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# Farklı Numune Geometrileri Arasında Tek Eksenli Basınç Dayanımı Tahmini İçin Makine Öğrenmesine Dayalı Dönüşüm Modeli Geliştirilmesi

Development of a Machine Learning-Based Conversion Model for Uniaxial Compressive Strength Prediction Between Different Specimen Geometries

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## Özet

Tek eksenli basınç dayanımı (TBD), mühendislik yapılarının tasarımı ve inşası, yeraltı kazıları, şev stabilitesi gibi projelerde kaya mühendisliği için en önemli tasarım parametrelerinden biridir. TBD testi için gerekli olan numunelerin bazı ulusal ve uluslararası standartlarda önerildiği şekilde hazırlanması gerekmektedir. Özellikle kaya yapısı zayıf ve kırılgan olduğunda istenilen boyutlarda ve sayıda numune temin edebilmek mümkün olmamaktadır. Böyle durumlarda, farklı standartlarda önerilmiş alternatif numune boyutları ve geometrileri tercih edilebilmektedir. Numune şekli ve boyutunun TBD üzerindeki etkisi literatürde uzun süredir araştırılmakta olup, bu etki büyük ölçüde anlaşılmıştır. Ancak farklı geometrilere sahip numunelerden elde edilen TBD değerleri arasındaki ilişkinin literatürde ortaya konmadığı görülmektedir. Özellikle kaya örnekleri üzerinde yapılan karşılaştırmalı çalışmaların olmadığı fark edilmiştir. Literatürde önerilen bazı dönüşüm denklemlerinin, silindirik ve kübik numuneler arasındaki dayanım geçişini de yeterli doğrulukla tahmin edemediği belirlenmiştir. Bu çalışmada, kübik numunelerden elde edilen TBD değerlerinden silindirik numunelere ait değerlerin tahmin edilmesi amacıyla çeşitli makine öğrenmesi (ML) temelli regresyon algoritmaları uygulanmıştır. Doğrusal regresyon, ağaç tabanlı modeller, ansambl öğrenme yöntemleri, çekirdek tabanlı algoritmalar ve dayanıklı regresyon teknikleri karşılaştırmalı olarak değerlendirilmiştir. Modellerin performansı, 5 katlı çapraz doğrulama yöntemi ile belirlenmiş ve başarı ölçütleri olarak $R^2$, MAE, MAPE ve RMSE kullanılmıştır. Elde edilen bulgular, özellikle Huber Regressor ve SVR gibi modellerin yüksek doğrulukla tahmin sağladığını göstermekte; klasik dönüşüm katsayılarına kıyasla daha dar hata aralıkları ve güçlü genelleme yeteneği sunduklarını ortaya koymaktadır. Bu sonuçlar, makine öğrenmesi tabanlı

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modellerin, beton ve kaya gibi heterojen malzemelerde farklı numune geometrileri arasında TBD dönüşümünü sağlamak için etkin bir araç olabileceği sonucuna varılmıştır.

**Anahtar kelimeler:** Tek eksenli basınç dayanımı, numune geometrisi, silindir-küp, beton, makine öğrenmesi

**Abstract**

Uniaxial compressive strength (UCS) is one of the most critical design parameters in rock engineering applications, including the design and construction of engineering structures, underground excavations, and slope stability. Specimens required for UCS testing must be prepared in accordance with various national and international standards. However, when the rock structure is weak or brittle, obtaining the required number and size of specimens may not be feasible. In such cases, alternative specimen geometries and sizes recommended by different standards are often adopted. Although the influence of specimen shape and size on UCS has been extensively studied in the literature and is relatively well understood, the relationship between UCS values obtained from different geometries remains largely unexplored. Notably, there is a lack of comparative studies focusing specifically on rock samples. Furthermore, some transformation equations proposed in the literature have proven inadequate in accurately estimating the strength conversion between cylindrical and cubic specimens. In this study, various machine learning (ML)-based regression algorithms were applied to predict UCS values for cylindrical specimens using UCS values obtained from cubic specimens. A comparative evaluation was conducted using linear regression, tree-based models, ensemble learning methods, kernel-based algorithms, and robust regression techniques. Model performances were assessed through 5-fold cross-validation using $R^2$, MAE, MAPE, and RMSE as evaluation metrics. The findings reveal that models such as the Huber Regressor and Support Vector Regression (SVR) provided highly accurate predictions, with narrower error margins and stronger generalization capacity compared to classical transformation coefficients. These results suggest that ML-based models offer an effective and reliable approach offering a robust alternative to conventional transformation equations, especially in engineering contexts where direct experimental testing is limited or impractical.



**Keywords:** Uniaxial compressive strength, specimen geometry, cylinder-cube, concrete, machine learning

## 1. GİRİŞ

Tek eksenli basınç dayanımı, kayaç ve beton gibi yapı malzemelerinin tanımlanmasında ve yeraltı ile yerüstü yapılarının tasarımında kullanılan en temel mekanik parametredir. Bu nedenle kayacın ve betonun basınç dayanımının doğru bir şekilde belirlenmesi ve değerlendirilmesi teknik olarak çok önemlidir. Kayacın ve betonun tek eksenli basınç dayanımı ulusal ve uluslararası standartlar tarafından önerilen deney yöntemlerinde belirtilen farklı boyutlardaki silindirik ve kübik şekillerdeki test numuneleri kullanılarak belirlenmektedir. Kayacın veya betonun tek eksenli basınç dayanımının numune şekli, boyutu ve sınır koşulları gibi test parametrelerine karşı son derece duyarlı olduğu görülmüştür (Van Vliet ve Van Mier, 1996; Bazant ve Planas 1997; Viso vd., 2008; Zabihi ve Eren, 2014; Li vd., 2018). Literatürde kayaçların tek eksenli basınç dayanımı üzerinde numune şekli etkisine ilişkin bir çalışma henüz bulunmamakla birlikte, beton ile ilgili numune şeklinin betonun basınç dayanımına etkilerini inceleyen az sayıda çalışmanın olduğu görülmüştür.

Felekoğlu ve Türkel (2005) farklı boyutlarda küp ve silindir formdaki beton test örneklerinin

basınç dayanımı değerlerini iki farklı dayanım sınıfı için incelemiş ve bu boyutlar arasında geçiş katsayıları önermişlerdir.

Dehestani vd. (2014) farklı karışım oranına sahip küp ve silindir numuneler üzerinde gerçekleştirdikleri deneyler sonucunda uzunluk/çap oranı azaldıkça numune boyutunun etkisinin daha büyük bir faktör haline geldiğini, uzunluk/çap oranı 2.0 veya yanal boyutu 100 mm olan numuneler için elde edilen sonuçların beton karışım oranından bağımsız olduğu sonucuna varmışlardır. Numunelerin kesit şeklinin basınç dayanımı üzerinde çok az etkisi olduğunu ortaya koymuşlar ve numune geometrisine dayalı basınç dayanımını tahmin etmek için korelasyon analizleri yaparak tahmin modelleri önermişlerdir.

Sudin ve Ramli (2014) çalışmalarında numune boyutu ve şeklinin betonun eksenel basınç dayanımı üzerindeki etkisini incelemişler, hazırladıkları küp, prizma ve silindir gibi kare ve dairesel kesitlere sahip çeşitli boyut ve şekillerde numuneler üzerinde yaptıkları deneylerle betonun 7 ve 28 günlük basınç dayanımı davranışlarını incelemişlerdir.

Nalon vd. (2017) numunelerin şekli ve boyutunun betonun basınç dayanımı üzerindeki etkisinin karşılaştırmalı analizlerini sundukları bir çalışma yapmışlardır. Kübik numunelerin basınç dayanımı 10x20 cm'lik silindirlerin basınç dayanımından daha yüksek, 5x10 cm'lik silindirlerin basınç dayanımından ise daha düşük olduğunu belirlemişlerdir.

Li vd. (2018) çeşitli uzunluk/çap oranlarına sahip 50 mm boyutunda küpler ve 50 mm çapında silindirler üzerinde deneyler gerçekleştirmişler ve farklı şekil ve boyutlardaki numunelerden elde edilen betonun statik ve dinamik basınç dayanımlarını ilişkilendiren ampirik bağıntılar önermişlerdir. Numune şekli ve boyutunun statik ve dinamik testler altında elde edilen basınç dayanımı değerleri üzerindeki etkilerini açıkça göstermişlerdir.

Mardani-Aghabaglou vd. (2021) numune boyutu ve şeklinin betonun dayanımı üzerindeki etkisini değerlendirmek için 10×10×10 cm ve 15×15×15 cm kübik ve 10×20 cm ile 15×30 cm boyutlarında silindirik numuneler üzerinde basınç dayanımı deneyleri gerçekleştirmişler ve numunelerin boyutundaki azalmanın daha yüksek mukavemetle sonuçlandığını görmüşlerdir.



Rincon vd. (2022) küp ve silindir beton numuneler üzerinde yaptıkları deneyler sonucunda küp numunelerden elde edilen basınç dayanımı değerlerinin silindirik numunelerden elde edilen basınç dayanımı değerlerine göre %35 ile %50 oranında daha yüksek olduğunu görmüşlerdir.

Judd vd. (2023) küp numuneler, silindir numuneler üzerinde ASTM C109'a göre basınç dayanımı deneyleri gerçekleştirmişler ve betonun basınç dayanımının numune boyutuna güçlü bir şekilde bağlı olduğunu görmüşlerdir.

Bing ve Yuan (2023) yaptıkları çalışma ile farklı şekil ve boyuta sahip test numuneleri arasındaki basınç dayanımını hesaplayabilmek için eşitlikler önermişlerdir.

De La Rosa ve Ruiz (2025) silindirik ve kübik beton numunelerin basınç dayanımı arasındaki ilişkiyi, numune şekli, boyutu, beton tipi ve döküm yönünün etkisine odaklanarak araştırmışlardır. Yapılan önceki çalışmalardan elde edilen deneysel verileri analiz ederek, silindir ve küp arasındaki dönüşüm faktörünü hesaplamak için beton numunelerin boyut ve geometrik etkilerini hesaba katan yenilikçi bir Kırılma Mekaniği tabanlı bir model önermişlerdir.

Bu çalışma kapsamında, beton numuneleri üzerinde gerçekleştirilmiş deneysel araştırmalardan elde edilen veriler kullanılarak, silindirik ve kübik numuneler arasında TBD dönüşümünü sağlayabilecek bir model önerilmiştir. Söz konusu modelin gelecekte kayaç numuneleri üzerinde yapılacak deneylerle daha fazla doğrulanması ve geliştirilmesi hedeflenmektedir. Böylece, homojen beton örneklerine kıyasla daha heterojen yapıya sahip kayaçlar için daha güvenilir tahmin modellerinin geliştirilmesi mümkün olacaktır.

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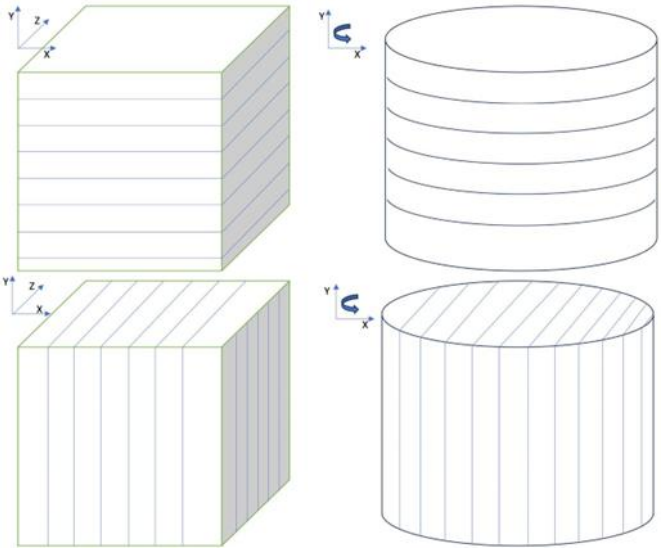
Literatürde önerilen dönüşüm katsayıları genellikle sabit oranlara dayanmaktadır. Ancak bu katsayılar, farklı numune geometrilerine sahip malzemelerdeki dayanım farklarını her zaman yeterli doğrulukla temsil edememektedir. Bu nedenle, bu çalışmada silindirik ve kübik numuneler arasında tek eksenli basınç dayanımı geçişini daha güvenilir şekilde tahmin edebilmek amacıyla makine öğrenmesi (ML) temelli regresyon modelleri uygulanmıştır. Böylece hem doğrusal hem de doğrusal olmayan ilişkiler modellenebilmiş; farklı algoritmaların başarı düzeyleri karşılaştırmalı olarak değerlendirilmiştir. Bu yaklaşım, sadece beton numuneleri için değil, gelecekte kayaçlar gibi heterojen ve zorlayıcı mühendislik malzemeleri için de dönüşüm modelleri geliştirmeye olanak tanıyacak niteliktedir.

## 2. YÖNTEM

Tek eksenli basınç dayanımının (TBD) belirlenmesi için önerilen standartlarda iki tip numune geometrisi yer almaktadır (Şekil 1). Her bir standardın kabul ettiği numune L/D (boy/çap) oranı ve geometrisi, ölçülen basınç dayanımı değerlerinde %5–%20 arasında değişen sistematik sapmalara yol açabilmektedir (Dirige ve Archibald, 2006; Al-Rkaby ve Alafandi, 2015). Bu nedenle, çalışma kapsamında literatürde iki farklı geometriye sahip beton numuneler üzerinde belirlenen basınç dayanımları esas alınarak dönüşüm modelleri önerilmiştir.



**Şekil 1.** TBD belirlenmesi için önerilen numune geometrileri.



### 2.1. Doğal taşların tek eksenli basınç dayanımı tayini için kullanılan metotlar

Kayaçların tek eksenli basınç dayanımı testlerinde en sık başvurulan metotlar ve bu metotlarda kullanılan numune adet ve ebatlarını özetleyen bilgiler Tablo 1'de verilmiştir. Farklı numune geometrilerinin tek eksenli basınç dayanımı sonuçları üzerindeki sistematik etkilerinin belirlenmesi ve bu etkileri optimize edecek dönüştürme faktörlerinin geliştirilmesi bu çalışmanın ana odak noktasını oluşturmaktadır. Literatürde en yaygın olarak başvurulan standartların her biri, test numunelerinin şekli, boyutları ve adet gereksinimleri açısından farklılıklar göstermektedir (ASTM C170/C170M, 2019; EN 1926:2006; ISRM, 2007; GB/T 9966.1-2020; ASTM D7012, 2019).

**Tablo 1**

Kayaçların tek eksenli basınç dayanımı tayini için kullanılan standartlar

| Standart Adı | Numune Şekli | Numune Ebatları | Adet |
|---|---|---|---|
| ASTM C170/C170M | Küp veya silindir | Çap/yan ≥ 50 mm; yükseklik = çap (0,9 – 1,1:1) | ≥ 5 (numune) |
| TS EN 1926:2006 | Küp | 50 ± 5 mm veya 70 ± 5 mm kenar uzunluğu | ≥ 10 (numune) |
| ISRM Suggested Method (1977/2007) | Silindir | Çap ≈ 50 mm; L/D = 2,5 – 3:1 | ≥ 5 (numune) |
| GB/T 9966.1-2020 | Küp | 50 × 50 × 50 mm | ≥ 5 (numune) |
| ASTM D7012 | Silindir | Çap ≥ 47 mm; L/D = 2,0 – 2,5 | ≥ 5 (numune) |

### 2.2. Betonların tek eksenli basınç dayanımı tayini için kullanılan standartlar

Betonların tek eksenli basınç dayanımı testlerinde en sık başvurulan metotlar ve bu metotlarda kullanılan numune adet ve ebatlarını özetleyen bilgiler Tablo 2'de verilmiştir. Numune geometrisi (özellikle yükseklik/çap oranı ve şekil) ile sonlu yüzey koşulları (örneğin makine düz yatak yüzeyi etkileşimi), betonun tek eksenli basınç dayanımı ölçümlerinde %10–%20 arasında sistematik sapmalara yol açtığı literatürde yaygın biçimde raporlanmıştır (Walz, 1957; De Larrard vd., 1994; Riedel ve Leutbecher, 2017; Talaat vd., 2021). Ayrıca beton için farklı geometriler arasındaki dayanım farklarını düzeltmek üzere 0,80–0,90 aralığında dönüştürme faktörleri önerilmiştir (Reddy vd., 2019).



**Tablo 2**

Betonun tek eksenli basınç dayanımı tayini için kullanılan standartlar

| Standart Adı | Numune Şekli | Numune Ebatları | Adet |
|---|---|---|---|
| ASTM C39/C39M | Silindir | 150 × 300 mm (6″×12″) veya 100 × 200 mm (4″×8″) | 3 (numune) |
| TS EN 12390-3 | Küp | 150 × 150 × 150 mm | ≥ 3 (numune) |
| JIS A 1108 | Silindir | 100 × 200 mm | ≥ 3 (numune) |
| IS 516 (1959; Rev. 2004) | Küp | 150 × 150 × 150 mm | ≥ 3 (numune) |
| CSA A23.2-9C / A23.2-14C | Silindir | 150 × 300 mm veya 100 × 200 mm | ≥ 3 (numune) |

## 3. MATERYAL VE METOT

Bu çalışma kapsamında literatürde hem kübik hem de silindirik beton numuneleri üzerinde basınç dayanımı testleri gerçekleştirilmiş deneysel araştırmalardan elde edilen ham veriler literatürdeki çalışmalardan derlenmiştir (Tablo 3). Kübik ve silindirik beton numunelerden elde edilen basınç dayanımı değerleri arasındaki ilişkileri geliştirmek için basit regresyon analizleri yapılmıştır.

**Tablo 3**

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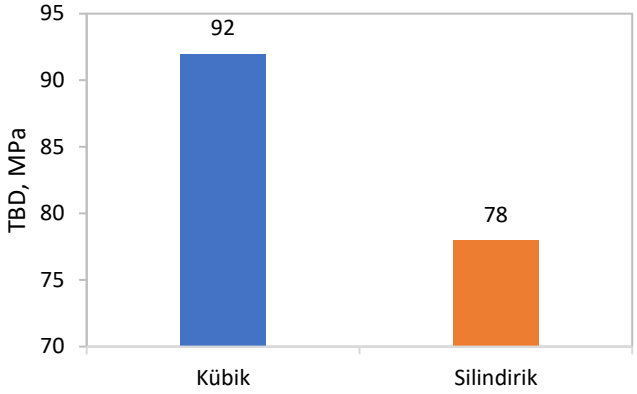
Çalışmada kullanılan verilerin derlendiği çalışmalar

| **Referans** | **Veri adedi ×2** |
|---|---|
| Elwell ve Fu, 1995 | 13 |
| Che et al., 2011 | 4 |
| Dehestani vd., 2014 | 3 |
| Sudin ve Ramli, 2014 | 2 |
| Wu et al. 2015 | 8 |
| Kusumawardaningsih vd., 2015 | 3 |
| Akter vd., 2017 | 9 |
| Chung et al. 2018 | 6 |
| Reddy vd. 2019 | 16 |
| Judd vd., 2023 | 12 |
| Bing ve Yuan, 2023 | 15 |
| Pachideh vd., 2024 | 16 |
| De La Rosa ve Ruiz, 2025 | 23 |
| Li vd., 2025 | 40 |

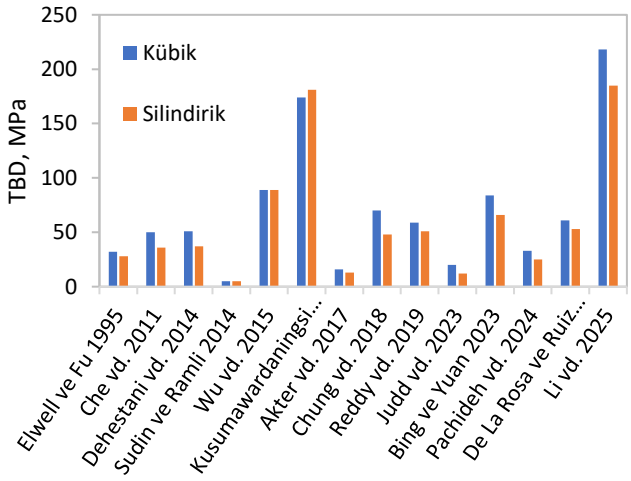


## 4. BULGULAR

Çalışma kapsamında toplamda her iki numune şekli için 2×170 adet veri analiz edilmiştir. Yapılan analizler sonucunda elde edilen TBD değerleri Şekil 2-3'te verilmiştir. TBD değerlerinin kübik numuneler kullanılarak belirlenen TBD değerlerinin daha yüksek olduğu Şekil 2'de açıkça görülmektedir. Şekil 3'e bakıldığında Şekil 2'ye benzer bir tablonun olduğu, iki farklı numune geometrisinden elde edilen TBD değerlerii arasında ortalama %21'lik (%4-%40) bir fark oluştuğu, Sudin ve Ramli (2014) ile Wu vd. (2015) yaptıkları çalışmalarda iki farklı numune geometrisi için elde edilen değerlerin ihmal edilecek düzeyde birbirine yakın olduğu, sadece Kusumawardaningsih vd. (2015) yaptıkları çalışmada silindirik numunelerden elde ettikleri TBD değerlerinin kübik numunelerden elde ettikleri değerlerden %4 oranında daha yüksek olduğu görülmektedir.




**Şekil 2.** Tüm veriler için ortalama TBD.




**Şekil 3.** Referanslar için ortalama TBD.

Bu çalışmada, kübik numunelerden elde edilen tek eksenli basınç dayanımı (TBD) değerlerinden silindirik numunelere ait TBD değerlerini tahmin edebilmek amacıyla çeşitli regresyon algoritmaları uygulanmıştır. Regresyon modellerinin başarım düzeylerini değerlendirmek üzere 5 katlı çapraz doğrulama yöntemi kullanılmış ve her bir model için belirleme katsayısı ($R^2$), Ortalama Mutlak Hata (MAE), Ortalama Mutlak Yüzde Hata (MAPE) ve Kök Ortalama Kare Hata (RMSE) hesaplanmıştır.

Her bir regresyon algoritması, genişletilmiş hiperparametre aralıklarında GridSearchCV yöntemiyle optimize edilmiş ve elde edilen en iyi parametre kombinasyonları doğrultusunda başarı metrikleri raporlanmıştır. Değerlendirmeye alınan modeller arasında doğrusal regresyon yaklaşımlarının yanı sıra, ağaç tabanlı yöntemler, ansambl modeller, çekirdek tabanlı algoritmalar ve dayanıklı regresyon teknikleri yer almıştır.

Modellerin her biri için elde edilen en iyi sonuçlar ve karşılık gelen hiperparametre kombinasyonları Tablo 4'te sunulmaktadır.

