2.62 and 2.70 for sand and quarry dust, respectively, are utilized for 30 grade cement. For the concrete mix, normal moist curing was used for curing. The cube specimens are tested using a 2000 KN capacity compression testing machine.

Figure 1: Quarry dust

4. Discussion of results

M30 grade of concrete with 20, 25, and 30 percentage replacement of quarry dust tested for 3 days, 7 days, 14 days, and 28 days is studied and the results are presented.

The samples were cast using standard materials, i.e., ordinary Portland cement (OPC) was used to cast the fine aggregate, which is naturally occurring river sand with an M30 grade.

The substitution of quarry dust as a fine aggregate by concrete with age might result in a 40% increase in compressive strength.

Conventional concrete workability is found to be 0.87 for M30 grade and w/c 0.45. Workability for 20% quarry dust is 0.84. Workability is further reduced to 0.73 for concrete that has been replaced by 30%. Workability for concrete containing 40% quarry dust is 0.83, while compacting factor was found to be 0.77 for concrete containing 50% replacement of quarry dust.

Graph 1: Compressive strength of concrete

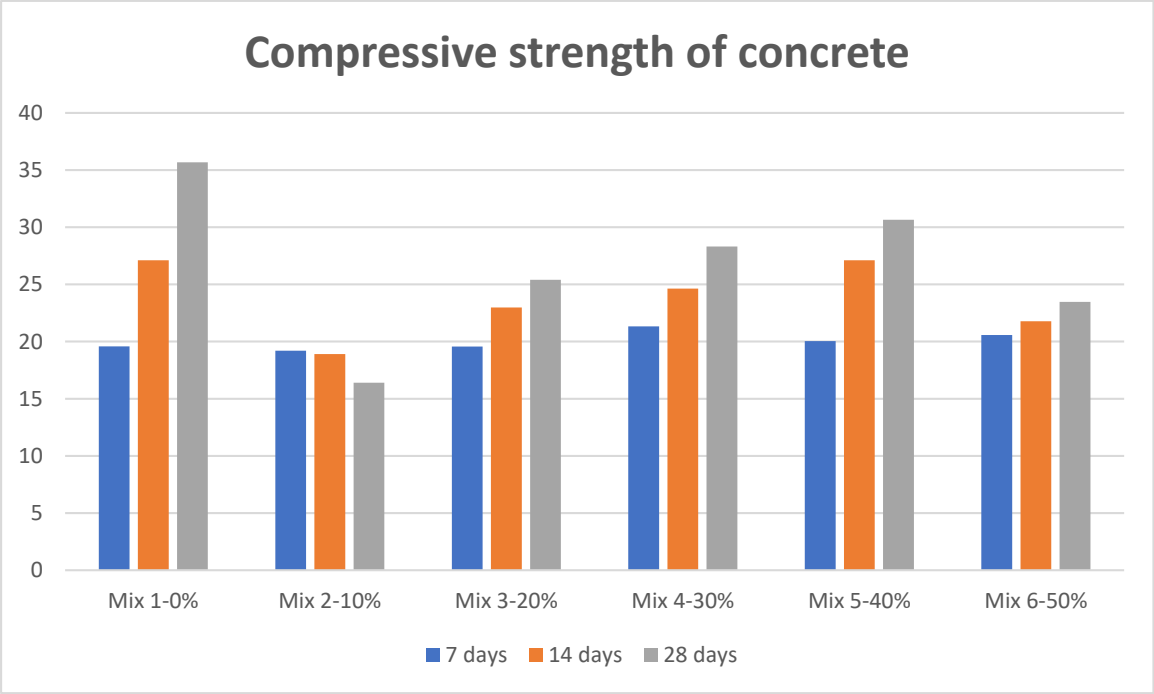

Table 1: Compressive strength of cement

Mix	7 days	14 days	28 days
0%	19.58	27.11	35.67
20%	19.20	18.9	16.4
25%	19.57	22.98	25.4
30%	21.33	24.63	28.31
40%	20.04	27.11	30.65
50%	20.57	21.78	23.47

5. Conclusion

The idea presented in this inquiry to substitute quarry dust for natural fine aggregate could enhance the use of the produced quarry dust, hence lowering the need for land fill space and protecting the limited supply of natural sand for sustainable development. The bonding of the fine particles, which fills in the spaces between the coarse aggregates, is primarily responsible for the strength of the concrete.

When quarry dust is substituted, the compressive strength diminishes as the amount of water increases. This is because quarry dust has the ability to absorb water. It's common knowledge that when strength declines, the w/c ratio rises. However, there is a nonlinear difference in the compressive strength of quarry dust and sand.