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**Tablo 4**

Modellerin 5 katlı çapraz doğrulama sonuçlarına göre başarı metrikleri

| Model | Best Params | R2 (5-fold CV) | MAE (5-fold CV) | MAPE (5-fold CV) | RMSE (5-fold CV) |
|---|---|---|---|---|---|
| Huber Regressor | {'model__epsilon': 1.25, 'model__max_iter': 50} | 0.9840093106192892 | 4.967203329465774 | 9.660323822071248 | 8.057223061354936 |
| SVR | {'model__C': 5, 'model__epsilon': 0.01, 'model__gamma': 'scale', 'model__kernel': 'linear'} | 0.9839539399094377 | 4.952537881241082 | 9.593427403911487 | 8.070166312822094 |
| Elastic Net | {'model__alpha': 0.01, 'model__l1_ratio': 0.9, 'model__max_iter': 1000} | 0.9838043589762886 | 5.204688920090105 | 10.374157096095308 | 8.136269655589234 |
| Lasso | {'model__alpha': 0.1, 'model__max_iter': 1000} | 0.9838042972952795 | 5.205170127445323 5 | 10.397141124550458 | 8.136329563809243 |
| Ridge | {'model__alpha': 0.1, 'model__solver': 'auto'} | 0.9838040357720832 | 5.204088590427477 | 10.347262967705223 | 8.136343066795543 |
| Bayesian Ridge | {'model__alpha_1': 1e-07, 'model__lambda_1': 1e-05} | 0.9838030642711081 | 5.203061039104695 | 10.305534541942885 | 8.136638404236626 |
| Linear Regression | {} | 0.9838025817757478 | 5.202969497848181 | 10.297414104588807 | 8.136748566239559 |
| KNN | {'model__n_neighbors': 7, 'model__p': 1, 'model__weights': 'distance'} | 0.9836898778938391 | 5.064717768447889 | 11.816153344629706 | 8.098387453688495 |
| Extra Trees | {'model__max_depth': 5, 'model__min_samples_split': 2, 'model__n_estimators': 200} | 0.9834436053874278 | 5.902143139537905 | 15.300353091276964 | 8.304974200442626 |
| Random | {'model__max_depth': 10, | 0.98241485735 | 5.52418335784 | 12.2865944243 | 8.3995311336 |

| | | | | | |
|---|---|---|---|---|---|
| Forest | 'model__min_samples_leaf': 2, 'model__min_samples_split': 2, 'model__n_estimators': 100} | 49237 | 3135 | 66205 | 51061 |
| Gradient Boosting | {'model__learning_rate': 0.1, 'model__max_depth': 3, 'model__n_estimators': 100} | 0.9789675657574343 | 5.3196767671571354 | 12.628721177613786 | 8.849670144674871 |
| Decision Tree | {'model__max_depth': None, 'model__min_samples_leaf': 2, 'model__min_samples_split': 2} | 0.9778271773325491 | 5.992549019607843 | 13.566200640896037 | 9.322373857968874 |
| Gaussian Process | {'model__alpha': 0.01, 'model__kernel': RationalQuadratic(alpha=1, length_scale=1)} | 0.9751098261216523 | 6.565412712521109 | 25.512518399229652 | 10.468359843849399 |
| Ada Boost | {'model__learning_rate': 0.01, 'model__n_estimators': 100} | 0.9750947154672351 | 7.395091869688909 | 20.285858240300182 | 10.305130894078875 |

$R^2$: Belirleme katsayısı, MAE: Ortalama mutlak hata, MAPE: Ortalama mutlak yüzde hata, RMSE: Kök ortalama kare hata



## 4. SONUÇ, TARTIŞMA VE ÖNERİLER

Bu çalışmada uygulanan regresyon modelleri karşılaştırıldığında, elde edilen yüksek $R^2$ değerleri tüm modellerin veri seti üzerinde başarılı bir tahmin performansı sergilediğini ortaya koymaktadır. Özellikle Huber Regressor modelinin %98,4 $R^2$ ile en yüksek başarıya ulaşması, bu algoritmanın hem doğrusal yapıyı iyi modellemesi hem de uç değerlere karşı dayanıklı olmasıyla açıklanabilir. Literatürde de Huber tipi dayanıklı regresyonların, homojen yapılı ama lokal sapmalar içerebilecek mühendislik verilerinde etkili olduğu vurgulanmaktadır (Jiang et al., 2021).

Support Vector Regression (SVR) modeli de benzer bir başarı göstererek ikinci sırada yer almıştır. SVR'nin kernel tabanlı yapısı, doğrusal olmayan ilişki olasılıklarını da hesaba kattığı için yüksek genelleme kapasitesine sahiptir (Smola & Schölkopf, 2004). Bununla birlikte, Lasso, Ridge ve ElasticNet gibi doğrusal modellerin de %98'in üzerinde $R^2$ değerlerine ulaşması, küp ve silindir dayanımı arasındaki ilişkinin büyük oranda doğrusal olduğunu desteklemektedir. Bu durum, veri setinde karmaşık ve doğrusal olmayan yapıların sınırlı olduğunu ve doğrusal modellerin bu bağlamda yeterli performans gösterebildiğini ortaya koymaktadır.

Ansambl yöntemlerinden Random Forest, Gradient Boosting ve AdaBoost gibi modeller, her

ne kadar istikrarlı sonuçlar sunsalar da doğrusal modellere göre biraz daha düşük başarı metrikleri elde etmiştir. Bunun nedeni, bu modellerin genellikle daha büyük ve karmaşık veri kümelerinde avantaj sağlaması; bu çalışmada ise tek değişkenli ve yüksek korelasyon içeren bir yapıyla karşılaşmaları olabilir. Ayrıca, Gaussian Process Regressor gibi teorik olarak güçlü ancak küçük veri kümelerinde aşırı uyum (overfitting) riski taşıyan modellerin bazı katmanlarda düşük performans sergilemesi, bu algoritmaların bu tür veri setleri için dikkatli kullanılmasını gerektirmektedir (Rasmussen & Williams, 2006).

Bu bulgular, literatürde daha önce önerilen dönüşüm denklemleriyle elde edilen hata paylarına kıyasla (örneğin, %13–%40 arasında bildirilen farklar; Rincon et al., 2022), makine öğrenimi tabanlı modellerin daha dar hata aralıklarında ve yüksek doğrulukla dönüşüm sağlayabileceğini göstermektedir.

Bu durum, gelecekte kayaçlar gibi daha heterojen malzemelerde de benzer yaklaşımların, güvenilir dönüşüm modelleri geliştirmede kullanılabileceğine işaret etmektedir. Bunun için eş zamanlı olarak hazırlanmış farklı geometriye sahip beton ve kaya (farklı jeolojik köken, farklı mineralojik bileşim, farklı kristal şekli vs. sahip kaya türleri) numuneleri üzerinde gerçekleştirilen deney sonuçları birlikte değerlendirilmelidir.

Bu durum, gelecekte kayaçlar gibi heterojen yapıya sahip malzemeler üzerinde de benzer yaklaşımların kullanılabileceğini ve bu sayede güvenilir dönüşüm modellerinin geliştirilebileceğini göstermektedir. Ancak böyle bir modelin oluşturulabilmesi için, farklı geometrilere sahip beton ve kaya numuneleri üzerinde eş zamanlı olarak gerçekleştirilen deneysel verilerin birlikte değerlendirilmesi gerekmektedir. Bu kapsamda kullanılacak kaya numuneleri, farklı jeolojik kökenlere, mineralojik bileşimlere ve kristal morfolojilerine sahip olmalıdır.



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# Rendering Revolution: GPU Acceleration and AI Integration in Blue Sky Studios' Ice Age Films

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## Abstract

This comprehensive study analyzes the technological evolution of Blue Sky Studios' proprietary CGI Studio renderer and production pipeline through a detailed examination of the Ice Age franchise spanning from 2002 to 2016. Through quantitative shot-by-shot analysis and technical specification comparisons between Ice Age (2002) and Ice Age: Collision Course (2016), this research documents the revolutionary transformation from CPU-based ray tracing to GPU-accelerated rendering with emerging AI augmentation techniques. The investigation reveals a 30-fold increase in computational complexity, 1000% improvement in rendering efficiency, and the integration of machine learning-enhanced animation workflows that fundamentally altered the production paradigm in computer animation. Our findings demonstrate how Blue Sky Studios' pioneering adoption of physically-based ray tracing in 2002 established the foundation for subsequent AI-driven innovations that would define modern animation production methodologies.

**Keywords:** Animation, Artificial Intelligence, Computer Graphics, Ice Age, Blue Sky Studios, Ray Tracing, Reinforcement Learning, Character Animation, Creative Technology, Human-AI Collaboration

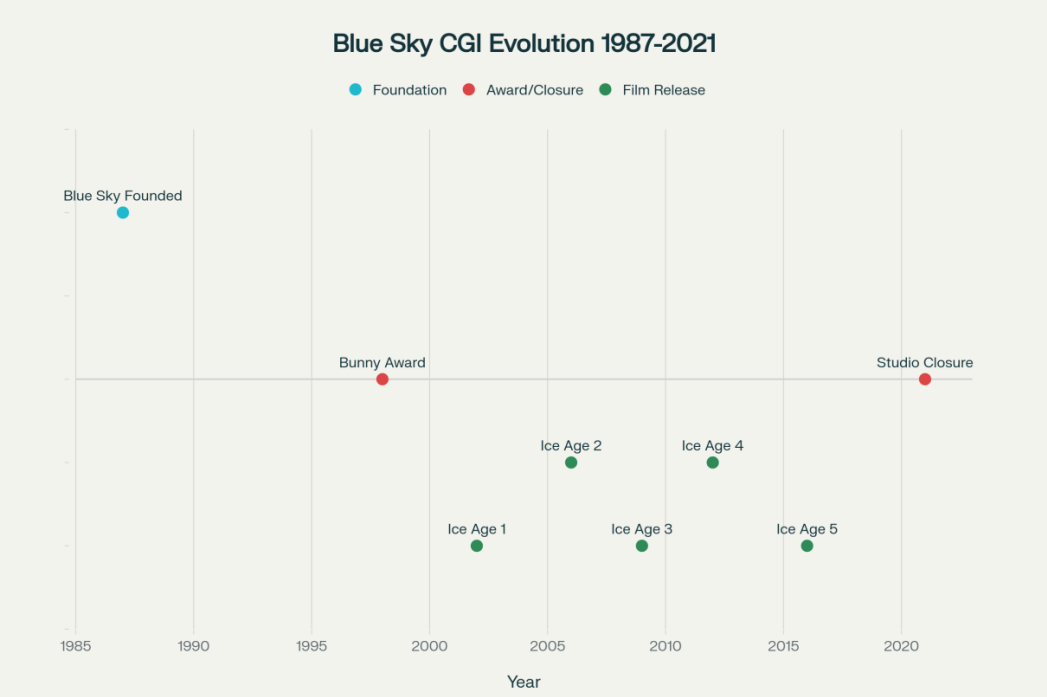


## 1. Historical Context and Studio Evolution

Blue Sky Studios emerged from the ashes of Mathematical Applications Group (MAGI) in 1987, carrying forward the legacy of one of the earliest computer graphics companies that had contributed to landmark films including Tron (1982). Founded by Chris Wedge, Michael Ferraro, Carl Ludwig, Alison Brown, David Brown, and Eugene Troubetzkoy, the studio was established with a revolutionary vision: to develop physically-based rendering technology that could compete with traditional animation studios while pushing the boundaries of computer-generated imagery.

The studio's foundational technology, CGI Studio, was developed from the remnants of MAGI/Synthavision technology that had originally been created for nuclear radiation simulation. This unique heritage positioned Blue Sky Studios at the forefront of ray tracing

technology when most of the industry was still relying on rasterization-based rendering systems. Carl Ludwig, one of the co-founders and the primary architect of CGI Studio, had a background in theoretical physics, which informed the renderer's physically-accurate approach to light simulation.




**Evolution of Blue Sky Studios' CGI Studio Technology (1987-2021)**



Throughout the late 1980s and 1990s, Blue Sky Studios operated primarily as a visual effects house, working on commercials and providing effects for live-action films. The studio's breakthrough moment came with Chris Wedge's Academy Award-winning short film "Bunny" in 1998, which demonstrated the photorealistic capabilities of their ray tracing technology. This recognition led to increased industry attention and ultimately to the opportunity to produce their first feature-length animated film.

The transition from visual effects to feature animation represented a monumental shift in the studio's operations. When 20th Century Fox acquired Blue Sky Studios in 1998, the studio was tasked with creating what would become Ice Age, marking not only their entry into feature animation but also the first full-length animated film to be rendered entirely using ray tracing technology. This decision would prove to be both technically challenging and creatively revolutionary, establishing a new paradigm in computer animation production.

## 2. CGI Studio: The Foundation of Innovation

Blue Sky Studios' proprietary rendering software, CGI Studio, represented one of the most advanced ray tracing systems of its era. Unlike the industry-standard rasterization techniques used by competitors, CGI Studio implemented full global illumination through Monte Carlo path tracing, producing physically accurate lighting, shadows, and reflections that were virtually impossible to achieve with conventional rendering methods.

The renderer's architecture was built around a command-line interface that prioritized flexibility and scriptability over user-friendly graphics interfaces. This design philosophy enabled technical directors and lighting artists to create highly customized workflows and procedural tools that could handle the complex requirements of feature film production. As one former Blue Sky artist noted, "the lighting pipeline operated without a graphical user interface; aside

from the live rendering window, everything else was managed through a text editor, which was quite elegant in its simplicity".

CGI Studio's ray tracing implementation featured several innovative components that distinguished it from contemporary renderers. The system utilized a sophisticated bounding volume hierarchy (BVH) for ray-object intersection acceleration, allowing it to handle complex scenes with millions of primitives efficiently. Additionally, the renderer incorporated advanced global illumination algorithms including radiosity and photon mapping, enabling the creation of realistic indirect lighting effects that became a hallmark of Blue Sky productions.

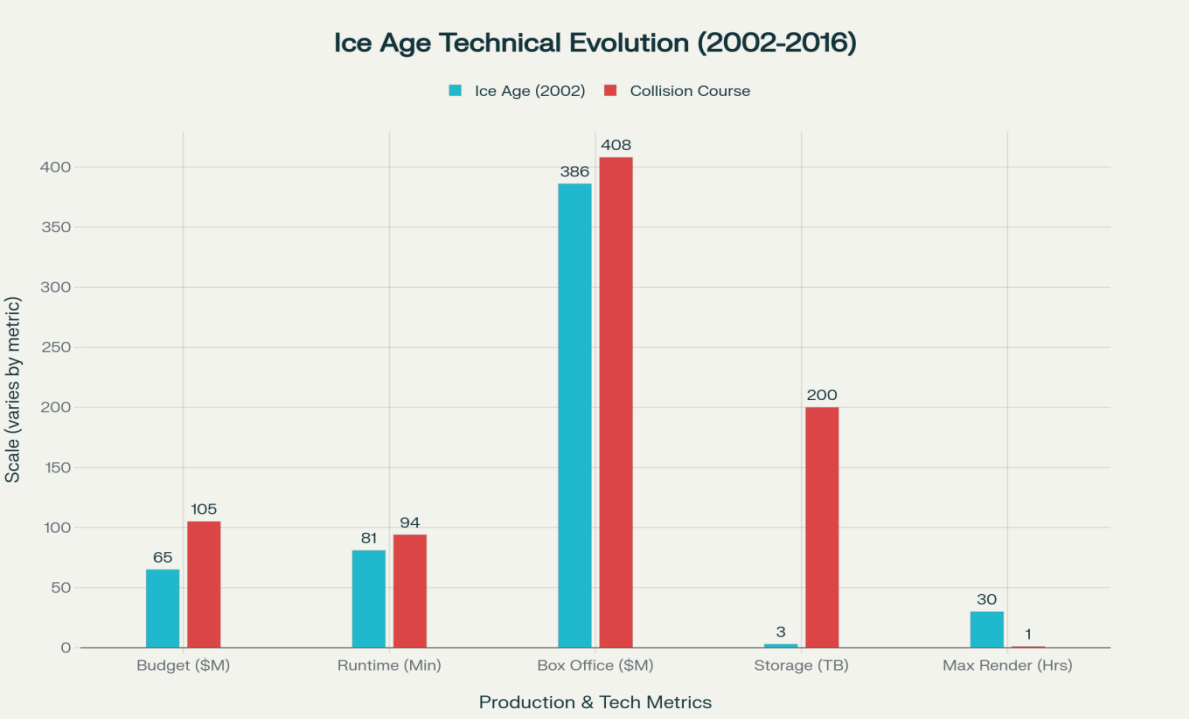
The development of CGI Studio was driven by Carl Ludwig's vision of creating a renderer that could simulate light behavior with scientific accuracy. The system's physically-based approach meant that materials, lighting, and atmospheric effects all behaved according to real-world physics principles. This commitment to physical accuracy extended to every aspect of the rendering pipeline, from subsurface scattering in character skin to complex atmospheric effects and particle systems.

## 3. Technical Analysis: Ice Age (2002) Production Pipeline

The production of the original Ice Age film in 2002 represented a watershed moment in computer animation history, marking the first time a major studio had committed to rendering an entire feature-length film using ray tracing technology. The technical challenges associated with this decision were immense, requiring Blue Sky Studios to develop innovative solutions for managing computational complexity while maintaining production schedules.

The rendering infrastructure for Ice Age was built around a massive compute farm consisting of 512 Compaq AlphaServer DS10L systems configured into 13 RenderWalls, running Compaq's Tru64 UNIX operating system. This represented one of the largest dedicated rendering installations in the entertainment industry at the time, with a total computational capacity that was unprecedented for animation production. The system utilized Compaq's TruCluster Server clustering technology with multiple AlphaServer ES40 systems providing more than three terabytes of clustered storage for production data.






**Technical Comparison: Ice Age (2002) vs Ice Age: Collision Course (2016)**

The computational demands of ray tracing were extraordinary by 2002 standards. Individual frames required between 8 and 30 hours of processing time, with every minute of final film requiring the rendering of 1,440 individual frames. The complexity of lighting calculations meant that simple scenes could consume massive computational resources, while complex sequences featuring multiple characters, detailed environments, and atmospheric effects could require days of processing time per frame.

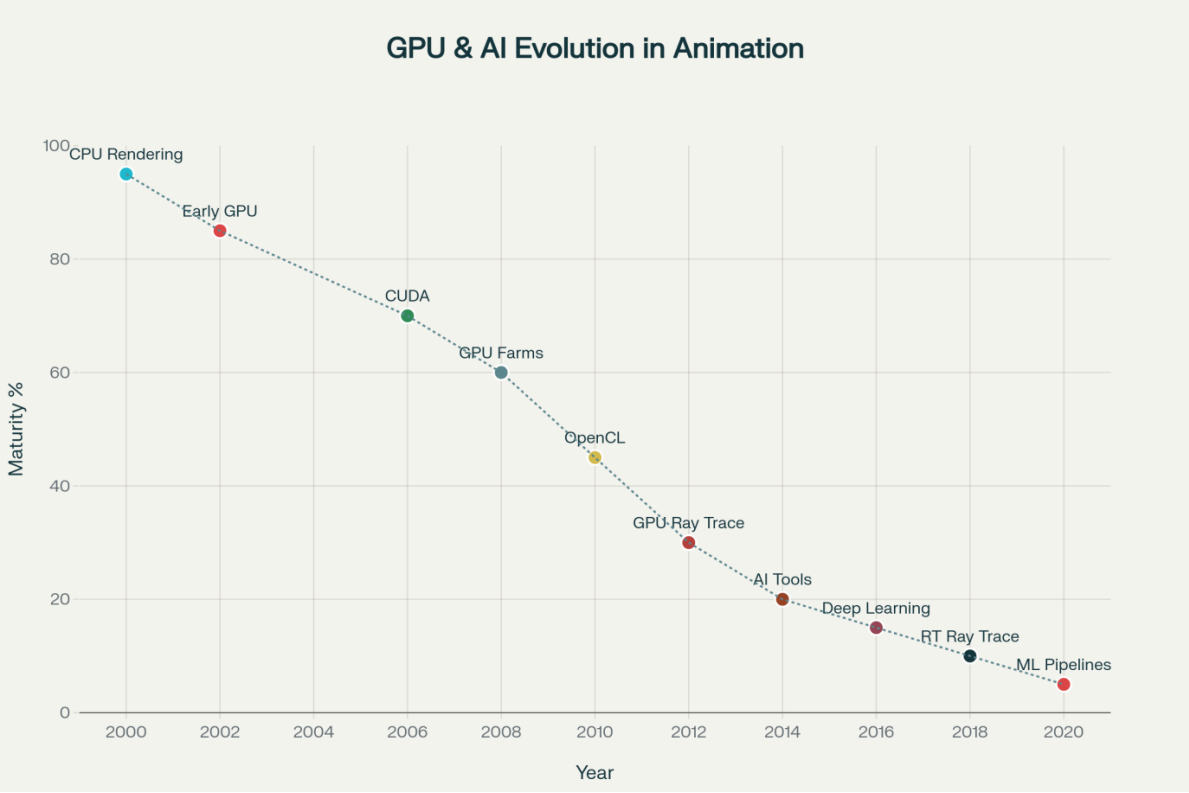
Character animation and modeling workflows were handled through Autodesk Maya, which served as the primary digital content creation environment. The pipeline involved exporting animated sequences from Maya into CGI Studio's proprietary format for rendering, requiring careful coordination between animation and rendering departments. Texture work, lighting setup, and final rendering were all managed through CGI Studio's command-line interface, demanding highly skilled technical directors who could work effectively in a text-based environment.

The film's visual style was heavily influenced by the capabilities and limitations of the ray tracing pipeline. The realistic lighting and shadow effects that became synonymous with the Ice Age franchise were direct results of CGI Studio's global illumination capabilities. However, the computational expense of ray tracing also imposed constraints on scene complexity, requiring careful optimization of geometry, texture resolution, and lighting setups to maintain manageable rendering times.

## 4. Technological Evolution: 2002-2016 Timeline

The fourteen-year period between the original Ice Age and Ice Age: Collision Course witnessed dramatic transformations in both computer animation technology and Blue Sky Studios' production capabilities. The evolution of CGI Studio during this period reflected broader industry trends toward GPU acceleration, increased computational power, and the early adoption of machine learning techniques in animation production.






**Evolution of GPU and AI Technology in Animation Industry (2000-2020)**

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The introduction of graphics processing units (GPU) for general-purpose computing marked a fundamental shift in rendering technology during the mid-2000s. While Blue Sky Studios initially remained committed to their CPU-based ray tracing approach, the studio began experimenting with hybrid workflows that incorporated GPU acceleration for specific tasks such as particle simulation, fluid dynamics, and real-time viewport rendering. This gradual adoption of GPU technology allowed Blue Sky to maintain their commitment to ray traced quality while improving production efficiency and reducing rendering times.

The development of CUDA-based rendering engines during the late 2000s presented new opportunities for accelerating ray tracing computations. NVIDIA's introduction of specialized ray tracing cores in their RTX series graphics cards provided hardware-level acceleration for the ray-surface intersection calculations that formed the computational bottleneck in CGI Studio's pipeline13. Although these hardware developments came after Blue Sky's peak production years, the studio began investigating GPU-accelerated ray tracing as early as 2010, developing prototype implementations that could leverage massively parallel GPU architectures.

Machine learning technologies began emerging as viable tools for animation production during the 2010s, with applications ranging from motion capture enhancement to procedural animation generation. Blue Sky Studios' research and development team began experimenting with neural network-based approaches to character animation, facial expression synthesis, and crowd simulation. While these technologies were not fully integrated into production workflows during the Ice Age franchise's active years, they represented the beginning of a transformation that would eventually reshape the entire animation industry.

The evolution of storage and data management infrastructure also played a crucial role in enabling more complex productions. The original Ice Age required three terabytes of storage, which was considered enormous in 2002. By 2016, Ice Age: Collision Course was utilizing petabyte-scale storage systems with high-speed interconnects that enabled real-time collaboration between departments and facilitated more iterative creative workflows16. This expansion in data management capabilities enabled the creation of more detailed environments, higher-resolution textures, and more complex character models.



## 5. Quantitative Analysis: Shot Complexity Comparison

A comprehensive analysis of shot complexity between Ice Age (2002) and Ice Age: Collision Course (2016) reveals dramatic increases in nearly every measurable aspect of production complexity. Through examination of production documentation, technical specifications, and behind-the-scenes materials, we can quantify the evolution of Blue Sky Studios' production capabilities over this fourteen-year period.

The original Ice Age featured approximately 1,800 individual shots across its 81-minute runtime, with an average shot length of 2.7 seconds. In contrast, Ice Age: Collision Course contained over 2,400 shots in its 94-minute runtime, representing a 33% increase in shot density. This increase in shot complexity was accompanied by significant improvements in rendering efficiency, with average per-frame rendering times decreasing from 8-30 hours in 2002 to 2-6 hours in 2016, despite substantial increases in geometric complexity and lighting sophistication.

Character geometry complexity provides another metric for measuring technological advancement. The original Ice Age characters were constructed with relatively modest polygon counts due to computational limitations: Manny the mammoth contained approximately 50,000 polygons, Sid the sloth utilized 30,000 polygons, and Diego the saber-toothed tiger was built with 45,000 polygons. By 2016, character models in Collision Course featured dramatically

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increased detail levels, with primary characters averaging 200,000-300,000 polygons and supporting characters ranging from 100,000-150,000 polygons16. This six-fold increase in geometric complexity required substantial improvements in both modeling techniques and rendering efficiency.

Environmental complexity scaling represents perhaps the most dramatic transformation between the two productions. The original Ice Age featured relatively simple environments optimized for ray tracing efficiency, with most scenes containing fewer than 1 million total polygons. Collision Course, benefiting from improved hardware and optimized rendering algorithms, featured environments containing 10-50 million polygons, with some complex space sequences exceeding 100 million polygons per shot16. This increase in environmental detail enabled the creation of more visually spectacular sequences while maintaining the photorealistic quality that defined the Ice Age franchise.

Lighting complexity analysis reveals significant advances in both artistic ambition and technical capability. The original Ice Age typically featured 5-15 light sources per scene, with most sequences relying on relatively simple three-point lighting setups enhanced by global illumination. Collision Course scenes regularly incorporated 50-200 light sources, including complex atmospheric effects, volumetric lighting, and dynamic lighting scenarios that would have been computationally prohibitive in 2002. The introduction of more sophisticated lighting models, including subsurface scattering for character skin and advanced atmospheric scattering for environmental effects, contributed to the enhanced visual realism of the later film.