It can be observed from the experimental study that quarry dust is a suitable substitute for fine aggregate. When compared to regular concrete, it is discovered that 40% replacement of sand with quarry dust yields the highest result in strength, which then drops from 50%. The findings demonstrated that increased compressive strength could be achieved by substituting up to 40% of the sand with quarry dust, and that as replacement increases, concrete's workability would decline. Consequently, garbage and its consequences on the environment can be greatly decreased.

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ASSESSEMENT OF THE RADIATION DOSE RATES AT FACULTY OF ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA

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ABSTRACT

This study evaluates natural background radiation exposure within the Faculty of Engineering, Ahmadu Bello University, Zaria, focusing on gamma radiation from potassium (^{40}K), uranium (^{238}U), and thorium (^{232}Th). We conducted measurements at selected locations using a gamma-ray spectrometer, with dose rates ranging from 83.6 nGy/h to 166.7 nGy/h. The highest Annual Effective Dose Equivalent (AEDE) recorded was 960.2 μSv/year, below the 1 mSv/year safety limit recommended by the International Commission on Radiological Protection (ICRP). The study highlights that geological and environmental variations in the area influence radionuclide distribution and associated radiation levels. We observed higher radiation levels in regions dominated by igneous rocks, richer in uranium and thorium, and lower levels in areas dominated by sedimentary rock formations with lower radionuclide concentrations. These findings indicate that the geological composition significantly determines the distribution of natural radioactivity in the study area. The results suggest that natural radiation exposure within the Faculty of Engineering is within safe limits, posing minimal health risks to the public and the university community. However, the observed variations underscore the importance of localized geological assessments in understanding natural radioactivity patterns. This study emphasizes the need for ongoing monitoring of radiation levels to ensure continued safety and to establish baseline data for future comparisons in environmental and radiological studies.

Keywords: Gamma-ray spectrometer, Annual Effective Dose Equivalent (AEDE), Radionuclide distribution, Geological variations

DESIGN OF A 48 V 28 Ah BATTERY FOR E-MOTOR VEHICLE

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ABSTRACT

Advances in battery technology have been pivotal in enabling the widespread adoption of electric mobility. In electric vehicles, including electric motorcycles, the battery plays a central role by supplying the energy required for propulsion, auxiliary systems, and onboard electronics. The growing demand for sustainable and efficient transportation solutions has led to significant advancements in electric vehicle technology, with battery design playing a crucial role in electric motorcycles. This paper focuses on designing a 48 V, 28 ah lithium-ion battery pack specifically tailored for electric motorcycle applications. The primary objective is to create a battery that balances high energy density, safety, thermal stability, and extended cycle life, meeting the specific power and endurance requirements of electric two-wheelers. This design involves a systematic approach of lithium-ion for safety, long cycle life, and thermal stability. The cell configuration is optimized to achieve a 48 V output and 28 ah capacity through a combination of series and parallel connections, enabling sufficient energy storage and power output for varying riding conditions. MATLAB-based simulations were conducted to evaluate the battery performance under variable load and speed conditions. COMSOL tool is used to model the battery and its performance study. Designing a lithium-ion cell involves modelling its physical and chemical structure. This includes the shape (cylindrical or prismatic) and the internal components such as electrodes, electrolyte, and separators. The results demonstrate the battery's ability to sustain performance under high-power demands while maintaining safe operating conditions.

Keywords: Battery, COMSOL study, E-motorcycle, MATLAB simulation.

IMPACT OF OXYGEN FLOW CONFIGURATION ON OZONE GENERATION EFFICIENCY AND ENERGY CONSUMPTION IN DBD OZONE GENERATORS

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ABSTRACT

This study investigates the influence of oxygen inlet and ozone outlet configurations on the performance and energy efficiency of DBD ozone generators. Three distinct models were experimentally evaluated: a single-inlet/single-outlet configuration, a dual-inlet/dual-outlet design, and a quad-inlet/quad-outlet system. The research aimed to determine the optimal configuration for maximizing ozone production while minimizing energy consumption. Experimental procedures involved rigorous testing of each model under controlled conditions, measuring ozone output, oxygen flow rates, and energy consumption. The dual-inlet/dual-outlet model served as a baseline for comparison, while the single-inlet/single-outlet design represented a simplified approach. The quad-inlet/quad-outlet configuration was hypothesized to offer superior performance due to enhanced gas distribution and reaction surface area. Results demonstrated a significant improvement in both ozone generation capacity and energy efficiency with the quad-inlet/quad-outlet model. This configuration exhibited a marked increase in ozone production rates compared to the other two models, attributed to improved oxygen distribution and more uniform plasma discharge across the generator's reaction chamber. Furthermore, the quad-configuration showed a notable reduction in energy consumption per unit of ozone produced, indicating superior energy efficiency.

Key words: ozone generator, Oxygen Flow, DBD, energy efficiency, Ozone.