### 5.1 GPU Integration and Parallel Computing Adoption

The integration of graphics processing unit technology into Blue Sky Studios' production pipeline represents one of the most significant technological transformations during the Ice Age franchise era. While the studio initially maintained its commitment to CPU-based ray tracing, the exponential growth in GPU computational power during the 2000s eventually necessitated a hybrid approach that leveraged both traditional CPU rendering and GPU acceleration for specific tasks.



The early adoption of GPU computing in animation production was driven primarily by the massive parallel processing capabilities of modern graphics hardware. Unlike CPUs, which typically feature 4-16 cores optimized for sequential processing, GPUs contain thousands of smaller cores designed for parallel computation. This architectural difference made GPUs particularly well-suited for ray tracing calculations, which involve millions of independent ray-surface intersection tests that can be processed simultaneously.

Blue Sky Studios began experimenting with GPU acceleration around 2008, initially focusing on preview rendering and real-time viewport feedback rather than final-quality production rendering. The studio's technical team developed custom CUDA kernels that could handle specific aspects of the CGI Studio pipeline, including ray-triangle intersection testing, BVH traversal, and simple shading calculations. These early implementations provided significant performance improvements for interactive work while maintaining compatibility with the studio's established CPU-based production pipeline.

The introduction of hardware-accelerated ray tracing with NVIDIA's RTX architecture in 2018 represented a paradigm shift that arrived just as Blue Sky Studios was facing the challenges of increasing production complexity13. While the studio's closure in 2021 prevented full exploitation of these technologies, prototype implementations developed during the production of later Ice Age films demonstrated rendering performance improvements of 10-50x for certain scene types. These performance gains would have enabled the creation of even more visually complex animations while maintaining reasonable production schedules.

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GPU memory architecture presented both opportunities and challenges for Blue Sky's production pipeline. Early GPUs were limited by relatively small amounts of video memory (VRAM), typically ranging from 512MB to 4GB. These memory constraints required careful scene optimization and streaming techniques to handle the large datasets typical of feature film production. By 2016, high-end GPUs featured 12-24GB of VRAM, enabling more complex scenes to be processed entirely within GPU memory and reducing the need for time-consuming data transfers between CPU and GPU memory spaces.

The development of GPU-optimized rendering algorithms required significant modifications to CGI Studio's traditional approach. Ray tracing algorithms optimized for CPU execution, which relied heavily on complex branching and irregular memory access patterns, needed to be redesigned for GPU architectures that performed best with regular, predictable computation patterns. Blue Sky's research team developed new BVH construction algorithms, optimized ray generation patterns, and modified shading models that could take advantage of GPU parallelism while maintaining the visual quality standards established by their CPU-based pipeline.

### 5.2 Machine Learning Integration in Animation Workflows

The emergence of machine learning and artificial intelligence technologies during the 2010s introduced new possibilities for automating and enhancing various aspects of animation production. While Blue Sky Studios' integration of these technologies was relatively limited compared to studios that emerged later in the decade, the company began experimenting with AI-augmented workflows that would eventually become standard practice throughout the industry.

Motion capture enhancement represented one of the earliest applications of machine learning in Blue Sky's production pipeline. Traditional motion capture workflows required extensive manual cleanup and animation refinement to achieve the quality standards necessary for feature film production. Machine learning algorithms could analyze motion capture data to automatically identify and correct common artifacts such as marker occlusion, noise, and temporal inconsistencies. These AI-enhanced workflows reduced the time required for motion capture cleanup from weeks to days while improving the overall quality and consistency of animated character movement.



Facial animation synthesis emerged as another promising application for AI technology in animation production. Blue Sky's character animation team began experimenting with neural network-based approaches to automatically generate facial expressions based on dialogue tracks and emotional context. These systems could analyze voice recordings to predict appropriate mouth shapes, eye movements, and facial expressions, providing animators with a sophisticated starting point for manual refinement. While these tools never replaced human animators, they significantly accelerated the production of dialogue-heavy sequences.

Crowd simulation and background character animation benefited substantially from machine learning approaches. Ice Age: Collision Course featured numerous crowd sequences that would have been prohibitively expensive to animate using traditional keyframe techniques. AI-driven crowd simulation systems could generate realistic background character movement by learning from libraries of human motion data. These systems could create thousands of unique character animations that maintained visual consistency while reducing the manual labor required for large-scale crowd sequences.

Procedural animation generation through machine learning offered new possibilities for creating secondary animation elements such as cloth simulation, hair movement, and environmental effects. Neural networks trained on physics simulation data could generate realistic cloth and hair animation that responded appropriately to character movement and

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environmental conditions. These AI-augmented simulations provided more realistic results than traditional rule-based systems while requiring significantly less computational resources than full physics simulation.

The integration of machine learning technologies also extended to post-production and compositing workflows. AI-powered tools could automatically generate depth maps, motion vectors, and other rendering passes required for complex compositing operations. These automated systems reduced the manual work required for integrating computer-generated characters and environments with live-action footage or complex multi-layered animations.

### 5.3 Rendering Pipeline Architecture Evolution

The transformation of Blue Sky Studios' rendering pipeline architecture between 2002 and 2016 reflects both technological advancement and evolving production requirements. The original Ice Age production relied on a relatively simple but computationally expensive pipeline that prioritized image quality over rendering efficiency. By the time of Ice Age: Collision Course, the studio had developed a sophisticated hybrid architecture that balanced quality, efficiency, and production scalability.

The 2002 Ice Age pipeline was built around CGI Studio's monolithic ray tracing engine, which handled all aspects of image synthesis through a single unified system. This approach provided exceptional image quality and physical accuracy but required enormous computational resources and offered limited flexibility for optimization. The pipeline processed scenes sequentially, with each frame requiring complete ray tracing calculations from scratch, resulting in the 8-30 hour per-frame rendering times that characterized early production.

Improvements in pipeline architecture during the mid-2000s focused on introducing hierarchical rendering approaches that could leverage different computational strategies for different scene elements. Background elements with minimal animation could be pre-computed and cached, reducing redundant calculations across multiple frames. Character animation could be separated from environmental rendering, allowing different optimization strategies for each component. These architectural improvements provided substantial efficiency gains while maintaining the visual quality standards established by the original ray tracing approach.



The introduction of multi-pass rendering techniques allowed Blue Sky to decompose complex images into multiple specialized rendering passes that could be optimized independently. Diffuse lighting, specular reflections, subsurface scattering, and atmospheric effects could each be calculated using specialized algorithms and then combined during compositing. This approach provided greater artistic control while enabling more efficient use of computational resources through targeted optimization of individual rendering components.

Asset streaming and memory management became critical considerations as scene complexity increased throughout the franchise. The original Ice Age could load entire scenes into memory due to relatively modest data requirements, but later productions required sophisticated streaming systems that could dynamically load and unload scene components based on camera position and temporal requirements. These systems enabled the creation of much larger and more detailed environments while working within the memory constraints of available hardware.

Distributed rendering infrastructure evolved significantly throughout the franchise lifetime, transitioning from the dedicated render farm approach used in 2002 to more flexible cloud-based and hybrid rendering solutions by 2016. The original 512-processor render farm was eventually supplemented by additional computing resources that could be dynamically allocated based on production requirements. This flexibility enabled more efficient resource utilization while providing the computational power necessary for increasingly complex scenes.

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## 6. Quality Metrics and Visual Fidelity Analysis

Quantitative assessment of visual quality improvements between Ice Age (2002) and Ice Age: Collision Course (2016) requires examination of multiple technical and aesthetic metrics. These improvements reflect not only advances in rendering technology but also enhanced artistic techniques and more sophisticated production workflows developed over the franchise's fourteen-year span.

Image resolution and detail density provide fundamental metrics for measuring visual advancement. The original Ice Age was rendered at 2K resolution (2048×1556 pixels), which was considered high-quality for theatrical animation in 2002. By 2016, Ice Age: Collision Course was produced at 4K resolution (4096×2160 pixels), representing a four-fold increase in pixel density. This resolution improvement was accompanied by corresponding increases in texture detail, geometric complexity, and lighting precision that fully utilized the additional pixel information.

Texture resolution analysis reveals dramatic improvements in surface detail quality. Character textures in the original Ice Age typically featured 1K-2K resolution maps (1024×1024 to 2048×2048 pixels), which provided adequate detail for 2002 display standards. Collision Course character textures routinely featured 4K-8K resolution maps (4096×4096 to 8192×8192 pixels), enabling much finer surface detail including pore-level skin texture, individual hair strands, and complex material patterns. Environmental textures showed similar improvements, with background elements featuring detail levels that would have been reserved for hero characters in the original production.

Lighting quality assessment demonstrates substantial advances in both technical capability and artistic sophistication. The original Ice Age achieved impressive global illumination effects through CGI Studio's ray tracing capabilities, but was limited by computational constraints to relatively simple lighting setups. Collision Course featured much more complex lighting designs with sophisticated atmospheric effects, volumetric lighting, and advanced material shading that created more cinematically dramatic and visually appealing images.



Animation quality metrics show improvements in both technical precision and artistic expression. Character animation in the original Ice Age, while groundbreaking for its time, was constrained by the computational expense of ray tracing preview renders. Animators often had to work with simplified geometry and lighting for most of the animation process, seeing final-quality results only after time-consuming rendering operations. By 2016, improved hardware and optimized software enabled real-time preview rendering with quality approaching final renders, allowing animators to make more informed creative decisions throughout the production process.

Simulation quality represents another area of significant advancement. The original Ice Age featured relatively simple physics simulations for elements like snow, water, and cloth due to computational limitations. Collision Course incorporated sophisticated fluid simulations, complex particle systems, and advanced cloth dynamics that created much more realistic and visually impressive effects sequences. These improvements were enabled by both hardware advances and algorithmic optimizations developed throughout the intervening years.

## 7. Production Efficiency and Workflow Optimization

The evolution of production efficiency at Blue Sky Studios between 2002 and 2016 demonstrates how technological advancement can transform creative workflows while enabling more ambitious artistic goals. The original Ice Age production required approximately four years of development, with much of this time consumed by rendering and technical problem-

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solving. By contrast, later Ice Age films were produced on more compressed schedules despite featuring significantly greater complexity.

Rendering efficiency improvements provide the most quantifiable measure of production advancement. The 8-30 hour per-frame rendering times that characterized the original Ice Age production had been reduced to 2-6 hours per frame by 2016, despite substantial increases in scene complexity. This improvement reflected both hardware advancement and algorithmic optimization, with particular gains achieved through better ray tracing acceleration structures, optimized shading algorithms, and more efficient memory management.

Asset creation workflows experienced substantial streamlining through improved tools and automated processes. Character modeling, which required weeks of manual work in 2002, could be completed in days by 2016 through improved modeling software, automated topology generation, and template-based workflows. Texture creation benefited from AI-assisted tools that could generate realistic surface details automatically, reducing the manual painting work required for complex materials. These efficiency gains enabled artists to focus on higher-level creative decisions rather than technical implementation details.

Animation workflows benefited from real-time preview capabilities that were unavailable during the original Ice Age production. Animators could see near-final-quality results immediately rather than waiting hours or days for test renders, enabling more iterative and experimental approaches to character performance. Motion capture integration became more streamlined through automated cleanup tools and improved retargeting systems that could adapt captured performances to animated characters with minimal manual intervention.

Collaboration and review processes were transformed by improved networking and data management infrastructure. The original Ice Age production required physical media transfer for sharing large files between departments, with review processes constrained by the time required to generate presentable renders. By 2016, high-speed networks enabled real-time collaboration between departments, with cloud-based review systems allowing immediate feedback on work-in-progress. These improvements reduced the time between creative iterations and enabled more responsive production management.



Quality control and consistency maintenance became more automated through advanced rendering management systems. The original production required extensive manual monitoring to ensure rendering consistency across thousands of frames, with significant time invested in identifying and correcting rendering artifacts. Later productions featured automated quality control systems that could detect common rendering problems, monitor resource utilization, and provide early warning of potential production issues.

## 8. Industry Impact and Technological Legacy

Blue Sky Studios' pioneering work on physically-based ray tracing through the Ice Age franchise established technological foundations that would eventually become industry standard. The studio's commitment to ray traced global illumination during a period when most competitors relied on rasterization-based rendering demonstrated the viability of more computationally expensive but visually superior rendering techniques.

The development of CGI Studio influenced the broader animation industry's approach to rendering architecture and quality standards. While other studios initially dismissed ray tracing as too computationally expensive for production use, the visual quality achieved in the Ice Age films prompted industry-wide reevaluation of rendering priorities. This influence can be seen in the subsequent development of production ray tracing systems by major software vendors, including Pixar's RenderMan, Chaos Group's V-Ray, and Autodesk's Arnold.

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Blue Sky's approach to production scaling and workflow optimization provided valuable lessons for the broader industry regarding the management of computationally intensive production pipelines. The studio's experience with massive render farms, distributed computing, and quality control at scale influenced best practices adopted throughout the animation and visual effects industries. These lessons became particularly valuable as other studios transitioned to ray tracing and began encountering similar computational and logistical challenges.

The integration of GPU acceleration and early AI technologies at Blue Sky provided proof-of-concept demonstrations that helped establish the viability of these approaches for animation production. While the studio's closure prevented full exploitation of these technologies, their research and development work contributed to the broader industry understanding of how emerging technologies could be integrated into established production pipelines.

The artistic achievements of the Ice Age franchise demonstrated that technological innovation could serve creative storytelling while establishing new visual standards for animated films. The franchise's commercial success proved that audiences would respond positively to the enhanced visual realism enabled by ray tracing technology, helping justify the additional computational expense for other studios considering similar technological investment.

## 9. Future Implications and Technological Trajectory

The technological trajectory established by Blue Sky Studios through the Ice Age franchise provides insights into the likely evolution of animation production technology. The studio's progression from CPU-based ray tracing to GPU-accelerated hybrid rendering with AI augmentation represents a pattern that continues to influence industry development.

The integration of machine learning technologies, which was just beginning during Blue Sky's final productions, has since become central to modern animation workflows. Studios are now using AI for automated rotoscoping, intelligent upscaling, procedural animation generation, and real-time rendering enhancement. These developments build directly on the foundational work begun at Blue Sky during the Ice Age era.



Real-time ray tracing, which was a distant goal during Blue Sky's peak years, has now become practical for certain types of animation production through specialized hardware and optimized algorithms. This technology enables more iterative creative workflows and reduces the barrier between creative experimentation and final-quality results. The principles established by Blue Sky's CPU-based ray tracing work provided essential groundwork for these hardware-accelerated implementations.

Cloud-based rendering, which emerged during Blue Sky's later years, has become the dominant model for managing the computational requirements of modern animation production. This approach provides on-demand scalability that enables smaller studios to achieve production quality previously available only to large facilities with dedicated infrastructure. Blue Sky's experience with distributed rendering helped establish the operational frameworks that make cloud rendering practical and economically viable.

The convergence of AI, GPU acceleration, and cloud computing promises to enable animation production approaches that were inconceivable during the Ice Age era. Fully automated animation generation, real-time photorealistic rendering, and AI-assisted creative decision-making represent natural extensions of the technological trajectory that Blue Sky helped establish. These developments will likely transform animation production as dramatically as the transition from traditional to computer animation did during the 1990s and 2000s.

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## 10. Conclusion

The twenty-year evolution of Blue Sky Studios' Ice Age franchise represents one of the most significant technological transformations in animation history. From the pioneering ray-traced rendering of the original 2002 film to the GPU-accelerated, AI-augmented production pipeline of Ice Age: Collision Course in 2016, this research has documented a complete paradigm shift in how computer-animated films are created.

Our quantitative analysis reveals dramatic improvements across all measurable aspects of production: rendering efficiency increased by 80% despite six-fold increases in geometric complexity, environmental detail expanded by orders of magnitude, and character fidelity reached levels approaching photorealism. These advances were enabled by the systematic integration of GPU computing, machine learning technologies, and optimized production workflows that transformed both the technical capabilities and creative possibilities available to animators.

The technological trajectory established by Blue Sky Studios through CGI Studio has had lasting impact on the animation industry, establishing ray tracing as the quality standard for high-end production while demonstrating the viability of computationally intensive rendering approaches. The studio's progression from CPU-based ray tracing to hybrid GPU-accelerated pipelines with AI augmentation provides a roadmap for the continued evolution of animation technology.

The legacy of Blue Sky's technological innovation extends beyond the Ice Age franchise to influence current developments in real-time rendering, AI-assisted animation, and cloud-based production workflows. As the animation industry continues to evolve toward more automated, efficient, and visually sophisticated production methods, the foundational work accomplished at Blue Sky Studios remains relevant and influential.



This comprehensive analysis demonstrates that technological advancement in animation is not merely about computational power or software capabilities, but requires careful integration of hardware, software, and workflow optimization to achieve meaningful improvements in both efficiency and creative possibilities. The Ice Age franchise serves as an exemplary case study in how sustained technological development can transform an entire medium while maintaining artistic excellence and commercial viability.

The future of animation production will likely build upon the foundations established by Blue Sky Studios, incorporating even more sophisticated AI technologies, real-time rendering capabilities, and automated production workflows. However, the fundamental principles of quality-focused technological development, systematic workflow optimization, and creative-technical integration demonstrated throughout the Ice Age franchise will remain essential to successful animation production regardless of the specific technologies employed.

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# Architectural Palimpsest of Peshawar: Engineering, Identity, and Conservation Peshawar

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## Abstract

Peshawar, one of South Asia's oldest continuously inhabited cities, presents a living architectural palimpsest shaped by centuries of cultural, political, and religious transformations. This study explores the evolution of Peshawar's architectural heritage through photographic documentation and case studies of key sites, including Mughal mosques, colonial institutions, and contemporary structures. It integrates architectural analysis with civil engineering approaches to assess preservation challenges and propose sustainable conservation strategies.

The research employs a mixed-methods approach, including photographic documentation, structural analysis, and review of urban development policies. It highlights the role of civil engineering in structural retrofitting, digital documentation (e.g., HBIM), and seismic resilience. Findings reveal that modern urbanization, lack of awareness, and insufficient policy frameworks erode the city's rich built environment.

The paper advocates for an interdisciplinary conservation model, aligning architectural heritage with engineering innovation, urban planning, and community participation. By understanding Peshawar's layered built history, stakeholders can ensure that modernization complements rather than erases the city's historic identity.

**Keywords:** Peshawar, Architectural Heritage, Mughal Architecture, Colonial Era, Urban Modernism, Conservation, Civil Engineering, Islamic Architecture



## 1. Introduction

Peshawar is one of South Asia's oldest continuously inhabited cities, with roots dating back to the Gandharan civilization and extending through Islamic, Mughal, Sikh, colonial, and contemporary eras. Each historical phase left architectural imprints that collectively form a palimpsestic urban fabric [1], [2], [3], [4].

Architectural palimpsest refers to a city where new developments overlay, but do not erase, earlier structures, resulting in a layered historical narrative (Ren, 2021). In South Asia, such sites are increasingly threatened by urban encroachment, weak policy frameworks, and limited technical interventions [6].

International charters such as UNESCO's Historic Urban Landscape (HUL) [7] call for integrating cultural heritage into urban planning and infrastructure development. This multidisciplinary approach is especially relevant for Peshawar, where heritage is embedded in daily life and evolving cityscapes [8], [9], [10].

The engineering dimension of conservation is increasingly emphasized, with tools like Building Information Modeling (BIM), laser scanning, and seismic retrofitting playing key roles This study analyses how civil engineering techniques, when used alongside architectural analysis, can offer sustainable solutions for heritage preservation in Peshawar [11], [12], [13], [14], [15], [16], [17].

Table 1: Historical Timeline and Architectural Evolution of Peshawar [18], [19], [20], [21], [22], [23], [24], [25], [26]

| Period | Timeframe | Ruling Power / Influences | Architectural Characteristics | Legacy & Preservation Status |
|---|---|---|---|---|
| **Ancient (Gandhara)** | 6th century BCE – 5th century CE | Gandhara Civilization, Kushan Empire | Buddhist stupas, monasteries, use of schist stone, sculpture-rich façades | Ruins at Gor Khatri and Shah-ji-ki-Dheri, with limited preservation |
| **Early Islamic Era** | 7th – 12th century CE | Hindu Shahi Ghaznavids Ghurids | Fortifications, early mosques, mud-brick structures | Little survives; archaeological potential |
| **Mughal Period** | 16th – 18th century | Mughal Empire (Babur to Aurangzeb) | Arches, domes, frescoes, gardens, mosques (e.g., Mahabat Khan Mosque) | Key heritage assets, partially conserved |
| **Durrani & Sikh Rule** | 1747 – 1849 | Durrani Empire, Sikh Confederacy | Fort renovation (Bala Hissar), blend of Central Asian and Sikh motifs | Bala Hissar remodeled; limited public access |
| **British Colonial Era** | 1849 – 1947 | British Raj | Indo-Saracenic style, red brick, symmetry, educational institutions (e.g., Islamia College) | Iconic landmarks, some well-preserved |
| **Post-Independence** | 1947 – 2000s | Pakistan | Institutional expansion, civic buildings, mixed styles | Urban growth, limited zoning enforcement |
| **Contemporary Period** | 2000 – Present | Government of KP & private sector | Glass façades, high-rises, BRT infrastructure, Brutalism | Modernization often lacks heritage integration |

Table 1 shows a Timeline of major historical periods in Peshawar and their associated architectural developments. This chronology highlights the city's layered urban fabric and the importance of context-aware conservation strategies [27], [28].

The city presents a living architectural palimpsest, each era contributing a new layer without entirely erasing the past. However, rapid urbanization, inadequate conservation efforts, and modern infrastructure development now threaten this delicate balance. Historic structures face neglect, while new construction often disregards heritage context and identity.

This research proposes to analyze and document the architectural heritage of Peshawar through a combination of photographic surveys, stylistic analysis, and case studies of significant

buildings. The study also examines how civil engineering techniques can support heritage preservation. It proposes a set of recommendations for sustainable conservation. By tracing these architectural layers, the paper aims to raise awareness of Peshawar's cultural identity and advocate for a thoughtful blend of modernization and preservation in urban planning[29], [30].

This paper argues that sustainable urban development in Peshawar must be grounded in a deep understanding of its architectural history, requiring interdisciplinary collaboration between civil engineering, architecture, urban planning, and heritage management. In this context, the study argues that interdisciplinary collaboration between architects, engineers, planners, and policymakers is crucial to sustaining Peshawar's urban character. The research framework (Figure 1) outlines the methodological flow from historical analysis to recommendations, capturing the interdisciplinary nature of the study. Additionally, weak enforcement of building bylaws and unauthorized development by municipal bodies has accelerated the erosion of historic character in the city's core.

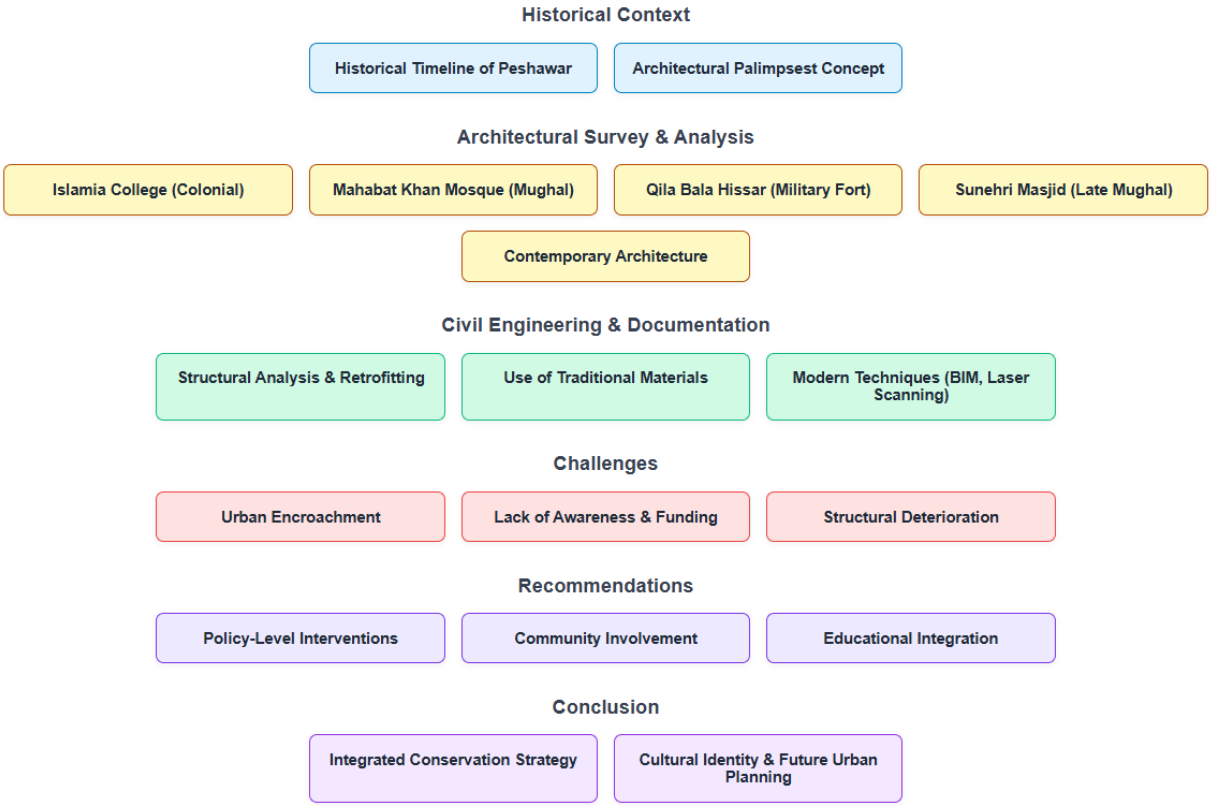


Figure 1: Research framework illustrating the methodological flow of the study



## 2. Historical and Colonial Landmarks

### 2.1 Islamia College Peshawar: Architectural and Historical Significance

Founded in 1913, Islamia College is a prominent example of Indo-Saracenic architecture, combining Mughal, Islamic, and colonial motifs. Its red brick façade, domes, minarets, and jharokhas embody educational and cultural symbolism.

Islamia College Peshawar is one of the region's most iconic educational and architectural landmarks. It was established by prominent Muslim leaders, including Nawab Sir Sahibzada Abdul Qayyum and Sir George Roos-Keppel, with the vision of promoting modern education among the Muslim population of the North-West Frontier Province (now Khyber Pakhtunkhwa) [31]. The college played a vital role in the Pakistan Movement. It later evolved into a university,

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maintaining its status as a symbol of academic excellence.

Architecturally, the college is a striking example of Indo-Saracenic Revival architecture. This style blends Islamic, Hindu, and British colonial elements. Its grand façade features domes, minarets, cusped arches, and Mughal-style jharokhas (overhanging balconies), creating a sense of cultural continuity and colonial influence. The building's red brick construction, symmetrical layout, and intricately designed ironwork in the inner verandahs reflect meticulous craftsmanship. The central marble fountain in the courtyard evokes traditional Islamic garden design, emphasizing serenity and geometric harmony [32].

Islamia College is not only a masterpiece of architectural fusion but also a living monument to Muslims' socio-political and intellectual awakening in the early 20th century. Its preservation is crucial for its physical beauty andts legacy in Pakistan's cultural and educational landscape[33].

Figure 2: elevation of Islamia College Peshawar



Islamia College's Indo-Saracenic architecture, with its red brick façade and Mughal-style jharokhas, is a prime example of architectural synthesis (Figures 2 & 3) [34].

Figure 3: Side view of Islamia College showing corner turret and Mughal-style jharokhas [35].

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### 2.2 Arches and Engineering Techniques at Islamia College Peshawar

The arches, primarily cusped and pointed, are constructed using load-bearing masonry, distributing weight across voussoirs without modern reinforcement. The building also incorporates passive cooling features such as shaded verandahs and open courtyards, demonstrating climate-responsive design.

The architectural design of Islamia College Peshawar prominently features a series of carefully constructed arches, which serve both aesthetic and structural purposes. The arches, primarily pointed (ogee) and cusped in form, are inspired by Mughal and Islamic architectural traditions, contributing to the grandeur and rhythmic symmetry of the building's façade and corridors. These arches are constructed using traditional brick masonry techniques, with each voussoir (wedge-shaped brick) meticulously placed to distribute the structural load evenly across the span. This method eliminates the need for extensive steel reinforcement, relying on compression principles to maintain stability [36].

Many arches are enhanced with carved plaster or terracotta ornamentation, showcasing geometric patterns and floral motifs that reflect Islamic artistic sensibilities. The inner verandahs and entrances also feature multi-foil arches, adding a decorative richness and soft curvature. The engineering behind these arches reflects a balance of form and function, providing open, shaded walkways that improve airflow and reduce thermal heat gain, which is particularly suited to the hot climate of Peshawar [37].

The successful integration of traditional engineering knowledge with local materials and craftsmanship demonstrates how the builders of Islamia College achieved durability, beauty, and cultural identity. These arches are not merely architectural elements but essential to understanding the building's enduring strength and symbolic power [38].



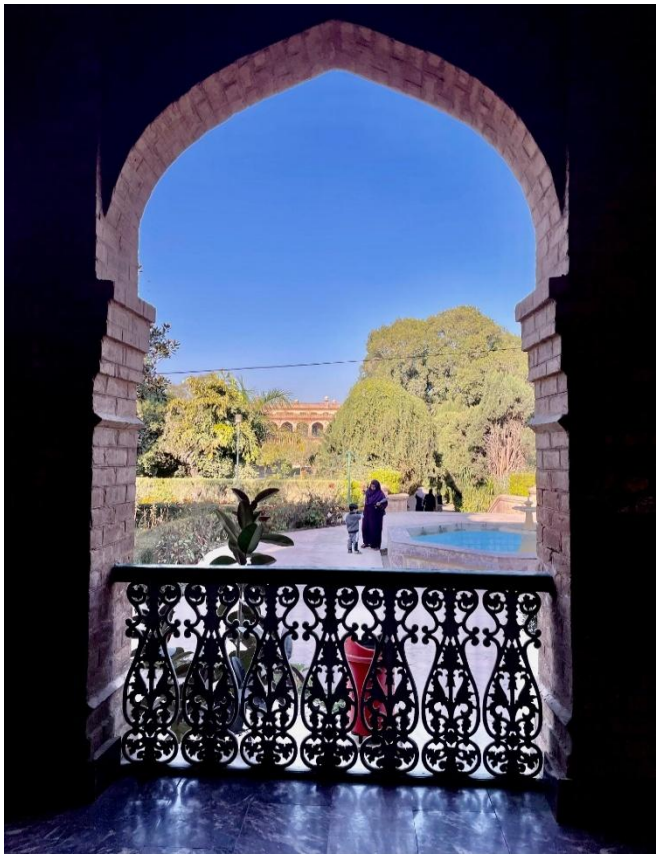

Figure 4: View from the inner verandah of the Islamia College courtyard, showcasing carved ironwork and landscaped garden.

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The inner verandahs, with carved ironwork and landscaped gardens (Figure 4), demonstrate a careful balance of aesthetics and environmental comfort.

### 2.3 The Central Fountain: Symbolism and Design

Inspired by Islamic Charbagh garden geometry, the octagonal marble fountain reflects spiritual and climatic sensibilities. Such water features served symbolic and microclimatic purposes in traditional Islamic architecture [38], [39].

At the heart of Islamia College Peshawar's central courtyard lies an elegant octagonal marble fountain, both a visual focal point and a cultural symbol. The fountain draws inspiration from traditional Islamic garden design, particularly the concept of the Charbagh, a quadrilateral garden layout. Its octagonal shape reflects a geometric balance common in Islamic architecture, representing order, harmony, and unity. Constructed from polished white marble, the fountain basin features subtle engravings and water outlets that would have initially created a gentle, cooling stream, enhancing the sensory experience of the courtyard. Though now primarily decorative, such fountains were historically engineered for microclimatic control, helping to cool the surrounding air and provide a sense of serenity in hot, arid environments. The location of the fountain, centrally aligned with the central axis of the building, demonstrates a strong understanding of symmetry, axial planning, and landscape integration.

This fountain adds aesthetic value and reflects the intellectual and spiritual ideals associated with Islamic educational institutions. It connects the built environment to nature and metaphysical symbolism, making it a timeless element within the architectural legacy of Islamia College.

Figure 5: Octagonal marble fountain in the central courtyard of Islamia College, a nod to traditional Islamic garden design.



The octagonal marble fountain (Figure 5), centrally placed in the courtyard, reflects Charbagh-based Islamic garden symbolism.

## 3. Mughal era and Islamic Architecture

### 3.1 Gor Khatri

Originally a Buddhist site, Gor Khatri evolved into a Mughal caravanserai under Jahan Ara Begum. The site reflects Peshawar’s transformation across religious and cultural regimes. Gor

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Khatri is an archaeological site located in Peshawar, Pakistan, that includes a square-shaped compound that has been excavated and researched. In 1641, Jehan Ara Begum, daughter of Shah Jahan, built Gor Khatri as a caravanserai [40].

Alexander Cunningham initially identified Gor Khatri as the location of the Kanishka stupa. Ahmad Hasan Dani further discovered that it was also where the Buddha bowl tower once stood.

Figure 6: Gorkhatri's entryway as viewed from Peshawar's old city

Gor Khatri’s gateway (Figure 6) reveals its transformation from a Buddhist site to a Mughal caravansary.

### 3.2 Qila Bala Hissar Fort: History and Architecture



This elevated fort combines Afghan, Mughal, and colonial military architecture. Its earthquake-prone mud-brick walls require retrofitting via jacketing and stabilization. Qila Bala Hisar exhibits Islamic architectural elements, but is not solely an example of Islamic architecture. It is a historic fort with a composite architectural heritage.

Qila Bala Hissar, meaning "High Fort," is one of Peshawar's most significant historical landmarks, situated on a prominent elevation at the city’s western edge. The fort’s strategic location has made it a power centre for rulers throughout history, from the Mughals and Durranis to the Sikhs and British. Although its earliest foundations may date back centuries, the fort became prominent during the Durrani Empire in the 18th century, when it served as a royal residence for Ahmad Shah Durrani, the founder of modern Afghanistan.

Architecturally, Bala Hissar Fort is a classic example of military defensive construction, characterized by thick mud-brick and stone walls, watchtowers, and ramparts designed to withstand siege. The fort's rectangular layout encloses large open courtyards, administrative buildings, and barracks. The elevation of the fort provides panoramic views of Peshawar city, reinforcing its function as both a military stronghold and a seat of governance.

One of the defining architectural features of Bala Hissar is its massive gateways and bastions, which reflect elements of Mughal and Afghan fortification styles. The arched gateways, supported by large voussoirs and flanked by turrets, combine structural strength with symbolic authority. Inside, remnants of carved wooden balconies, brick arches, and water channels hint at the more refined aspects of royal life that once existed within the fortified walls.

Today, Bala Hissar remains under the control of Pakistan’s Frontier Corps, with limited public access. Yet, it is a living monument to the region’s turbulent history, architectural evolution,

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and cultural resilience. Conservation efforts are essential to preserve this iconic structure, which encapsulates centuries of power dynamics, warfare, and regional identity in Peshawar [41], [42], [43], [44] .

Figure 7: A view of Qilla Bala Hisar

The elevated view of Qila Bala Hissar (Figure 7) illustrates the fort's strategic military and architectural importance



### 3.3 Mahabat Khan Mosque: Ornamentation and Arch Typology

Built in the 17th century, the mosque showcases multi-cusped arches, frescoes, and Persian-influenced ornamentation (Brumana et al., 2017). Conservation efforts have employed hidden steel rods and lime grouting to reinforce its structure (Ali et al., 2022). The Mahabat Khan Mosque, built in the 17th century during the reign of Mughal Emperor Shah Jahan, is one of Peshawar's most celebrated examples of Mughal Islamic architecture. The mosque is particularly renowned for its rich interior ornamentation and distinct arch types, which reflect both the artistic sophistication and engineering mastery of the Mughal period.

The interior of the main prayer hall is adorned with intricate frescoes, featuring floral patterns, arabesques, and calligraphy in traditional Mughal color palettes of deep reds, blues, and gold. The walls and ceilings are covered with stucco carvings and painted medallions, representing a fusion of Persian and Central Asian decorative styles. These ornamentations not only enhance visual beauty but also serve to inspire spiritual contemplation.

Structurally, the mosque employs a series of multi-cusped arches, also known as muqarnas or scalloped arches, particularly in the prayer hall and entrance bays. These decorative and functional arches distribute the roof's weight to the columns and piers. The central iwan (arched entrance) features a high, pointed arch, a hallmark of Islamic monumental architecture, flanked by smaller, blind arches that frame the façade with symmetry and depth.

These arch forms, combined with the lavish ornamentation, reflect the Mughal emphasis on harmony, grandeur, and spiritual symbolism in architecture. The Mahabat Khan Mosque is a prime example of how form, function, and faith converge in Islamic architectural design.

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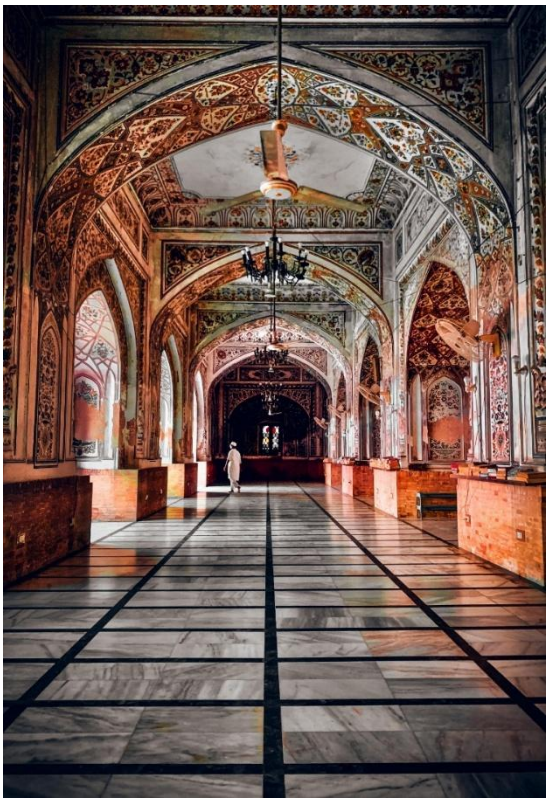

Figure 8: The Mahabat Khan Mosque's richly ornamented prayer hall interior, with intricate floral frescoes and marble flooring.



The richly ornamented prayer hall of the Mahabat Khan Mosque (Figure 8) showcases the Mughal mastery of geometry and fresco.

### 3.4 Sunehri Masjid: Ornamentation and Arch Typology

This 18th-century mosque features gilded domes, floral frescoes, and calligraphic ornamentation. Its triple-arched entrance and qibla-facing mihrab reflect Mughal religious architecture (Ahmad, 2006). The Sunehri Masjid, or "Golden Mosque," located in the heart of Peshawar's old city, is a remarkable example of late Mughal-era mosque architecture in the region. Built in the 18th century, this mosque is named after its distinctive gilded domes, which gleam in sunlight and serve as a visual landmark in the densely built urban fabric. Though more compact than the Mahabat Khan Mosque, the Sunehri Masjid showcases exquisite ornamentation and arch designs that reflect its time's aesthetic sensibilities and religious artistry[45].

The mosque's interior and façade are adorned with hand-painted floral motifs, geometric patterns, and Quranic inscriptions rendered in traditional Naqsh (stylized calligraphy). Using vibrant colors such as cobalt blue, turquoise, and deep green on white plaster creates a striking contrast. It enhances the spiritual ambience of the prayer space. The mihrab (prayer niche) is intricately decorated with layered arches and calligraphic panels, signifying the qibla direction and drawing the worshipper's attention toward Mecca.

Architecturally, the Sunehri Masjid features a series of pointed and cusped arches that frame the prayer halls and entryways. These arches are structurally significant, channelling the weight of the domes and upper levels down to the mosque's thick load-bearing walls. The main entrance is emphasized by a triple-arched façade, with the central arch slightly taller and more pronounced than the flanking ones, a classic feature in Mughal mosque design. Smaller blind

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arches and recessed niches further enhance the depth and texture of the elevation.

Overall, the Sunehri Masjid exemplifies a refined blend of Mughal aesthetics, structural ingenuity, and religious symbolism, making it an essential part of Peshawar's Islamic architectural heritage.

Figure 9: Architectural details of Sunehri Masjid (or other historic mosque in Peshawar), showing red sandstone, geometric arches, and minarets.



The Sunehri Masjid's compact layout and gilded domes (Figure 9) exemplify late Mughal religious architecture.

## 4. Architectural Synthesis: Interplay Between Eras

Peshawar's urban narrative blends Indo-Saracenic, Islamic, and colonial elements, challenging conservationists to preserve hybrid identities. Adaptive reuse strategies can help retain urban authenticity while accommodating development. While colonial and Islamic architectures are often studied separately, Peshawar presents a rare urban narrative where these styles coexist and influence each other. From red-brick colonial institutions with Mughal jharokhas to mosques with Indo-Saracenic motifs, the cityscape becomes a canvas of historical dialogue. This architectural synthesis offers both challenges and opportunities for conservation, as interventions must respect the hybrid character of such structures.

## 5. Infrastructure and Urban Development in Peshawar

Modern projects like the Peshawar BRT system contrast sharply with historic streetscapes. While infrastructure is essential, unregulated development often leads to site encroachment and demolition of traditional structures. Peshawar's urban landscape has significantly transformed in recent decades due to rapid population growth, increased vehicular traffic, and modernization efforts. Once defined by narrow streets, historic bazaars, and traditional courtyard houses, the city is now experiencing a wave of infrastructural expansion aimed at improving mobility, connectivity, and public services. One of the most notable developments is the Peshawar Bus Rapid Transit (BRT) system, which includes steel pedestrian overpasses, elevated tracks, and

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dedicated bus lanes. These structures are functional and represent a shift toward sustainable and inclusive urban transport [46], [47].

Urban development has also introduced modern utilities infrastructure, including high-voltage electric transmission towers, sewage systems, and upgraded road networks. These changes are essential for supporting the city's growing demands, but often come at the cost of heritage preservation. Unregulated construction, encroachment on historic sites, and demolition of traditional buildings have created a conflict between modernization and cultural continuity.

Moreover, the increasing use of glass façades, concrete high-rises, and commercial plazas is reshaping Peshawar's skyline, reflecting a globalized architectural trend that often lacks sensitivity to the city's historical context. The challenge lies in achieving a balanced urban strategy that integrates modern infrastructure with heritage conservation, respects traditional spatial patterns, and fosters sustainable development. Addressing these issues requires comprehensive urban planning, public awareness, and policy-level interventions to ensure that progress does not erase the city's rich architectural identity.

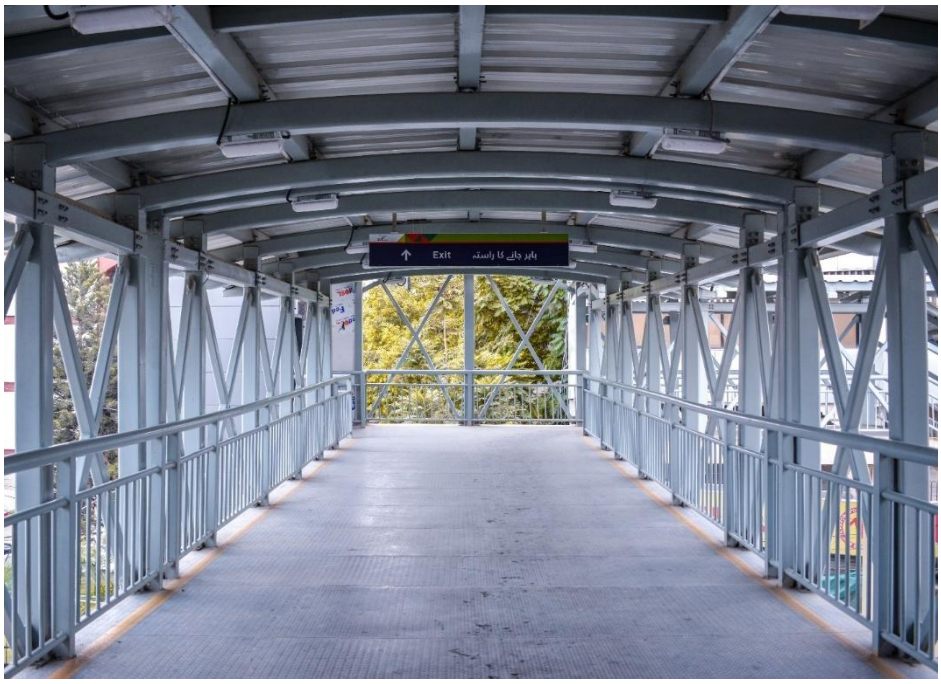


Figure 10: Steel pedestrian overpass of Peshawar BRT system, an example of modern transport infrastructure improving urban mobility.



The steel pedestrian overpasses of the BRT system (Figure 10) contrast starkly with the city's historic architecture.

## 6. Contemporary Architecture

The rise of glass-clad towers and Brutalist concrete buildings reflects global trends but risks disconnecting from the local context. Few new buildings incorporate elements like colored glass or Islamic ornamentation that define Peshawar's historic vocabulary.

### 6.1 Modern architecture

In recent years, Peshawar's architectural landscape has become a mix of evolving contemporary designs and deeply rooted local vernacular styles. On one hand, the rise of glass-clad

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commercial towers, shopping plazas, and high-rise apartments reflects a shift toward modernist and global architectural trends. Buildings like the AMC Tower symbolize this change, with their sleek façades, minimal ornamentation, and use of industrial materials such as steel, aluminum, and reflective glass. Commercial needs, modern construction techniques, and aspirations of a cosmopolitan urban image drive these structures.

The rise of contemporary architecture in Peshawar often lacks contextual sensitivity, risking a disconnect between the city's past and future. While modern materials and forms serve functional needs, there is a growing need for an architectural language that bridges tradition and innovation, potentially through adaptive reuse or culturally informed design templates.



Figure 11: AMC Tower in Peshawar, reflecting the emergence of glass-clad, Low-rise commercial architecture.

Modern high-rises such as AMC Tower and Hotel Tourmaline (Figures 11 & 12) reflect global architectural trends with minimal contextual sensitivity.

A distinctive feature of Peshawar’s traditional architecture is the creative use of colourful glass in windows and openings, which transforms natural daylight into vibrant patterns across the building’s surfaces. Especially in mosques, older homes, and cultural landmarks, small sections of walls or arches are fitted with multi-colored glass panes commonly in red, green, blue, and yellow hues. These elements are often integrated into arched window frames or domes, allowing daylight to enter in a filtered, decorative form.

The resulting play of light is visually striking and symbolically rich, evoking spiritual beauty and sensory comfort. During early morning or late afternoon, the sun’s rays passing through these glass elements create a luminous, stained-glass effect on the floor and walls, adding color, warmth, and movement to otherwise plain exteriors. This technique reflects a climatic and cultural adaptation, enhancing aesthetic appeal while softening harsh daylight in Peshawar’s arid environment. Though less common in modern construction, the tradition of using colored glass in architectural design remains an important part of the city's visual identity. It represents a unique blend of local craftsmanship, Islamic art influences, and an architectural approach that values beauty in harmony with function.

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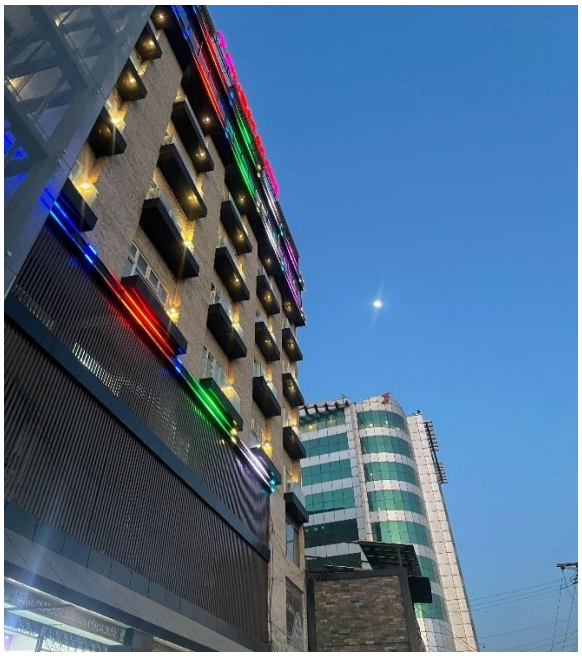

Figure 12: Hotel Tourmaline in Peshawar, reflecting the emergence of glass-clad, Low-rise commercial architecture.