RESPONSE OF HIGH RISE BUILDING AGAINSTEARTHQUAKE FORCE AND WIND FORCE UNDER DIFFERENT SOIL CONDITIONS

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ABSTRACT

Wind and earthquake loadings are the two most common forms of lateral dynamic excitations experienced by high-rise buildings. An effective design must assure thesafety of a building's structural and non-structural components against both types of loads. Reinforced concrete building structures are made up of horizontal elements (beams and slabs) and vertical members (columns and walls) that are held together by a foundation. The structure is susceptible to loads such as self-weight, living load, wind load, and earthquake load, among other things. Normally, the structural strength of the slab and thebrick walls is not taken into account in the structure's study. In general, the foundation support is supposed to be either hinged or permanent, whereas foundations transmit the load to the soil medium, which settles (vertically) based on the loads from the structure and the soil medium's properties, generating extra pressures in the structure. However, due to the complexities of structural analysis, this influence is frequently overlooked. By spring, an attempt is made to assess the construction while taking into account the foundation soil as clay and soft rock like soil media. The seismic zones III and wind force with soil structure interaction of a G+12 structure are investigated. ETABS software is used to do the analysis. According to the findings of the study, behavior of Building with soil structure interaction are found better against wind forces when compared against earthquakeforces. Significant increase in response of building when SSI is considered is because of flexibility induced to the base by the softness of clayey and soft rock soil.

Keywords: Base shear, story drifts, Displacement, Time period and Soil structure interaction

ASSESSMENT OF POTABLE WATER DEMAND AND SUPPLY IN CITIES OF WEST AFRICA, CASE OF ENUGU, SOUTH EASTERN, NIGERIA.

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ABSTRACT

It is very necessary to start addressing the worrisome situation of water scarcity in cities of undeveloped and developing nations in the continent of Africa in pursuit of Sustainable Development Goal (SDG) of 2030. The desire is to resolve the severe water shortage vis-à-vis rapid population growth in the cities of West Africa, one of which is Enugu in Enugu State, South Eastern, Nigeria. Over the years, residents of Enugu City have been suffering from severe scarcity of potable water. This study was aimed at evaluating the potable piped water demand and supply in Enugu capital city using measurable water sources as a first step to wrestling the water scarcity challenge. The objectives were to acquire potable water daily supply records from the government agency responsible for keeping potable water supply records of the city, the demography of the city, interview residents and juxtapose the results with the World Health Organization's (WHO) standard on minimum water consumption per capita per day for proper estimation of the adequacy or not of the quantity of water supplied . The result shows that 16,261,534 litres of water was supplied to a population of 1,026,097 persons, which implies that an average of **15.8 litres** of water amounting to **11%** of **150** litres specified by WHO is what is supplied per capita per day. This exposes the gross inequality between potable water demand and supply in Enugu metropolis.

Keywords: Potable Water, Sustainable Development Goal, Water Demand, Water Supply, West African Cities, Enugu Nigeria

ANALYSIS OF ADMIXTURES FOR CONCRETE

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ABSTRACT

Admixtures are liquids or powders that are added to concrete based on calculations for the mix design with the goal of improving the qualities of the concrete both in its fresh and hardened states. Concrete's workability, strength, and finish affect the product's quality, cost, and longevity. Concrete Adoption of smart building practices is crucial given the escalating environmental pollution issues and the need for sustainable construction methods, as well as the cost-quality-time pyramid of construction projects. One solution to the aforementioned problems is the use of admixtures in the manufacturing of concrete. The mix water and chemical admixtures have an effect on the rheology of concrete. Chemical admixtures affect the characteristics of concrete in both its fresh and hardened states. The mega structures built in the recent period under constructor serve as a visible representation of the advantageous effects of using chemical admixtures in concrete mixes. Admixture chemistry is important in converting a typical concrete mix into a high-performance concrete mixture. The invention of chemical admixtures, transformations seen in head mixture chemistry, and the uses of the admixtures in certain significant concrete constructions are all attempted to be presented in this study.

Keywords: Concrete; Admixtures; High Performance Concrete

SUSTAINABLE URBAN DEVELOPMENT IN MASCARA (ALGERIA) CHALLENGE AND PERSPECTIVES

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ABSTRACT

In Mascara, the problems related to rapid urbanization include disordered urban sprawl, inefficient management of resources (water, energy), as well as the absence of coherent strategies to ensure the long-term sustainability of the urban space.

Faced with these challenges, it becomes essential to assess the extent to which the city can adopt sustainable urban development practices that meet both current needs and future requirements. How can Mascara reconcile its rapid development with the need for sustainable urban development, while ensuring efficient management of its resources, preservation of its environment, and a better quality of life for its inhabitants?