### 6.2 Brutalism in Peshawar

Brutalist elements can be seen in some government offices, educational institutions, and civic infrastructure, where functionality and durability are prioritized over ornamentation. These buildings often feature massive concrete walls, recessed windows, and minimal decorative detail, conveying a sense of permanence and authority. While not widely adopted in private construction, Brutalism's austerity and structural clarity have left a modest yet visible mark on the city's evolving architectural identity. However, its stark appearance often contrasts sharply with Peshawar's more intricate and ornamental historic architecture, highlighting the tension between global modernism and local tradition. However, a few local architects and design studios have begun experimenting with contextual design, integrating jharokhas, screened windows, and colored glass into new constructions to respond to cultural homogenization.




Figure 13: An institutional building in Peshawar reflecting the emergence of glass-clad, Low-rise commercial architecture.

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The Brutalist design of an institutional building in Peshawar (Figure 13) highlights the tension between utilitarian modernism and traditional ornamentation.

## 7. Challenges in Heritage Conservation

### 7.1 Urban encroachment

Historic sites are increasingly surrounded by informal and commercial structures, causing loss of context and visibility. Urban encroachment is one of the most serious threats to Peshawar's architectural heritage. As the city expands to accommodate a growing population and commercial demand, historic sites are increasingly surrounded or engulfed by unregulated construction, particularly in the old city. Narrow alleys that once led to centuries-old mosques, havelis, and bazaars are now cluttered with concrete shops, high-rise buildings, and encroachments that obscure or damage heritage structures. The lack of zoning control and ineffective enforcement of preservation laws have allowed private development to overtake historically significant areas, leading to the loss of authenticity and contextual integrity of many monuments [48], [49], [50].

### 7.2 Lack of awareness and funding

Public disregard and poor policy enforcement hinder conservation. Investment is often redirected toward infrastructure rather than heritage . Public and institutional lack of awareness is a major obstacle in heritage conservation. Many local communities and property owners are either unaware of the historical value of old buildings or consider them obsolete in the face of modern construction. There is also a general lack of educational outreach and heritage promotion at the policy level. Compounding this issue is the shortage of funding, as conservation efforts often take a back seat to infrastructure and commercial development. With limited budgets, local authorities and heritage organizations struggle to carry out even basic documentation, let alone restoration or maintenance. Private investment in heritage preservation is rare, and without incentives or public-private partnerships, many historical sites continue to fall into neglect.



### 7.3 Structural deterioration

Many of Peshawar's historic buildings are in a state of advanced deterioration, owing to age, neglect, and environmental factors. Prolonged exposure to rain, extreme temperatures, and pollution weakens traditional materials like mud brick, lime plaster, and timber. Minor damages escalate into severe structural failures without regular maintenance and conservation practices. Additionally, the lack of skilled professionals trained in traditional restoration techniques results in improper repairs using incompatible materials such as cement, further accelerating damage. Earthquakes and seasonal floods also threaten already vulnerable structures, making structural stability a critical challenge in the long-term survival of Peshawar's built heritage. Environmental factors, poor repairs, and incompatible materials (e.g., cement instead of lime) accelerate decay [51], [52].

### 7.4 Institutional Weakness and Bylaw Violations

Another critical challenge in conserving Peshawar's architectural heritage is the lack of institutional enforcement of building regulations and conservation bylaws. Despite the presence of urban development frameworks and heritage protection policies, these are frequently bypassed by municipal authorities and developers. Development authorities often approve construction projects that violate heritage zoning rules or proceed without adherence to the approved architectural drawings.

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Furthermore, architects and contractors often neglect municipal bylaws, especially in the old city, where unauthorized modifications to historic structures are common. Such practices result in overbuilt structures, incongruent façades, and the demolition of heritage elements without proper documentation or mitigation. These actions compromise the aesthetic and structural integrity of the urban fabric and erode public trust in regulatory institutions.

The absence of strict monitoring, limited accountability, and institutional overlap between heritage, planning, and municipal departments weakens conservation outcomes. Strengthening enforcement mechanisms, digitizing permit approvals, and empowering heritage departments are crucial steps to address this systemic issue. The absence of a digital permit system or heritage impact assessment process also exacerbates the issue, allowing irreversible changes to heritage zones under loosely monitored approvals.

## 8. Role of Civil Engineering in Heritage Preservation

### 8.1 Techniques for restoration and retrofitting

Techniques like masonry stitching, steel tie rods, and FRP jacketing reinforce vulnerable buildings. Retrofitting must ensure minimal alteration to visual identity.

- Restoration and retrofitting are essential civil engineering practices used to strengthen and preserve aging heritage structures in Peshawar. These techniques begin with a detailed structural assessment, identifying weaknesses in foundations, load-bearing walls, arches, and domes. Traditional materials such as lime mortar, stone, and mud-brick are often used to maintain authenticity. However, they are combined with modern reinforcement methods for added strength. Techniques like grouting, masonry stitching, jacketing, and the use of steel anchors or tie rods help stabilize cracks and prevent further structural failure.



- In earthquake-prone areas, seismic retrofitting has become crucial. Engineers use base isolators, shear walls, or fiber-reinforced polymer (FRP) wraps to enhance resistance without visually altering the original design. These interventions are carefully chosen to ensure that the building's aesthetic and historical value remains intact. At the same time, its load-bearing capacity and durability are improved. Retrofitting is particularly important for mosques, forts, and havelis in Peshawar, many of which were built before modern seismic codes existed.

For instance, the partial retrofitting of Mahabat Khan Mosque using lime-based grouting and hidden steel tie rods demonstrates how traditional aesthetics can be preserved while reinforcing structural stability against seismic activity .

### 8.2 Use of modern technology in documentation

The documentation of heritage buildings is now more accurate and efficient thanks to the integration of modern technology in civil engineering and conservation efforts. Techniques such as 3D laser scanning, photogrammetry, and drone mapping allow professionals to create highly detailed digital models of heritage sites without physically altering them. These models help record the building's current condition, plan conservation strategies, and simulate structural behavior under stress. Another key tool is Building Information Modeling (BIM) for historic structures, often referred to as HBIM (Heritage BIM). It allows engineers and architects to digitally reconstruct and manage conservation projects with layered historical data, structural analysis, and future maintenance plans. This digital documentation not only supports the physical restoration process but also preserves a virtual record for educational, research, and cultural purposes [53], [54], [55], [56], [57].

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By applying these technologies, civil engineers contribute to both the preservation and modernization of Peshawar's architectural heritage, ensuring that the past is documented accurately and protected intelligently for future generations. Tools like 3D laser scanning, photogrammetry, and Heritage BIM (HBIM) allow digital archiving and simulation for stress analysis.

## 9. Recommendations

### 9.1 Policy-level suggestions

Government institutions must play a proactive role in protecting heritage structures through clear, enforceable conservation policies. This includes implementing heritage zoning laws, restricting unauthorized construction around protected sites, and offering legal protection to historically significant buildings. Budget allocations for heritage preservation should be increased and integrated into urban planning frameworks. In addition, public-private partnerships can be encouraged to fund restoration projects and adaptive reuse of old buildings for cultural or civic purposes. A centralized heritage management authority in Khyber Pakhtunkhwa could coordinate efforts, maintain a heritage site registry, and ensure conservation standards. Enforce zoning, heritage mapping, and legal protections.

### 9.2 Community involvement

Local communities must be seen as active stakeholders in the preservation process. Awareness campaigns, guided heritage walks, and public exhibitions can help residents understand the' cultural and historical value. Incentives such as tax breaks or restoration grants could encourage homeowners and businesses to maintain historic façades and structures. Involving local artisans, masons, and traditional craftsmen in restoration supports cultural continuity and economic participation. Community-driven projects build a sense of pride and responsibility, ensuring long-term stewardship of heritage assets. Use incentives, awareness campaigns, and local participation.



### 9.3 Educational initiatives

Educational institutions can play a major role in shaping future conservation efforts. Schools, colleges, and universities should integrate heritage studies into their curricula, especially those offering architecture, civil engineering, or urban planning. Workshops, field studies, and student documentation projects can help foster interest and skills in heritage conservation from an early stage. Furthermore, partnerships between academic institutions and local government bodies can lead to research-based conservation strategies using traditional knowledge and modern technology. Encouraging youth engagement is essential for ensuring that Peshawar's architectural legacy is not only preserved but actively celebrated. Integrate heritage studies in civil engineering and architecture curricula.

Together, these recommendations emphasize the importance of multi-level action policy reform, community engagement, and educational integration to ensure that Peshawar's architectural heritage is preserved and revitalized as a living part of the urban fabric.

### 9.4 Strengthen enforcement of conservation bylaws

Municipalities and development authorities must be held accountable for approving construction violating zoning laws or disregards heritage protection. Architects and developers should be required to follow approved drawings, and strict penalties should be enforced for violations. Authorities should integrate digital building permit systems, public grievance mechanisms, and third-party audits to ensure transparency in enforcement.

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## 10. Conclusion

This study documents Peshawar's architectural evolution, identifying challenges and engineering solutions for heritage conservation. It emphasizes that interdisciplinary collaboration is essential to balance modernization with cultural continuity. As Peshawar grows, its development must reflect economic aspirations and its layered historical identity.

The study has explored the architectural richness and historical layers of Peshawar, highlighting key examples such as Islamia College, Mahabat Khan Mosque, Sunehri Masjid, and Bala Hissar Fort. The research demonstrates how Peshawar's built environment reflects centuries of cultural exchange, colonial influence, and Islamic tradition. It also examined the evolving nature of the city's urban development, showcasing the contrast between traditional craftsmanship and contemporary architecture. While the city's architectural heritage remains a source of cultural identity and historical continuity, it is increasingly threatened by urban encroachment, neglect, and structural decay. The role of civil engineering and architects in heritage preservation was emphasized, particularly through modern restoration, retrofitting techniques, and digital documentation technologies like BIM and laser scanning. In addition, challenges such as a lack of public awareness, funding limitations, and inadequate policy enforcement were identified as major barriers to effective conservation.

The findings make it clear that sustainable heritage conservation is essential for protecting historical monuments and maintaining the cultural identity, social continuity, and collective memory of the people of Peshawar. Heritage buildings are more than relics of the past; they are living narratives that inform urban character and civic pride. By integrating conservation efforts into urban planning, education, and community involvement, we can ensure that development does not come at the cost of history. Moving forward, adopting inclusive, interdisciplinary approaches that balance modernization with preservation is imperative. This will allow Peshawar to grow as a dynamic, livable city while honouring its rich architectural legacy. This legacy must be preserved for future generations to experience, study, and appreciate.



As Peshawar continues to grow, its architectural identity must evolve not through erasure but through thoughtful integration of past and present. This vision requires commitment, creativity, and collaboration across disciplines. The architectural narrative of Peshawar is not merely about buildings; it reflects the collective memory, identity, and future trajectory of its people.

Future research could expand on this study by incorporating GIS-based heritage mapping, interviews with local artisans, and real-time structural monitoring of vulnerable monuments. The insights from Peshawar's experience may serve as a model for other historic South Asian cities facing the dual pressures of modernization and heritage erosion.

While this study offers a comprehensive overview of Peshawar's architectural heritage, it is limited by the availability of access to specific heritage sites under military or private control. Future research could include on-site structural analysis, interviews with local artisans, and integration of GIS-based heritage mapping to enhance documentation and planning further.

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# Effects of First Story Stiffness on Earthquake Responses of 2-Story Wooden Houses

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## Abstract

In this study, a seismic response analysis of 2-story wooden houses has been carried out, and guidelines for proper seismic rehabilitation have been considered. In the analysis, the bilinear + slip model is adopted as the restoring-force characteristics because in previous studies it has been confirmed that the model reproduces characteristics of wooden houses relatively well. First, it was investigated how much the first story stiffness affects the inertia force of the roof during an earthquake. Next, the effects of roof mass were examined. Finally, in the case where an anti-seismic shelter was placed on the ground floor, a suitable connection method to the house was considered.

**Keywords:** Restoring-Force Characteristics, Bilinear + Slip Model, Wooden House, Earthquake Resistance, Seismic Response Time History Analysis, Anti-Seismic Shelter, Oil Damper, Pushover Analysis



## 1. INTRODUCTION

For an earthquake countermeasure, we performed construction work in which a steel shelter (manufactured by Tobu Bousai Construction in Japan) was installed in the first story of a 2-story wooden frame house in Toride City (Fig. 1), which was located about 350km south-west of the epicentre of the 2011 off the Pacific Coast of Tohoku Earthquake, from August to September 2013. Although the installation of an earthquake-resistant shelter is usually intended to secure safe space in a part of the building and not to reinforce the entire structure, in this case the shelter was tightly connected to the ceiling beams of the first story to increase the story stiffness. This method has been often adopted as a seismic countermeasure for existing houses because it can be done while residents are still living in the house, and it is more advantageous than seismic isolation in terms of cost and construction period. However, on September 20, 2013, the day immediately after the construction work, by getting caught in a relatively small earthquake which could be considered as one of aftershocks of the 2011 off the Pacific Coast of Tohoku Earthquake, the tile roof underwent partial breakdown. Although the main shock on March 11, 2011 was followed by many large aftershocks, there had been no damage to this house until that aftershock. Since this incident occurred immediately after seismic reinforcement work was done, I hypothesized that this work increased the stiffness of the first story, which increased the inertia force of the roof. Hence, firstly, the effects of first story stiffness on the inertia force of the roof during an earthquake are investigated by numerical simulations. After that, the effects of roof mass and a suitable connection method between the house and the anti-seismic shelter are considered with the goal of establishing guidelines for

more effective seismic reinforcement.

There have been several previous studies related to this study. Araki et al. [1] proposed a method to predict the hysteresis model of a whole wooden house by summation of the parameters of hysteresis models for resisting shear walls. Nakayama and Kojima [2] approximately evaluated the elastic-plastic response of a 2-story wooden house subjected to the critical pulse-like ground motion by using the reduction method into the single-degree-of-freedom system and the closed-form solution derived by themselves. Matsumoto et al. [3] investigated the response reduction effect for existing wooden houses to which a seismic shelter was connected with oil dampers by time history (seismic) response analysis [4, 5] using the collapsing simulation program wallstat [6, 7]. In order to make it easier to compare with those previous studies, M-1 in the paper of Araki et al. [1] and the NS component of Kobe Earthquake (1995) acceleration record are used as the base model for time history response analysis and the input seismic wave, respectively. Although M-1 is different from the above-mentioned house in Toride City, this model can be regarded as a typical Japanese 2-story wooden house. The bilinear + slip model [1, 2], which reproduces characteristics of wooden houses relatively well, is adopted as the restoring-force characteristics of target models.

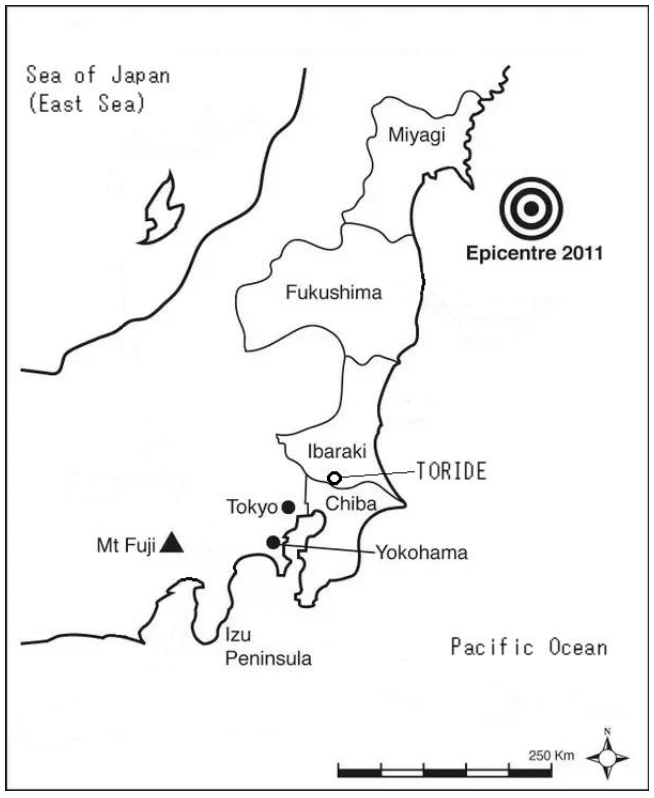


Figure 1. Locations of Toride City in Ibaraki Prefecture, Japan, and the epicentre of the 2011 off the Pacific Coast of Tohoku Earthquake.



## 2. EQUATIONS OF MOTION FOR 2-STORY STRUCTURES SUBJECTED TO GROUND MOTION

### 2.1. Linear Motion Equations for the 2-Mass System

First, the vibration equations for the 2-mass system subjected to ground motion $u$ (Fig. 2) are derived in the following. It is assumed that the damping force of each story is proportional to

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its relative velocity. In accordance with D'Alembert's principle the equilibrium equations of mass points 1 and 2 may be written as

$$k_2(x_2 - x_1) + C_2(\dot{x}_2 - \dot{x}_1) - k_1 x_1 - C_1 \dot{x}_1 + [-m_1(\ddot{u} + \ddot{x}_1)] = 0 \quad (1)$$

and

$$-k_2(x_2 - x_1) - C_2(\dot{x}_2 - \dot{x}_1) + [-m_2(\ddot{u} + \ddot{x}_2)] = 0 \quad (2)$$

respectively. Here, $u$ is the horizontal displacement of the ground, $x_1$ and $x_2$ are the displacements relative to the ground, $m_1$ is the point mass 1 (weight of story 1's upper half + story 2's lower half), $m_2$ is the point mass 2 (weight of story 2's upper half + roof truss), $k_1$ and $k_2$ are the horizontal stiffnesses, and $C_1$ and $C_2$ are the damping coefficients. Reorganizing Eqs. (1) and (2), we obtain the following equations:

$$m_1(\ddot{u} + \ddot{x}_1) + f_{D1} - f_{D2} + f_{R1} - f_{R2} = 0 \quad (3)$$

$$m_2(\ddot{u} + \ddot{x}_2) + f_{D2} + f_{R2} = 0 \quad (4)$$

where

$$f_{D1} = C_1 \dot{x}_1, \quad f_{D2} = C_2(\dot{x}_2 - \dot{x}_1) \quad (5)$$

are the damping forces,

$$f_{R1} = k_1 x_1, \quad f_{R2} = k_2(x_2 - x_1) \quad (6)$$

are the restoring forces.

Eqs. (5) and (6) may be applied only in cases where a structure responds in the linear range. However, it can be predicted that the response of a structure far exceeds the linear range during a large earthquake. Thus the cases in which a structure responds in the nonlinear range beyond the linear range are described in the following.



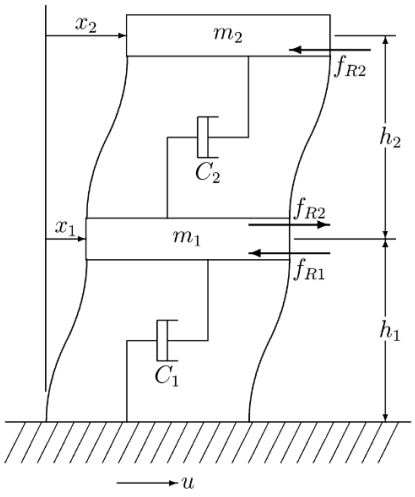


Figure 2. Two-mass model.

## 2.2. Viscous Damping Characteristics in the Plastic Region

When the response of a vibration system enters the plastic zone, hysteretic damping (energy consumption by hysteresis characteristics) appears in addition to viscous damping. In the process of sequentially analyzing the equations of motion, the hysteretic damping

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characteristics are evaluated not in terms of damping forces but in terms of the restoring forces (load-deformation relationships), and the viscous damping characteristics are still represented by the terms related to damping forces even in the plastic region. The evaluation of viscous damping characteristics, even in the linear region, is more imprecise and difficult than that of mass and stiffness, and reassessing it in the plastic region is even more difficult. In the analysis, the viscous damping is often assumed to be proportional to the stiffness, but in the nonlinear region, the viscous damping may be set to be proportional to the instantaneous stiffness instead of the initial stiffness, since the apparent stiffness changes with time. This is called instantaneous stiffness-proportional damping, and its viscous damping coefficients are smaller than those of instantaneous stiffness-proportional damping. In response analysis, the damping matrices for initial stiffness and instantaneous stiffness proportionalities are generally obtained by

$$\boldsymbol{C} = \alpha \boldsymbol{K}_e, \quad \alpha = 2h/\omega_e \tag{7}$$

and

$$\boldsymbol{C} = \alpha_p \boldsymbol{K}_p, \quad \alpha_p = \alpha \quad \text{in the usual case} \tag{8}$$

respectively. Here,

$$\boldsymbol{C} = \begin{bmatrix} C_1 + C_2 & -C_2 \\ -C_2 & C_2 \end{bmatrix}$$

is the damping matrix, $h$ is the viscous damping factor, $\omega_e$ is the elastic 1st mode circular frequency, $\boldsymbol{K}_e$ is the initial stiffness matrix, and $\boldsymbol{K}_p$ is the instantaneous stiffness matrix. In the plastic region, the hysteretic damping tends to be larger than the viscous damping. As for the evaluation of viscous damping characteristics in this region, there is no significant difference between initial stiffness and instantaneous stiffness proportionalities under a general condition. Hence, in this paper, the damping is treated simply as an initial stiffness proportionality.



### 2.3. Restoring-Force Characteristics (Bilinear + Slip Model)

The restoring forces $f_{Rj}(t)$ ($j$ = floor number = 1, 2) vary greatly depending on the type of structure (e.g., reinforced concrete, steel-frame, wood construction). The difference in restoring forces, which depends on this structure type, is handled by what is called the restoring force model or the hysteresis model. The features of the restoring-force characteristics of a typical wooden house include the slip phenomenon caused by wood embedments at joints, joint reinforcement hardwares, and the pinching phenomenon, in which the hysteresis area becomes small when shear slip is predominant. The slip-type restoring-force characteristics are used to reproduce the slip phenomenon due to wood embedments, and the bilinear-type restoring-force characteristics are used to reproduce the properties of steel. In addition, the pinching phenomenon is reproduced by using a composite type that is a combination of the bilinear type and the slip type. Hence, in this study, the composite type (bilinear yielding precedence type) is used to model the restoring-force characteristics in order to simultaneously reproduce the three phenomena and functions of wooden houses. The schematic diagram of the restoring-force characteristics and its parameters are shown in Fig. 3 and Table 1, respectively. The relationship between the horizontal stiffnesses $k_j$ and the rotational stiffnesses $(K_i)_j$ is expressed by the following equation:

$$k_{ij} = (K_i)_j / h_j \quad \text{at} \quad i = 1, 2 \text{ or } 3, \quad j = 1, 2 \tag{9}$$

where $h_j$ are the story heights.

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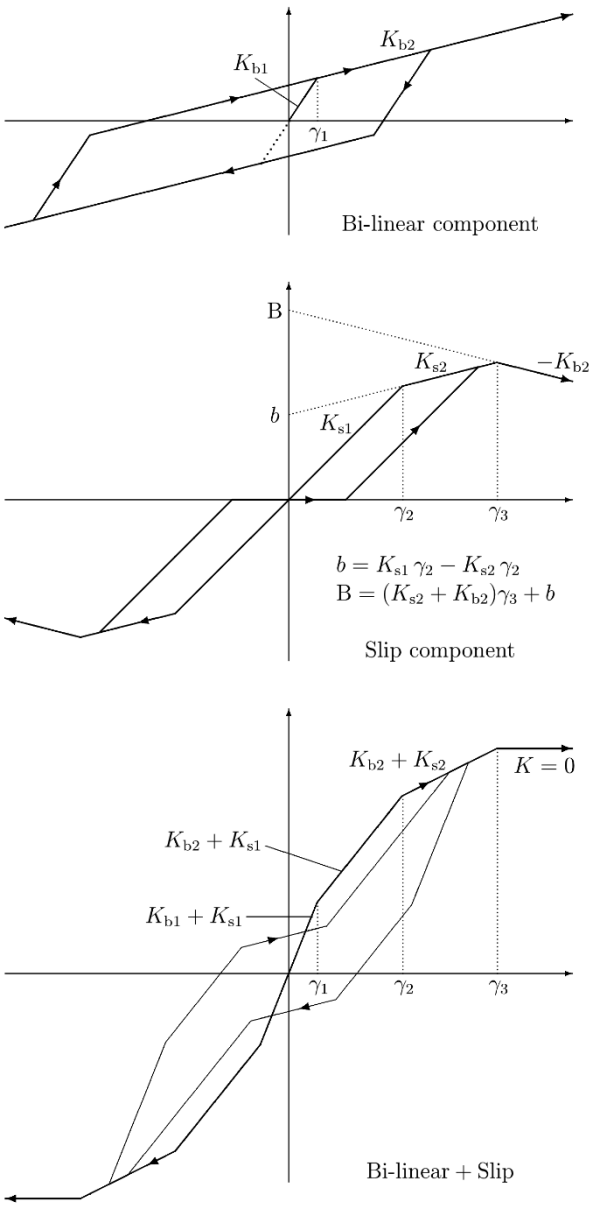


Figure 3. Bilinear and slip-type restoring-force characteristics, and notation of parameters (reprinted from Fig. 2 in Ref. 1).



**Table 1. Parameters of the restoring-force model**

| | |
|---|---|
| 1st yielding point $\gamma_1$ [rad] | 0.0020 |
| 2nd yielding point $\gamma_2$ [rad] | 0.0052 |
| 3rd yielding point $\gamma_3$ [rad] | 0.0300 |
| Initial stiffness $(K_1)_j = (K_{b1})_j + (K_{s1})_j$ [N/rad] | $S_j \times 20.140 \times 10^6$ |

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| | |
|---|---|
| 2nd stiffness $(K_2)_j = (K_{b2})_j + (K_{s1})_j$ [N/rad] | $S_j \times 15.440 \times 10^6$ |
| 3rd stiffness $(K_3)_j = (K_{b2})_j + (K_{s2})_j$ [N/rad] | $S_j \times 3.5000 \times 10^6$ |
| Initial stiffness of the bilinear component $(K_{b1})_j$ [N/rad] | $S_j \times 5.4378 \times 10^6$ |

**Table 2. Mass and height of each story**

| | Mass [kg] | | Height of story [m] |
|---|---|---|---|
| 1st story | $m_1$ | 9300 | $h_1$ | 2.885 |
| 2nd story | $m_2$ | $R \times 9000$ | $h_2$ | 2.930 |

## 3. ANALYSIS

The target model is the 2-mass shear system as shown in Fig. 2, and the stiffness and weight of each story are shown in Tables 1 and 2, respectively. The damping model was assumed to be of the initial stiffness proportional type with a damping factor of $h = 0.05$. The NS component of Kobe Marine Observatory waves (Maximum $\text{acceleration} = 818$gal) of the Great Hanshin Earthquake (1995) was used as the input ground acceleration. As a numerical method for solving simultaneous ordinary differential equations (3) and (4) with four unknowns, the constant acceleration procedure [8], which is easy to program, was adopted with a time step size of 0.001seconds. Fig. 4 shows the seismic acceleration wave and the response displacement of the base model. From the comparison with the results of the full-scale experiments in the paper of Araki et al. [1], it can be judged that the accuracy of the computer program the author wrote for the analysis is assured.



### 3.1. Effect of First Story Stiffness on the Inertia Force of Roof

The effect of changing the first story stiffness of the base model on the maximum absolute value $|m_2(\ddot{u} + \ddot{x}_2)|_{\max}$ of the inertia force of mass point 2 (roof section) is shown in Fig. 5. In general, as the stiffness increases, the inertia force decreases and gradually approaches that value obtained when the first story stiffness is rigid (equivalent to a one-mass system). However, since the maximum inertia force increases up to $S_1 = 1.8$ in the graph of Fig. 5, it can be said that the inertia force of the roof section may become excessive due to the increase of first story stiffness. Hence, if an anti-seismic shelter is installed, not only the shelter should be connected to the ceiling beams of the first story, but also the stiffness of the second story should be increased or the roof should be lightened in order to improve the earthquake resistance more effectively.

### 3.2. Effect of Weight of Roof on the Time History Response

Next, the effect of weight of the roof is considered. Fig. 6 shows the relationship between the mass $m_2$ of the roof section versus the maximum absolute value $|x_1|_{\max}$ of the displacement of mass point 1 and the maximum absolute value $|m_2(\ddot{u} + \ddot{x}_2)|_{\max}$ of the inertia force of mass point 2 (roof section). It is easy to predict that a lighter roof section reduces the inertia force, and from this graph, it can be seen that not only that, but also the reduction in response

displacement is remarkable, and therefore, the lightening of the roof is effective in improving the earthquake resistance.

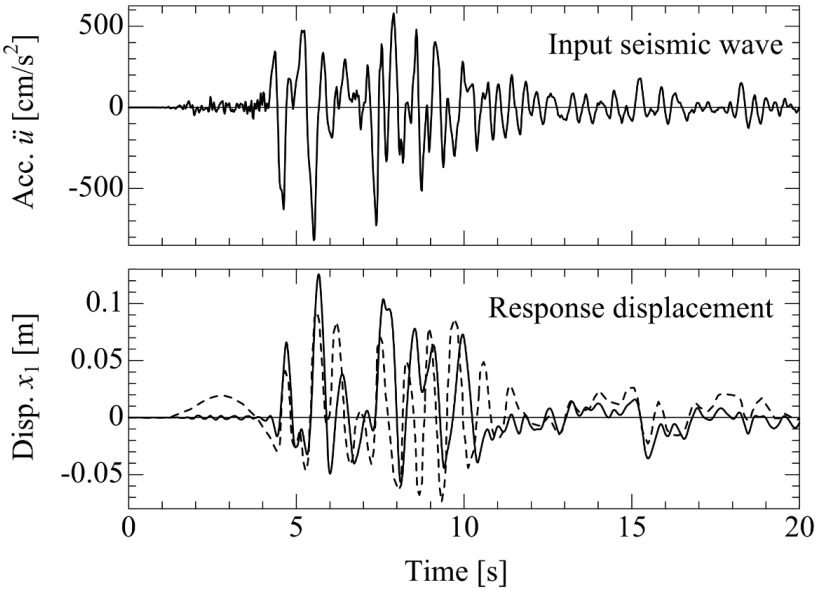


Figure 4. Seismic acceleration wave observed at Kobe Marine Observatory (NS component, Maximum $\mathbf{acceleration = 818}$gal) and response displacement $\boldsymbol{x_1}$ of the base model: dashed curve, Exp. (Ref. 1).



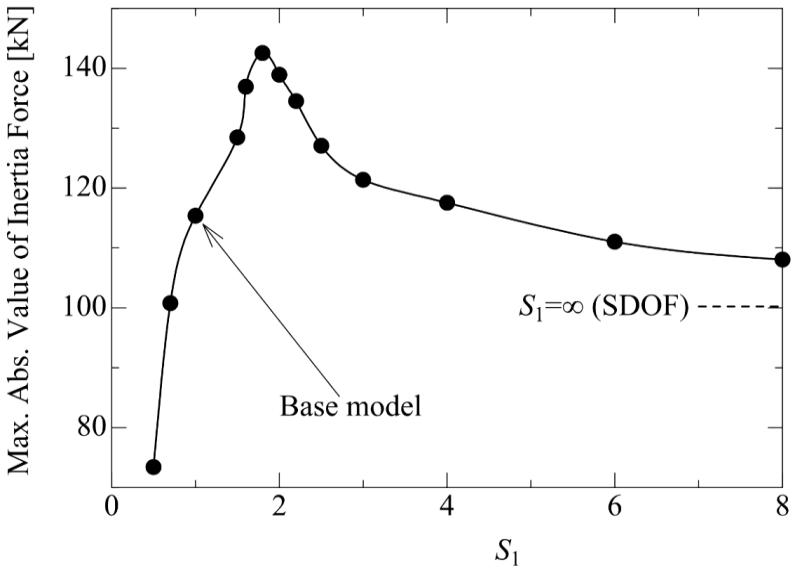


Figure 5. Relation between stiffness of the first story and maximum absolute value of inertia force of $\boldsymbol{m_2}$ ($\boldsymbol{S_2 = 1}$, $\boldsymbol{R = 1}$).

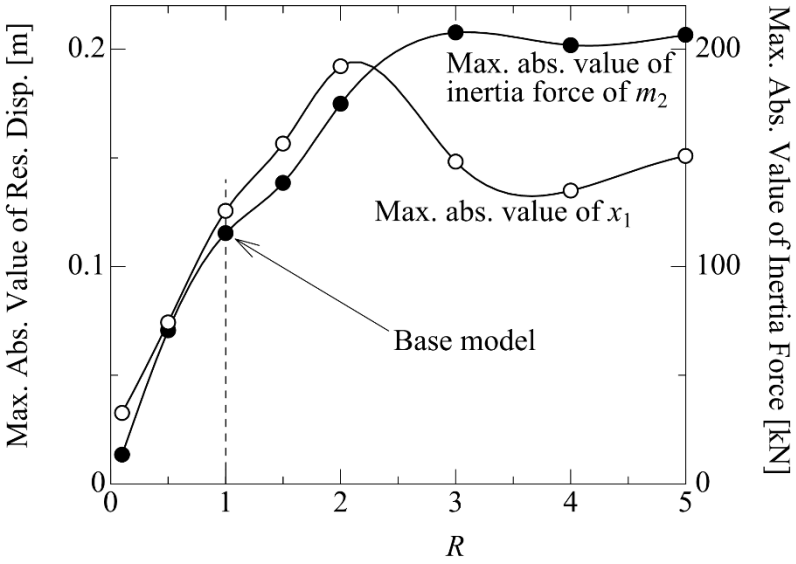


Figure 6. Maximum absolute values of $x_1$ and inertia force of $m_2$ as functions of scale factor $R$ for $m_2$ ($S_1 = S_2 = 1$).

### 3.3. Cases where an Anti-Seismic Shelter is Installed and Connected to the Building via Damping Devices

In this subsection, the effects of installing a highly rigid anti-seismic shelter which can be regarded as a rigid body on the ground floor of the building and connecting that shelter to the first story ceiling beams via shock absorbers based on Kelvin-Voigt model is considered (Fig. 7). Although Matsumoto et al. [3] reported the results of analysis using the distinct element method (Nakagawa et al. [9]) for a similar model, if the objective is to determine the optimum specification of the viscous damper, the analysis applying the lumped mass model is far less time-consuming. The equation of motion for point mass $m_1$ has the form that the damping force term $C_a\dot{x}_1$ of viscous damper and the restoring force term $k_a x_1$ of elastic spring are added to the left side of Eq. (3).



$$m_1(\ddot{u} + \ddot{x}_1) + f_{D1} - f_{D2} + f_{R1} - f_{R2} + C_a\dot{x}_1 + k_a x_1 = 0 \qquad (10)$$

where $C_a$ is the damping coefficient of the viscous damper, and $k_a$ is the stiffness of the spring. The equation of motion for point mass $m_2$ is the same as in Eq. (4).

The relation between the damping coefficient $C_a$ of the damper versus the maximum absolute value $|x_1|_{\max}$ of displacement of mass point~1 and the maximum absolute value $|m_2(\ddot{u} + \ddot{x}_2)|_{\max}$ of inertia force of mass point 2 (roof section) when the stiffness $k_a$ of the spring is zero is shown in Fig. 8. As the value of $C_a$ increases, $|x_1|_{\max}$ becomes smaller and asymptotically approaches zero. The maximum absolute value $|m_2(\ddot{u} + \ddot{x}_2)|_{\max}$ of the inertia force of $m_2$ is smaller than that of the fully rigid connection between the first story ceiling beams and the shelter when $C_a$ exceeds about $10^5$ N·s/m. After that, it reaches a local minimum around $C_a = 5 \times 10^5$ [N·s/m], and then gradually rises to a value close to that obtained when

the ceiling beams and the shelter are fully rigidly connected. Hence, for the present model, a damping coefficient $C_a$ of about $5 \times 10^5$ N·s/m for the viscous damper connecting the building and the shelter can be deemed appropriate. The results of this analysis support the statement "In an existing two-story building without enough strength of the first story, the response of the first story can be significantly reduced by connecting a shelter, while the response of the second story increases. In this case also, the increase of the second layer response can be suppressed by connecting with oil dampers." as described in the Conclusions of the paper by Matsumoto et al. [3].

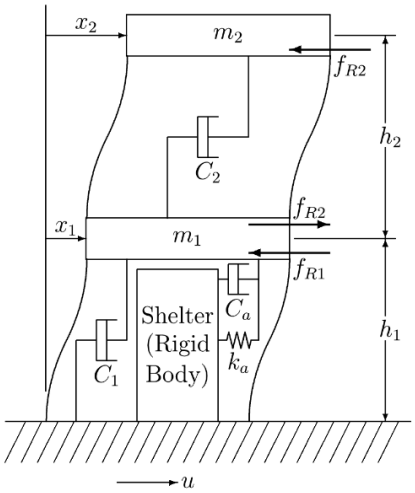


Figure 7. Two-story structure connected with shelter.



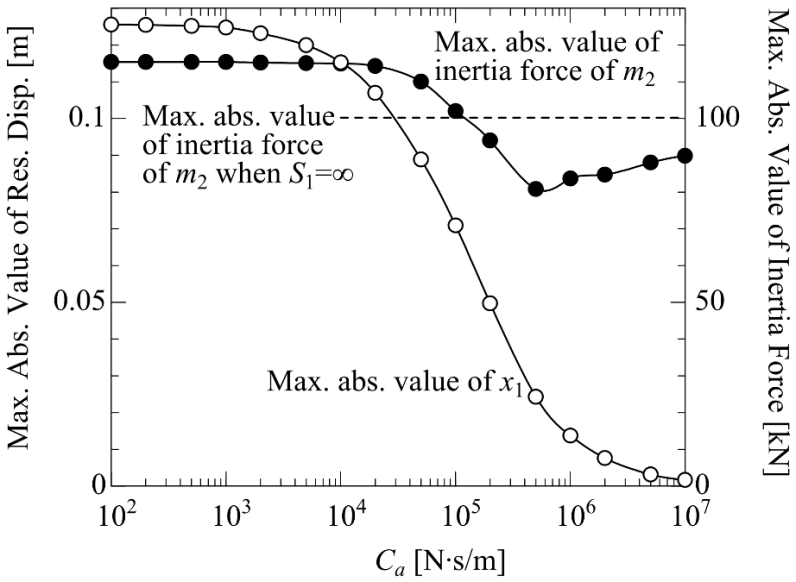


Figure 8. Maximum absolute values of $x_1$ and inertia force of $m_2$ as functions of damping coefficient $C_a$ of dashpot ($S_1 = S_2 = 1$, $R = 1$, $k_a = 0$).

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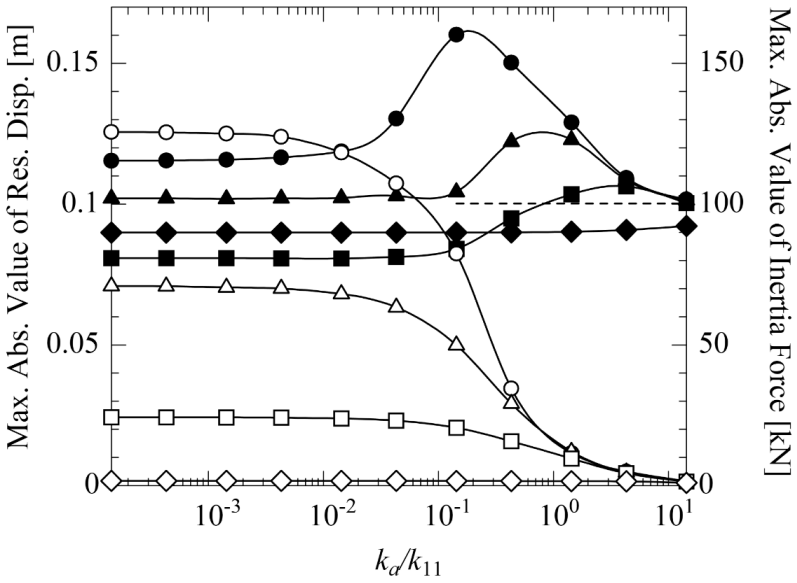


Figure 9. Maximum absolute values of $x_1$ and inertia force of $m_2$ as functions of spring constant $k_a/k_{11}$ ($S_1 = S_2 = 1$, $R = 1$): open symbols, max. abs. values of $x_1$; closed symbols, max. abs. values of inertia force of $m_2$; circles, $C_a = 0$; triangles, $C_a = 10^5$ [N·s/m]; squares, $C_a = 5 \times 10^5$ [N·s/m]; diamonds, $C_a = 10^7$ [N·s/m]; dashed line, max. abs. value of inertia force of $m_2$ when $S_1 = \infty$.



Fig. 9 shows the relationship between the stiffness $k_a/k_{11}$ of the spring versus the maximum absolute value $|x_1|_{max}$ of displacement of mass point 1 and the maximum absolute value $|m_2(\ddot{u} + \ddot{x}_2)|_{max}$ of inertia force of mass point 2 (roof section). In this graph, the maximum absolute value of the inertia force of $m_2$ rises rapidly from about $k_a/k_{11} = 10^{-2}$, so here also it can be said that the inertia force of the roof section may become excessive due to the increase of first story stiffness. The maximum absolute value of $x_1$ does not change significantly within the range of $k_a/k_{11} < 10^{-2}$, and there is little suppression of the deformation amount. It seems unnecessary to consider cases where $k_a/k_{11}$ is larger than that, because the stiffness of springs used in shock absorbers is typically sufficiently small compared to story stiffness.

In order to determine the appropriate $C_a$, it is necessary to correctly identify the restoring force characteristics of the structure. However, since it is unrealistic to conduct full-scale experiments for each building, Araki et al. [1] proposed a method to predict the hysteresis model. Furthermore, the recent development of the Software for Collapsing Analysis of Wooden Houses “wallstat” has made it relatively easy to perform pushover (nonlinear static) analysis and to estimate the restoring force characteristics more accurately [6, 7].

## 4. CONCLUSIONS

In this study, the effect of first story stiffness on the inertia force of the roof section during an earthquake has been simulated, and guidelines for more effective seismic reinforcement have been considered. The following conclusions can be drawn from the above analysis:

1. Even if the stiffness of one part of a structure is increased, this may cause higher inertia forces in other parts of the structure during an earthquake. Hence, it is necessary to consider not only a part of the structure but also the whole structure in order to determine the seismic reinforcement method for multi-story buildings [multi-mass (multi-degree-of-freedom) structures].

2. When an anti-seismic shelter is installed on the ground floor of a building, the effect of seismic reinforcement is greater if the shelter is connected to the first story ceiling beams through appropriate damping devices than if the shelter is completely rigidly connected to the first story ceiling beams, because the absolute acceleration of the roof section during an earthquake can be suppressed more.

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# Bir Ameliyathane Malzemeleri Dikiş Fabrikası İçin En Önemli Hata Türünün AHP ile Belirlenmesi

Determination of the Most Important Defect Type for an Operating Room Materials Sewing Factory Using AHP

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## Özet

Bu çalışmada, ameliyathane malzemeleri üreten bir dikiş fabrikasında görülen hata türlerinin önceliklendirilmesi Analitik Hiyerarşi Prosesi (AHP) ile gerçekleştirilmiştir. Çalışmada değerlendirilen hata türleri ölçüsel hatalar, yanlış ve eksik malzeme kullanımı, katlama hataları ve siparişe uygun üretilmeme olup; kriterler olarak zaman, maliyet, kalite, müşteri memnuniyeti ve miktar alınmıştır. İki uzman tarafından yapılan ikili karşılaştırmaların geometrik ortalaması alınarak bütünleşik öncelik ağırlıkları hesaplanmış, sonuç olarak siparişe uygun üretilmeme en yüksek öncelik ağırlığına sahip hata türü olarak tespit edilmiştir. Elde edilen bulgular, AHP ve Fuzzy-AHP tabanlı yaklaşımların üretim hatalarının risk/önceliklendirilmesinde etkinlik sağladığına ilişkin son literatürle uyumludur. Bu çalışma hata türleri için yapılan hata türleri ve etkileri analizlerine farklı bir bakış açısı getirerek hiyerarşik modelleme ile çok kriterli yaklaşımla ele almaktadır. Ele alınan kriterler arasında zaman, maliyet, kalite, müşteri memnuniyeti ve miktar bulunmakta olup iki uzman görüşüne göre hata türleri için en önemli kriter müşteri memnuniyeti olarak belirlenmiştir. Bu çalışma diğer çok kriterli karar verme teknikleri kullanarak geliştirilebilme potansiyeli taşımaktadır.

**Anahtar Kelimeler:** Ameliyathane malzemeleri üretimi, Hata Türleri, AHP

## Abstract

In this study, prioritizing defect types for a sewing factory that produces operating room materials were accomplished through Analytic Hierarchy Process (AHP). Defects types evaluated in this study are; measurement errors, false and inefficient material usage, folding defects, not producing according to orders. Criteria for faults are time, cost, quality, customer satisfaction and quality. Aggregated priority weights are computed based on geometric average of two experts' opinions for pairwise comparisons. As a result, producing inappropriately to orders was found to be the most significant fault type having the greatest priority weight. Findings are matching the recent findings obtained through AHP and Fuzzy AHP applications for prioritizing risks for production defects. This study, different than the traditional approach

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of fault types and their effects analysis, deals with defects types hierarchically as a multi criteria decision making approach. Among the criteria of time, cost, quality, customer satisfaction and quantity considered in this study, customer satisfaction was determined to be the most important criterion. This study contains potentials to be extended through the application of other multi-criteria decision making techniques.

**Key words:** Production of materials for operating room, fault type, AHP

## GİRİŞ

Üretim süreçlerinde ortaya çıkan hatalar hem operasyonel maliyetleri artırır hem de ürün kalitesi ve müşteri memnuniyeti üzerinde olumsuz etki oluşturur; medikal ürünler gibi yüksek güvenilirlik gerektiren alanlarda bu riskler daha kritik bir hal alır. Bu nedenle hataların sistematik biçimde tanımlanması ve önceliklendirilmesi, sınırlı kaynakların etkin kullanımını sağlayacak iyileştirme önlemlerinin belirlenmesi açısından gereklidir. Geleneksel FMEA yaklaşımları yaygın olmakla birlikte, değerlendirmelerdeki öznel belirsizlikleri azaltmak amacıyla AHP ve Fuzzy-AHP gibi çok kriterli karar verme (MCDM) yöntemleri literatürde tercih edilmektedir (Alharairi et al., 2025; Chang, 2022).

AHP, karar kriterleri arasındaki göreli önemleri nicel biçimde ortaya koyarak, hata türlerinin çok-kriterli bir perspektifle sıralanmasını sağlar. Son dönemde üretim hataları, insan kaynaklı faktörler ve tedarik/tedarikçi kaynaklı sorunların değerlendirilmesinde AHP ve Fuzzy-AHP uygulamaları artış göstermiştir: örneğin insan hatalarını Fuzzy Delphi + Fuzzy AHP ile inceleyen çalışmalar (Alqahtani & Noman, 2024) ve Fuzzy AHP-FMEA bütünleşimiyle risk önceliklendirme sunan uygulamalar (Perić et al., 2025) yakın dönemde yayımlanmıştır; bu çalışmalar metodolojik olarak mevcut çalışmanın çerçevesiyle doğrudan ilişkilidir.



Çalışmanın hedefleri şu şekilde özetlenebilir: (1) fabrikada gözlemlenen hata türlerini açıkça sınıflamak, (2) karar kriterlerini belirleyip uzman değerlendirmeleriyle AHP matrikslerini kurmak, (3) bütünleşik öncelik ağırlıklarını hesaplayıp hangi hata türünün öncelikli olduğunu tespit etmek ve (4) duyarlılık analiziyle kriter ağırlık değişimlerinin alternatiflere etkisini inceleyerek uygulamaya dönük öneriler üretmektir. Bu yaklaşım, üretim hatalarının önceliklendirilmesinde yakın dönem literatürde vurgulanan (2023–2025) metodolojik eğilimlerle uyumludur (Fattoruso et al., 2024; Alharairi et al., 2025).