Our study shows that the spatial development of the city must correspond to a modernist and futuristic vision that meets the aspirations of its inhabitants in the areas of quality of urban life and planned urban sprawl. The Division entitled "Urban Planning and Development" is thus responsible for conducting studies and research on all themes specific to the city, its history, its evolution and even its future representation. We must urgently find ways to achieve economic and socially equitable growth without further encroaching on the environment. The solution lies partly in the way cities are planned, governed and provide services to their citizens. "Poorly managed urbanization can be an obstacle to sustainable development."

Keywords: urban modernization, sustainable development, city, architecture

RISING BEYOND CHALLENGES: SUSTAINABLE URBAN SOLUTIONS FOR VULNERABLE COMMUNITIES IN PAHARTALI, CHATTOGRAM

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ABSTRACT

This study explores sustainable urban planning strategies tailored to the urban poor in Pahartali, Chattogram, addressing housing challenges within the broader framework of resilient cities. Positioned near Fay's Lake, the area possesses economic potential but is threatened by landslide risks exacerbated by heavy rainfall. The proposed initiative focuses on developing affordable, climate-resilient housing that ensures safety while improving socio-economic conditions.

The research emphasizes eco-friendly design, ecological planning, and resource sustainability to foster urban resilience. By integrating micro-business zones, communal gardens, and farming opportunities, the project empowers local communities and enhances economic self-sufficiency. It aligns with key urban themes, such as rethinking green spaces, adapting zoning policies, and incorporating financial innovations to achieve sustainability goals.

To address urbanization and deforestation impacts, the study adopts community-driven resilience practices and innovative planning approaches. Strategies such as universal design, climate adaptation, and green technology are central to mitigating risks and improving living conditions. This holistic framework also tackles critical urban issues, including overcrowding, evictions, and resource scarcity, creating a blueprint for sustainable urban regeneration.

By restoring urban quality of life through sustainable design and planning, this initiative provides insights and practical solutions applicable to cities facing similar challenges. It contributes to global urban discourse, offering replicable models that balance economic growth, environmental protection, and community empowerment in building resilient, inclusive cities.

Keywords: Sustainable urban planning**,** Resilient cities**,** Urban poor**,** Affordable housing**,** Climate-resilient housing

IMPROVING SUSTAINABLE SAND CONCRETE PERFORMANCE: UTILIZING RECYCLED QUARRY WASTE AS CRUSHED LIMESTONE SAND

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ABSTRACT

This research explores the potential of repurposing quarry waste as crushed limestone sand to produce eco-friendly sand concrete and address environmental challenges. Five different mixtures were designed with limestone sand proportions. The physical and mechanical performance of these mixtures was evaluated through tests such compressive strength, flexural strength and microstructural analysis.

The results revealed significant improvements in the properties of sand concrete when limestone sand was added. Among the tested mixtures, the one with a 60% limestone sand content exhibited the best overall performance, indicating an optimal balance between strength and workability. Notably, the compressive and flexural strengths, as well as the density and dynamic elastic modulus, showed marked enhancements at this ratio.

This research highlights the potential of using crushed limestone sand not only as a high-performance construction material but also as a sustainable solution for managing quarry waste. By integrating recycled materials into sand concrete production, the study addresses pressing environmental issues, such as waste disposal and resource conservation. Furthermore, it underscores the feasibility of adopting eco-friendly practices within the construction industry, promoting the concept of a circular economy.

In conclusion, the findings suggest that quarry waste, in the form of crushed limestone sand, can be effectively recycled and utilized in sand concrete mixtures to achieve both improved material performance and environmental sustainability. This dual benefit paves the way for more sustainable construction practices and a reduction in the environmental footprint of the industry.

Keywords: sand concrete, quarry, microstructure, sustainability and waste recycle

THERMAL INSULATION PROPERTIES OF GEOPOLYMER FOAM FOR SUSTAINABLE BUILDING APPLICATIONS

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ABSTRACT

Global interest to develop durable thermal insulation materials with low CO_2 emissions makes geopolymer foams a friendly alternative to conventional insulator materials. In this context, this study presents an experimental investigation into the properties of geopolymer foams prepared using metakaolin (MK) and red clay brick waste (RBW). Using hydrogen peroxide as a foaming agent and olive oil as a stabilizing agent resulted in geopolymer foams with lower thermal conductivities in the range of 0.11-0.08 W/m.K. Microstructural analysis revealed that without olive oil, the average pore size was approximately 230 μm. However, increasing the olive oil content up to 10 wt.% resulted in a smaller, more uniform pore structure, averaging around 67 μm. This enhances air entrapment and improves thermal insulation properties of the produced geopolymer foams. Furthermore, the cost and environmental assessment of the developed geopolymer foams highlight their potential as sustainable and cost-effective alternatives to the most common insulation materials. However, further investigations, including fire resistance and durability, are warranted to fully assess the industrial applicability of these materials.

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