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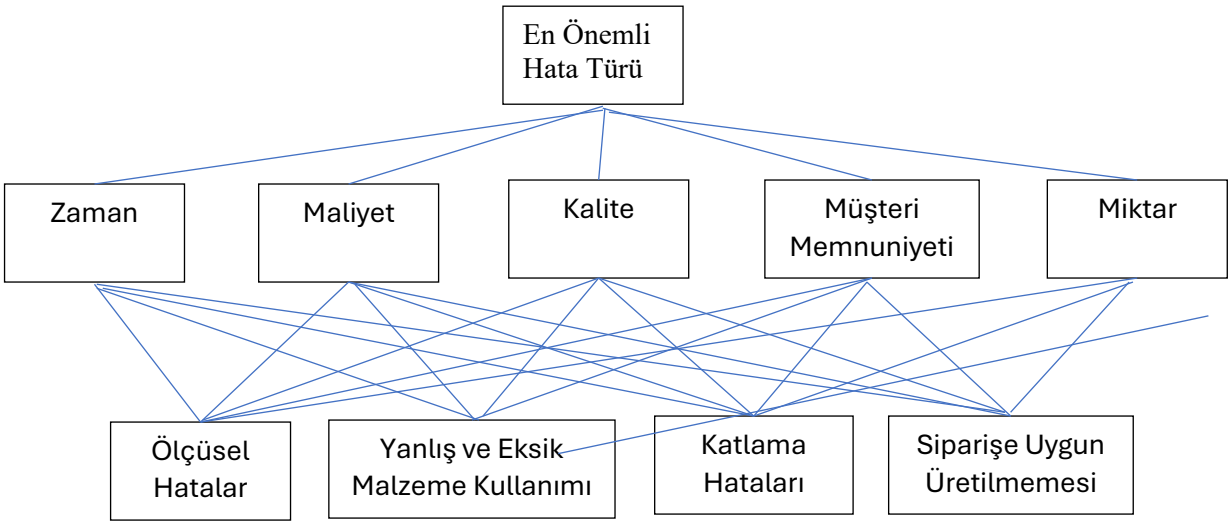
## YÖNTEM

Çalışmanın hiyerarşisi aşağıdaki şekilde verilmiştir.




Şekil 1. En Önemli Hata Türü için AHP Hiyerarjisi

En önemli hata türünü belirlerken hataların sebep olduğu "zaman" kaybı, "maliyet", "kalite"ye olumsuz etkisi, "müşteri memnuniyetine" olan etkisi ve hatanın "miktarı" dikkate alınmış. Hata Türleri ve Etkilerinden esinlenerek fabrikada gözlemlenen "ölçüsel hatalar", "yanlış ve eksik malzeme kullanımı", "katlama hataları" ve "siparişe uygun üretilmeme" AHP tekniği kullanılarak 2 uzmanın görüşüne göre değerlendirilmiş. Değerlendirmelerin geometrik ortalamaları ile bütünleşik değerlendirme de elde edilmiştir.



Kriterlerin (Zaman, maliyet, kalite, müşteri memnuniyeti, miktar) her iki değerlendirici ve bütünleşik sonuca göre öncelik ağırlıkları Tablo 1. De verilmektedir.

Tablo 1. Kriterlerin Öncelik Ağırlıkları

| **Kriter** | **1.Değerlendirici** | **2.Dğerlendirici** | **Bütünleşik Sonuç** |
|---|---|---|---|
| Zaman | 0.328 | 0.334 | 0.065 |
| Maliyet | 0.322 | 0.295 | 0.124 |
| Kalite | 0.186 | 0.153 | 0.289 |
| Müşteri Memnuniyeti | 0.091 | 0.158 | 0.495 |
| Miktar | 0.073 | 0.059 | 0.028 |

Birinci ve ikinci uzman değerlendiriciye göre en önemli kriter "zaman" (öncelik ağırlığı sırasıyla 0.328 ve 0.334) iken en az önceliğe hata miktarı (sırasıyla 0.073 ve 0.059) gözükürken bütünleşik değerlendirmede en önemli kriter müşteri memnuniyeti (0.495) en az öneme sahip kriter "miktar" (0.028) olarak gözükmektedir.

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Tablo 2. Hata Türlerinin Öncelik Ağırlıkları

| **Hata Türü** | **1.Değerlendirici** | **2.Dğerlendirici** | **Bütünleşik Sonuç** |
|---|---|---|---|
| Ölçüsel Hatalar | 0.198 | 0.169 | 0.166 |
| Yanlış ve Eksik Malzeme Kullanımı | 0.266 | 0.302 | 0.111 |
| Katlama Hataları | 0.064 | 0.070 | 0.194 |
| Siparişe Uygun Üretilmeme | 0.472 | 0.458 | 0.529 |

Birinci, ikinci uzmanların ve bütünleşik değerlendirmelerine göre en önemli hata türü "Siparişe uygun üretilmeme"(öncelik ağırlıkları sırasıyla 0.472, 0.458 ve 0.529) iken birinci ve ikinci uzmanlara göre en düşük öneme "katlama hataları" (öncelik ağırlıkları sırasıyla 0.064 ve 0.070) bütünleşik değerlendirmeye göre ise en az önceliğe "yanlış ve eksik malzeme kullanımı" (0.111) sahip olarak görülmektedir.

Her bir kriter için alternatiflerin bütünleşik karar matrislerine göre öncelik ağırlıkları Tablo 3 te görülebilir.

Tablo 3. Hata Türlerinin Her Bir Kriter için Öncelik Ağırlıkları

| **Hata Türü** | **Zaman** | **Maliyet** | **Kalite** | **Müşteri Memnuniyeti** | **Miktar** |
|---|---|---|---|---|---|
| Ölçüsel Hatalar | 0.463 | 0.611 | 0.037 | 0.048 | 0.660 |
| Yanlış ve Eksik Malzeme Kullanımı | 0.324 | 0.095 | 0.095 | 0.080 | 0.233 |
| Katlama Hataları | 0.035 | 0.037 | 0.257 | 0.232 | 0.064 |
| Siparişe Uygun Üretilmeme | 0.178 | 0.257 | 0.611 | 0.640 | 0.043 |

Zaman (0.463), maliyet (0,611) ve miktar (0.660) kriterlerine göre en öncelikli hata türü "ölçüsel hatalar" iken, "kalite" ve "müşteri memnuniyeti" için en öncelikli hata türü 0.611 ve 0.640 öncelik ağırlıklarıyla "siparişe uygun üretilmeme" olarak ortaya çıkmıştır.

Elde dilen çözümün esnekliği ve uygulanabilirliği hakkında fikir elde etmek için gerçekleştirilen duyarlılık analizleri bütünleşik çözüm için aşağıda sunulmaktadır. Öncelikle her bir kriter ağırlığı için alternatiflerin (hata türleri) nasıl etkilendiğini ortaya koymak için ExpertChoice'den performans duyarlılık analizleri kriter ağırlıklarına göre gerçekleştirilmiştir.

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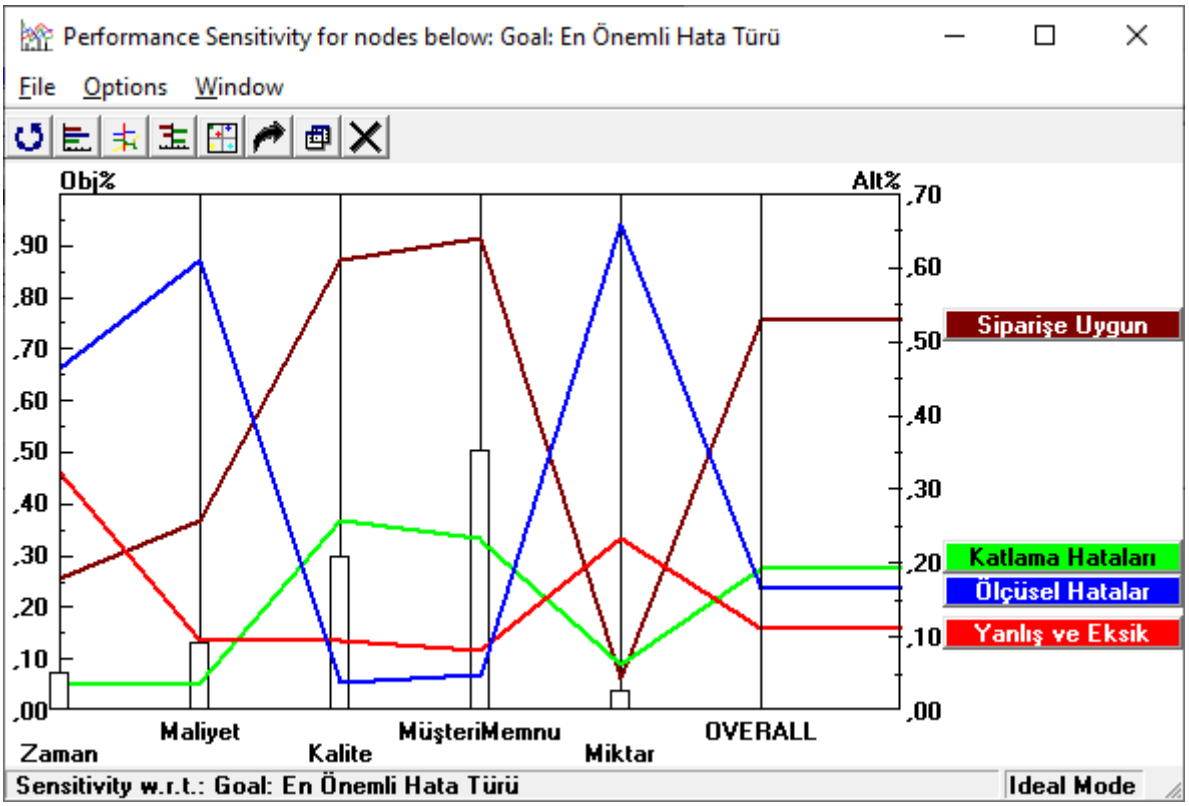
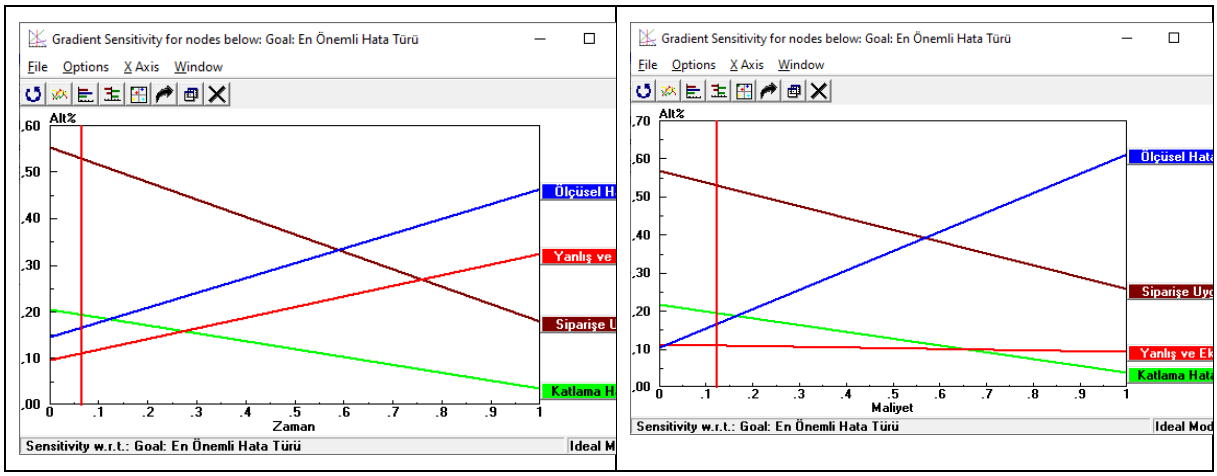


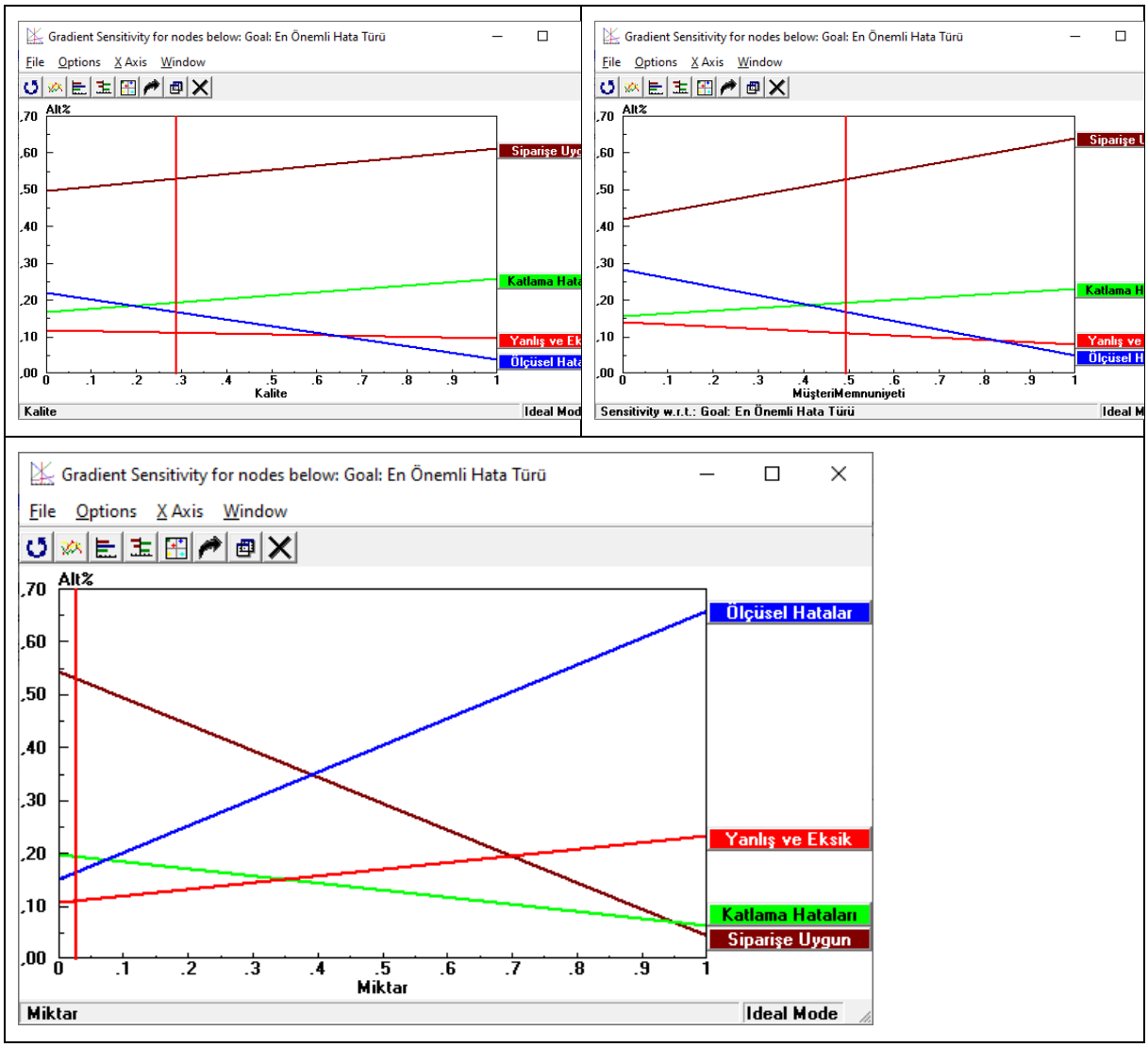

Şekil 2. Kriter Ağırlıklarına Göre Hata Türleri Performans Analizleri



Alternatiflere bakıldığında en önemli hata türü 0.5 in üzerinde öncelik ağırlığı ile "siparişe uygun üretilmeme" olduğu görülürken en etkili kriter 0.5 civarındaki öncelik ağırlığı ile "müşteri memnuniyeti olarak görülmektedir.

Gradient Aanaliz her bir kriter ağırlığından alternatiflerin nasıl etkilendiğini açıkça ortaya koymaktadır.

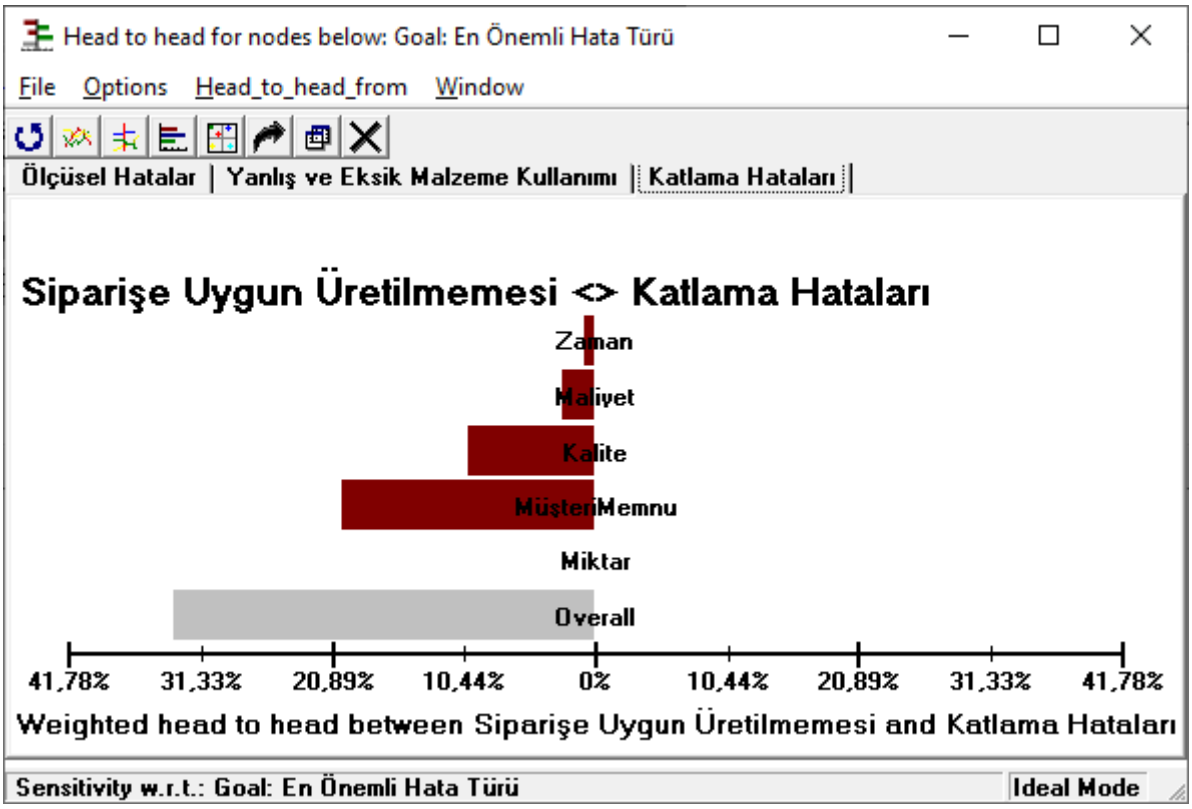





Şekil 3. Kriter Ağırlıklarına göre Duyarlılık Analizi

"Zaman" kriter ağırlığı ile "ölçüsel hatalar" ve "yanlış ve eksik malzeme kullanımı" doğrusal ilişki gösterirken "siparişe uygun üretilmeme" ve "katlama hataları" arasında ters ilişki olduğu görülmektedir. "Maliyet" kriterinin ağırşığı attıkça "Ölçüsel hatalar" ın önemi artarken, "siparişe uygun üretilmeme"nin önemi azalmaktadır. "Kalite" kriteri ile ise "ölçüsel hatalar" ile "yanlış ve eksik malzeme kullanımı" ters ilişkili gözükmekte diğer hata türleri ("siparişe uygun üretilmeme", "katlama" ) doğru ilişkiye sahip gözükmektedir. Müşteri memnuniyeti ile en çok "siparişe uygun üretilmeme" arasında pozitif ilişki gözlemlenirken "ölçüsel hatalar" arasında ters ilişki görülmektedir. "Miktar" ile "ölçüsel hatalar" ve "yanlış ve eksik malzeme kullanımı" arasında pozitif ilişki varken "siparişe uygun üretilmeme" ve "Katlama hataları" arasında negatif ilişki görülmektedir.

Öncelik ağırlıklarına göre ilk iki sırada yer alan "siparişe uygun üretilmeme" ve "katlama hataları" için başa-baş duyarlılık analizi yapılarak hangi kriterlerin hangi hata türüne daha çok desteklediği ortaya konmuştur.

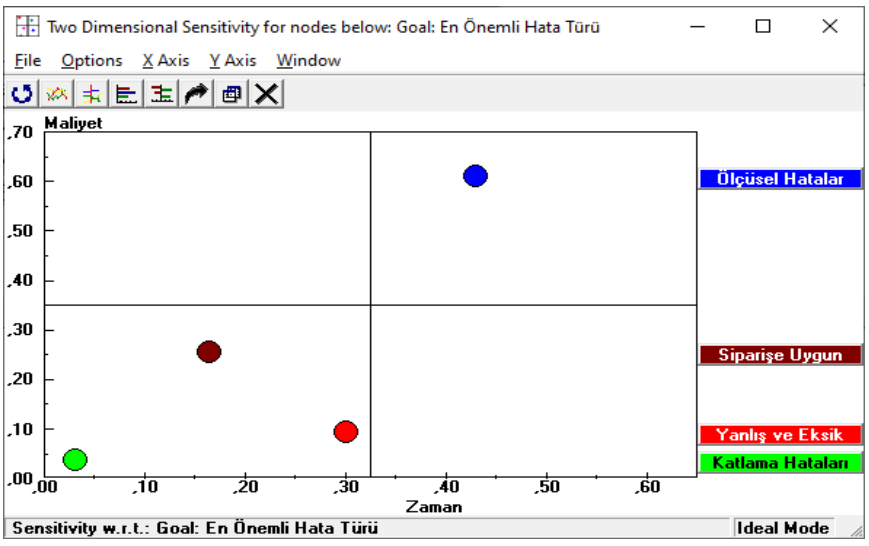



Sekil 4. Siparişe Uygun Üretilmeme ve Katlama Hataları için Başa-baş Analizi



Şekil 4'e göre en çok "Müşteri memnuniyeti" olmak üzere bütün kriterlerde Siparişe Uygun Üretilmeme Katlama Hatalarına göre daha fazla öneme sahip görülmektedir.

Alternatiflerin iki boyutlu (kriterler) için önem seviyeleri aşağıdaki duyarlılık şekillerinde gösterilmektedir.




Şekil 5. Zaman ve Maliyet için Alternatiflerin 2B Analizi

Zaman ve Maliyet göz önünde bulundurulduğunda "ölçüsel hataların" diğer hata türlerine (siparişe uygun üretilmeme, yanlış ve eksik malzeme kullanımı, katlama hataları) baskınlık kurduğu görülmektedir.

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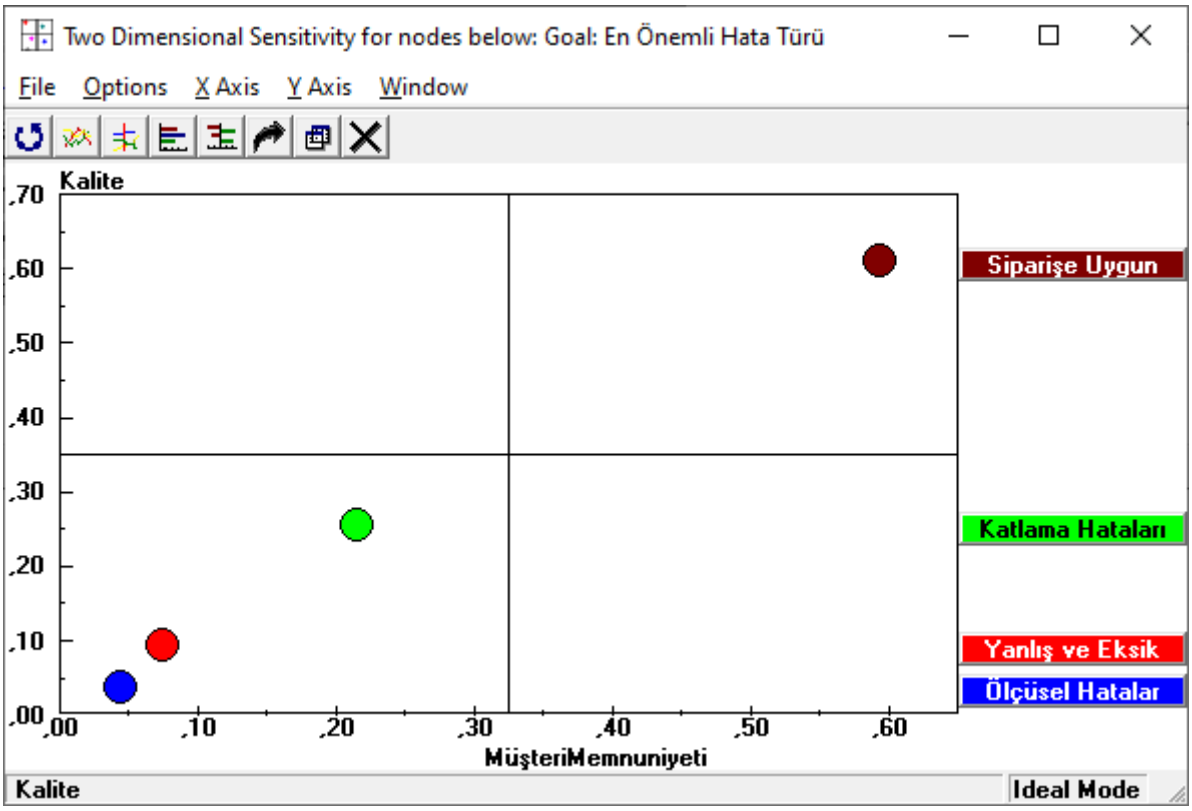


Şekil 5. Müşteri memnuniyeti ve Kalite için Alternatiflerin 2B Analizi



"Müşteri memnuniyeti" ve "Kalite" kriterleri göz önünde bulundurulduğunda "Siparişe Uygun Üretilmememe" hata türü diğer hata türlerine (katlama hataları, yanlış ve eksik malzeme kullanımı, ölçüsel hatalar) baskınlık kurmaktadır. Bu bulgular yukarda belirtilen önceki bulgularla örtüşmektedir.

## SONUÇ ve ÖNERİLER

Bu çalışma i,le bir ameliyat malzemeleri üretici fabrikada hata türlerinin önemi çok kriterli karar verme tekniklerinden analitik hiyerarşi metodu ile incelenmektedir. Literatürde yaygın olarak hata türleri ve etkileri analiz metodu kullanılırken farklı bir yaklaşım olarak fabrika da çalışan iki uzman değerlendiriciye göre "zaman", "maliyet", "kalite", "müşteri memnuniyeti" ve "miktar" kriterlerine göre "ölçüsel hatalar", "yanlış ve eksik malzeme kullanımı", "katlama hataları" ve "siparişe uygun üretilmeme" hata türleri değerlendirilmiş, bütünleşik ikili karşılaştırma matrislerinden elde edilen sonuçlara göre duyarlılık analizleri yapılmıştır.

Bulgulara göre en önemli hata türü "siparişe uygun üretilmeme" olarak tespit edilirken en az öneme "yanlış ve eksik malzeme kullanımı" sahip görülmektedir. Yapılan duyarlılık analizlerine göre "zaman" ve maliyet" kriterleri göz önünde bulundurulduğunda "ölçüsel hatalar" diğer hata türlerine baskınlık sağlarken "müşteri memnuniyeti" ve "kalite" kriterlerine göre ise "siparişe uygun üretilmeme" diğer hata türlerine baskınlık sağlamaktadır.

Bu çalışma ile sınırlı kaynakları iyileştirme faaliyetlerinde kullanmak için kullanırken "siparişe uygun üretilmeme" konusunda daha dikkatli ve titiz olmanın önemi ortaya çıkmaktadır. Çalışma literatürde var olan vikor, promethee, topsis, elektre gibi diğer çok kriterli karar verme metotlarının uygulanmasıyla genişletilebilir ve karşılaştırmalı sonuçlar analiz edilebilir.

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# Orman Yangınlarıyla Mücadeleye Yapay Zekâ Destekli Farklı Bir Çözüm Önerisi

A Different Solution to Forest Fires, Supported by Artificial Intelligence

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## Özet

Ormanlar, oksijen kaynağı olan ağaçların yanında birçok canlının da yuvasıdır. Yangınlar ise ormanları yok eden felaketlerin başında gelmektedir. Özellikle orman yangınlarının tespitinin gecikmesi bu gecikmenin sonucunda da erken müdahale edilememesi yangının kontrolünü zorlaştırmakta bunun sonucunda da faciaya neden olmaktadır.

Teknoloji geliştikçe yaşantımızı, hayatımızı kısacası her şeyimizi bu doğrultuda geliştiririz. Problemlerimizin çözümünü de teknoloji de ararız. Dünyamız ve hayat için gerekli olan orman yangınları ile mücadele önem arz etmekte olup orman yangını ile mücadele eden ekipleri rahatlatacak çalışmalarında yapılması gereklilik arz etmektedir.

**Anahtar Kelimeler:** Yapay zeka, Orman, Yangın, Teknoloji

## Summary

Forests are not only a source of oxygen but also a home for many living creatures. Fires are a leading cause of forest destruction. Delayed detection of forest fires, and the resulting inability to intervene early, makes fire control difficult and ultimately leads to disaster.

As technology advances, we evolve our lives, our lives—in short, everything—in this direction. We also seek solutions to our problems in technology. Fighting forest fires, essential to our world and to life itself, is crucial, and efforts to provide relief to forest firefighters are essential.

**Keywords:** Artificial Intelligence, Forest Fire, Technology

## 1. Giriş

Depremler, aktif fay hatları üzerinde bulunan ülkeler için ciddi bir tehdit oluşturmaktadır ve Türkiye, dünyanın en çok deprem riski taşıyan bölgelerinden biridir. Resmi sismik tehlike haritalarına göre Türkiye topraklarının %92'si deprem bölgeleri içinde yer almakta ve nüfusun %95'i bu sürekli risk altında yaşamaktadır. Depremler, insan hayatı ve altyapı üzerinde yıkıcı

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etkiler yaratabilmektedir. Büyük bir depremin ardından karşılaşılan en büyük zorluklardan biri, “altın 72 saat” olarak bilinen kritik sürede enkaz altında kalan hayatta kalmış kişilere ulaşabilmektir. Hayatta kalanlar genellikle yıkıntılar arasında oluşan doğal boşluklarda bulunurlar, ancak zaman geçtikçe yaşama şansları hızla azalır. Bu nedenle, yapıların çökmesini erken tespit etmek ve içeride kalan kişilere ait bilgilere hızlıca erişmek, arama kurtarma çalışmalarının etkinliği açısından hayati öneme sahiptir. 6 Şubat'ta Türkiye'yi vuran yıkıcı deprem, kurtarma ekiplerine anında kritik verileri sunabilecek teknolojik bir sistemin ne kadar gerekli olduğunu ortaya koymuştur. Bu veriler; içeride kalan bireyin bulunduğu kat ve daire konumu, telefon numarası, acil durumda aranacak yakınları, kronik hastalıkları ve düzenli kullandığı ilaçlar gibi bilgileri içermektedir. Bu tür bilgilere ulaşmak, kurtarma sürecini önemli ölçüde hızlandırarak hayatta kalma oranlarını artırabilir.

## 2. Amaç

- Deprem sonrası yıkılan bina/yapı içinde mahsur kalan insanları belirleyerek bilgilerini, bina krokisini, adres ve konumunu beli bir yere gönderebilen yapay zeka temelli bir sistem tasarlamak.
- Tasarlanabilirse bina/yapılarda kullanılabilmek.
- Geliştirdiğimiz arama kurtarma ekiplerinin enkaza müdahalesi daha hızlı olabilmesini sağlamak.

## 3. Önem

Yapmış olduğumuz sistem sayesinde enkaz/enkazlar altında kalan insanlara arama kurtarma ekiplerinin ulaşımı daha hızlı olacağından dolayı can kayıpları azalacaktır.



## 4. Metod

### 4.1. Araştırma Yöntemi

Çalışmamızda deneysel araştırma yöntemi, saha çalışması uygulanmıştır.

### 4.2. İşlem adımları

Problem tespit edildi. Literatür taraması yapıldı. Hipotez ileri sürüldü. Projemizde kullanacağımız ‘Raspberry Pi 5, MPU6050 ivmeölçer, A2 microSd card, Raspberry Pi Kamera 3 Geniş Açı, Wi-Fi Bağlantısı, jumper kablo, breadboard, powerbank’ den oluşan elektronik malzemeler temin edildi. Elektronik malzemelerin devre şeması çıkarılıp proje amacına uygun şekilde bütünleşik hale getirildi Bina/yapı girişlerine yerleştirilecek olan sistemin proje amacına uygun olarak çalışabilmesi için kodlama/yazılımlar yazılarak, Raspberry Pi 5karta yükleme yapıldı. Sistemimizi kuracağımız kutu Fusion 360 programı kullanılarak çizildi ve 3D baskısı alındı. Sistemimizin bilgileri ileteceği panel oluşturuldu ve sistem ile panel arasında iletişim kuruldu. Geliştirdiğimiz sistem test edildi. Bu sistem ile ilgili hipotezimizi sınamak için bina/yapıya yerleştirildi ve saha çalışması yapılarak raporlaştırıldı.

Sistemimizin, belirlediğimiz amaçlara ulaşması için panel kodlaması php framework olan laravel ile ile yapılmış olup panel yazılımı için bir buçuk milyon kod tarafımızdan yazılmıştır. Projemizin hem yüz tanıma hem de deprem sensörü verilerini okuma gibi işlemleri içermesi nedeniyle, kod düzenleme, hata ayıklama ve genişletilebilirlik açısından daha güçlü bir IDE

tercih edilmesi gerekmektedir. Bu bağlamda, PyCharm kullanımı tercih edilmiş olup bu bölümün %70 nin yazılımı tarafımızdan yazılarak oluşturulmuştur. Enkaz altında kalan kişilerden hayatta olup olmadığı ile ilgili bildirim alabilmek için mobil uygulama tasarlanarak panel' e entegre edildi.Bu uygulama Figma üzerinden gerçekleştirerek kullanıcı dostu ve etkileşimli bir arayüz oluşturduk. Uygulamanın kodlamasını ise Flutter kullanarak geliştirdik.

### 4.3. Sistemin çalışma prensibi

Deprem sonrası arama işleminin sonunda kurtarma operasyonlarına geçilir. Arama işlemi ne kadar kısa sürede bitirilirse o kadar çabuk kurtarma operasyonu başlar. Bunu sağlamak için yaptığımız sistemde MPU6050 ivmeölçer kullandık. Depremi algılayan bu sensör, yazdığımız yazılım sayesinde taşınabilir modem vasıtasıyla gene yazılım/kodlaması tarafımızdan milli ve yerli olarak yazılarak oluşturulmuş panelimize bilgileri iletir. Bu bilgiler o an bina/yapıda bulunan ve çıkamayan kişilerin hangi katta hangi cephede oturdukları, cep numaraları, sağlık durumları, sürekli kullandıkları ilaçlar, yakınlarına ait telefon numaralarıdır. Panelimize giriş yapan yetkili bu bilgiler ile birlikte daha önceden panele yüklenmiş olan bina/yapı krokisi ve konum bilgilerini tek tuşla indirir. Bu bilgileri arama kurtarma ekibine yönlendirerek kurtarma işleminin daha çabuk başlanası sağlanmış olur

## 5. Bulgular

| NO | Deprem Tarihi | Deprem Merkezinin Sistemimize Uzaklığı | Derinlik | Büyüklük | Sistemin Çalışması |
|---|---|---|---|---|---|
| 1 | 2024-06-11 23:15:536 | 7 KM | 6.2 | 3.6 | Çalıştı |
| 2 | 2024-06-16 20:24:51 | 24 KM | 7.0 | 4.4 | Çalıştı |

**Tablo 1**. Saha Çalışması

Sistemimiz Malatya ili Yeşilyurt ilçesi Bıla mahallesi Arpacı sokakta bulanan YıldızAnka apartmanına 08.06.2024 tarihinde kurulmuştur. Binamızda 13 kadın ve 16 erkekten oluşan 29 kişi yaşamaktadır. En genci 3, en yaşlısı 68 yaşındadır. Kurulumdan 23.06.2024 tarihine kadar 2 adet deprem olmuş ve sistemimiz çalışarak sunucuya apartmanda kalan kişilerin bilgilerini iletmiştir. Sistem yöneticisi hazırlamış olduğumuz siteye girerek sistemimizden gelen binada kalan kişilerin bilgileri, kroki, bina konumuna tek tuşla ulaşmıştır. Aynı bilgiye AFAD yada diğer kurumlarda sisteme girerek ulaşmaktadır.

11 Haziranda meydana gelen deprem sonucunda sistemimizden alınan bilgi Tablo 2' de gösterilmiştir.

| **Kat/No ve Yön** | **Binada Oturanların adı soyadı ve telefonları** | **Yaş** | **Yakınlarına Ait Telefon** | **Sürekli Kullandığı İlaçlar / Geçirdiği Ameliyatlar** |
|---|---|---|---|---|
| Z.KAT 1 DOĞU | ARİF UYAR 0530 ****** YASİN DUTLU | 54 26 | MEHMET UYAR 0530 ** SİNEM | BYPAS AMELİYATI …… |

| | | | | |
|---|---|---|---|---|
| | 0530 ****** | | DUTLU 0530 ** | |
| Z. KAT 2 BATI | SADIK ÇİFTÇİ 0530 ****** | 68 | MELİS ÇİFTÇİ 0530 *** | YOK |
| 1. KAT 3 DOĞU | KADİR ÖZCAN 0530 ****** FERİDE ÖZCAN 0530 ****** MUSTAFA ÖZCAN 0530 *** | 42 45 17 | SADIK ÖZCAN 0530 *** | BEL FITIĞI ……. ASTIM (ASMOL-EPAQ) |
| 1. KAT 4 BATI | EMRAH GÜRCÜ 0530 **** SIDIKA GÜRCÜ 0530 **** HAKAN GÜRCÜ 0530 ***** MELİKE GÜRCÜ | 42 39 12 3 | ALİ GÜRCÜ 0530 ****** | YOK |
| 2. KAT 5 DOĞU | MURAT CANPOLAT 0530 ** GÜNEŞ CANPOLAT 0530 ** ALPEREN CANPOLAT 0530 AHMET CANPOLAT 0530 ** | 47 45 18 11 | BUĞRAHAN CANPOLAT 0530 *** | YOK YOK YOK ASTIM(VENTOLİN) |
| 2. KAT 6 BATI | GÖKÇE NAZ KAYA 0530 ** | 67 | A. ÖNDER KAYA 0530 ** | YÜRÜME ENGELLİ VE İŞİTME KAYBI VAR.(%70) |
| 3. KAT 7 DOĞU | NİHAT TOROMAN 0530 *** AYŞE TOROMAN 0530 **** DUYGU TOROMAN 0530 * | 52 41 13 11 | VELİDE AHİN 0530 **** | YOK YOK ASTIM (ASMOL) YOK |

| | | | | | |
|---|---|---|---|---|---|
| 3. KAT<br>8<br>BATI | ŞAHİN AYBAR<br>0530 ******<br>ÖMER AYBAR<br>0530 ******<br>NEJMİYE AYBAR<br>0530 *** | 48<br>71<br>42 | MUSTAFA AYBAR<br>0530 ****** | YOK<br>KAYBI<br>Y.TANSİYON(KAPTORİL) | İŞİTME |
| 4. KAT<br>9<br>DOĞU | AHMET YEGİN 0530 ******<br>ZÜLEYHA YEGİN 0530 *** | 32<br>57<br>51 | MURAT YEGİN 0530 *** | C | YOK |
| 4. KAT<br>10<br>BATI | HATİCE NUR KAYA<br>0530 ** | 22 | VELİ KAYA<br>0530 ****** | YOK | |
| 5. KAT<br>11<br>DOĞU | ŞEYMA TAYİLAN<br>0530 *** | 38 | EMİNE TAYİLAN<br>0530 ** | YOK | |
| 5. KAT<br>12<br>BATI | ZEHRA ANGİŞHAN<br>0530 ***<br>FERİDE AKTAY<br>0530 ****** | 32<br>57 | YUSUF AKTAY<br>0530 *** | YOK<br>TANSİYON VE ŞEKER (KAPTORİL) | Y. |



**Tablo 2**. Sistemden Alınan Bilgi

Bu bilgiye göre deprem gece saat 23:15 de olduğundan dolayı binamızda 26 kişi bulunmakta olup sisteme gelen bilgi yukarıda gösterilmiştir.

16 Haziranda meydana gelen deprem sonucunda sistemimizden alınan bilgi Tablo 3' de gösterilmiştir.

| **Kat/No ve Yön** | **Binada Oturanların adı soyadı ve telefonları** | **Yaş** | **Yakınlarına Ait Telefon** | **Sürekli Kullandığı İlaçlar / Geçirdiği Ameliyatlar** |
|---|---|---|---|---|
| Z.KAT<br>1<br>DOĞU | ARİF UYAR<br>0530 ****** | 54<br>26 | MEHMET UYAR 0530 **<br>SİNEM DUTLU<br>0530 ** | BYPAS AMELİYATI |
| Z. KAT<br>2<br>BATI | SADIK ÇİFTÇİ<br>0530 ****** | 68 | MELİS ÇİFTÇİ 0530 *** | YOK |

| | | | | |
|---|---|---|---|---|
| 1. KAT 3 DOĞU | KADİR ÖZCAN 0530 ****** FERİDE ÖZCAN 0530 ****** | 42 45 | SADIK ÖZCAN 0530 *** | BEL FITIĞI ..... |
| 1. KAT 4 BATI | SIDIKA GÜRCÜ 0530 ***** MELİKE GÜRCÜ | 39 3 | ALİ GÜRCÜ 0530 ****** | YOK |
| 2. KAT 5 DOĞU | ALPEREN CANPOLAT 0530 AHMET CANPOLAT 0530 ** | 18 11 | BUĞRAHAN CANPOLAT 0530 *** | YOK ASTIM(VENTOLİN) |
| 2. KAT 6 BATI | GÖKÇE NAZ KAYA 0530 *** | 67 | A. ÖNDER KAYA 0530 ** | YÜRÜME ENGELLİ VE İŞİTME KAYBI VAR.(%70) |
| 3. KAT 7 DOĞU | AYŞE TOROMAN 0530 **** M. ALİ TOROMAN 0530 * DUYGU TOROMAN 0530 * | 41 13 11 | VELİDE AHİN 0530 **** | YOK ASTIM (ASMOL) YOK |
| 3. KAT 8 BATI | ÖMER AYBAR 0530 ****** | 71 42 | MUSTAFA AYBAR 0530 **** | İŞİTME KAYBI |
| 4. KAT 9 DOĞU | BATUHAN YEGİN 0530 **** AHMET YEGİN 0530 ****** | 32 57 | MURAT YEGİN 0530 *** | |
| 4. KAT 10 BATI | HATİCE NUR KAYA 0530 *** | 22 | VELİ KAYA 0530 ****** | YOK |
| 5. KAT 11 DOĞU | ŞEYMA TAYİLAN 0530 ***** | 38 | EMİNE TAYİLAN 0530 ** | YOK |
| 5. KAT 12 BATI | FERİDE AKTAY 0530 ****** | 32 57 | YUSUF AKTAY 0530 *** | Y. TANSİYON VE ŞEKER (KAPTORİL) |

**Tablo 3**. Sistemden Alınan Bilgi

Bu bilgiye göre deprem gece saat 20:24 de olduğundan dolayı binamızda 18 kişi bulunmakta olup sisteme gelen bilgi yukarıda gösterilmiştir.

Projemiz ile ilgili İnönü Üniversitesi Yazılım Mühendisliği öğretim görevlileri ile yapılan görüşmede projemiz anlatılmış, çalışma sistemi de uygulamalı olarak gösterilmiştir. Projemiz ile ilgili olarak "**Projeyi beğendiniz mi? Binalarda/yapılarda uygulanabilir mi?**" soruları sorulmuştur. Bu sorulardan H.A.1 kodlu akademisyen birinci soruya "*çok beğendiğini…*" ikinci soruya "*uygulanabilir…"* şeklinde açıklama yapmıştır. Aynı sorulardan N.B.2 kodlu akademisyen birinci soruya "*beğendiğini, yapay zekanın çok farklı alanlarda kullanıldığını ancak bu amaçla kullanılan böyle bir sistem görmediğini…*" *ikinci soruya "gayet güzel bir şekilde uygulanabileceğini"* şeklinde açıklama yapmıştır.

Projemiz ile ilgili Malatya AFAD Müdürlüğü arama kurtarma teknikerleri ile yapılan görüşmede projemiz anlatılmış, çalışma sistemi de uygulamalı olarak gösterilmiştir. Projemiz ile ilgili olarak "**Projeyi beğendiniz mi? Enkaz alanına gittiğinizde bu sistemden alınan verilerin size sağladığı faydalar olur mu?** soruları sorulmuştur. Bu sorulardan V.D.1 kodlu tekniker birinci soruya "*çok beğendiğini…*"ikinci soruya "*sahaya gittiğimizde adresi bulunmasından, enkazın kroki çizilmesine, binada kalanların bilgisine ulaşılmasından hangi katta oturdukları bilgisine kadar bu bilgilere ulaşmak için çok zaman harcadıklarını hatta bazı zamanlarda toplayamadıklarını söyleyerek bu sistemin kendilerine çok ama çok faydası olacağı…"* şeklinde açıklama yapmıştır. Aynı sorulardan Y.H.2 kodlu tekniker birinci soruya "*beğendiğini, çok şaşırdığını ve etkilendiğini…*" *ikinci soruya "bizim işimizde kurtarma çalışmalarına geçmek çok önemlidir ve sizin sisteminiz bize çok büyük bir zaman kazancı sağlamakta…"* şeklinde açıklama yapmıştır.

## 6. **Kaynakça**



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# Exploration of Contemporary Space Dynamics: Spatial Design[1]

Çağdaş Mekân Dinamiklerinin Ortaya Çıkartılması: Mekansal Tasarım

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## Özet

Bu çalışmanın ana amacı çağdaş mekân dinamiklerine odaklanmak ve geleneksel mekân strüktürlerinden farklı olarak günümüz çağdaş esnek kullanıcı dostu, gün ve gün gelişen çağdaş mekân strüktürlerini ortaya çıkartmaktır. Mekânsal tasarım geleneksel mekân strüktürlerinden farklı bir şekilde mekânın dinamikleri olan, esneklik, zamansal büyüyebilme, konvekste, gibi parametreler ile çağdaş geçirgen esnek hafif mekânsal sınırların tasarımına odaklanır. Mekânsal tasarımda mekanlar arası sınırlar geleneksel yöntemlerden çok farklı olarak, duvar ve kapı ilişkisi ile değil, tasarımsal esnek öğeler ile sağlanır. Mekânsal tasarımın algıya dayalı bir tasarımdır, dolayısıyla oldukça hafif, esnek, geçirgen v e çok çeşitli dinamikler mekânsal tasarıma dahil olabilir. Gestalt algı kuramı ilkeleri mekânsal tasarımın ana kurgusunu oluşturarak, her türlü kompozisyona bir düzen ve estetik katar. Bu yüzden mekânsal tasarım algı kuramına dayalı olarak, mekân sınırlayıcılarını; noktasal elemanlar, düzlemsel elemanlar, kot farklılıkları, renk ve doku farklılığı, mobilyalar, 3 boyutlu mekân strüktürleri, aydınlatma ve baş üstü düzlemleri olarak asma tavanlar olarak sınıflandırır. Dolayısıyla mekânsal tasarım farklı mekanları bu sınırlayıcılar ile tanımladıktan sonra yine geleneksel oda-koridor mekân organizasyonu ilişkisinden farklı bir mekânsal organizasyon ile mekanları ilişkilendirir; derinlik, yoğunluk ve iç-içe geçme. Yeni mekân sınırlayıcılara ve mekânsal ilişkilere ek olarak mekânsal tasarımda grup mekân karakteristikleri olarak; gece ve gündüz kompartmanları, tekil mekân karakteristikleri olarak servis kompartmanları ve yeni mekân tipleri olarak; eşik, ikili, tekrarlı, ara, niş ve açık mekanlar olarak çağdaş mekân tipleri sunar. Bu çalışmada mekânsal tasarımın tüm dinamikleri ile tanıtılması ve örnekler üzerinden açığa çıkartılması amaçlanmış ve günümüz çağdaş, esnek, kullanıcı-dostu, değişebilen ve dönüşebilen, farklı senaryolara adaptasyon yeteneği yüksel çağdaş mekân dinamikleri sunulmuştur.

**Anahtar kelimeler:** Mekansal tasarım, Esneklik, Çağdaş mekanlar

## Abstract

The primary objective of this study is to focus on contemporary spatial dynamics and, unlike traditional spatial structures, to develop contemporary, flexible, user-friendly, and evolving spatial structures. Spatial design focuses on the design of contemporary, permeable, flexible, lightweight spatial boundaries, incorporating parameters such as flexibility, temporal

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scalability, and convexity, which are inherent to spatial dynamics. In spatial design, boundaries between spaces are established not through walls and doors, but through flexible design elements, significantly different from traditional methods. Spatial design is a design based on perception, and therefore, it can be quite lightweight, flexible, permeable, and incorporate a wide variety of dynamics. The principles of Gestalt theory of perception form the fundamental foundation of spatial design, bringing order and aesthetics to any composition. Therefore, based on perception theory, spatial design categorizes spatial boundaries as point elements, planar elements, elevation differences, color and texture variations, furniture, three-dimensional spatial structures, lighting, and overhead suspended ceilings. Therefore, after defining different spaces with these boundaries, spatial design associates these spaces with a spatial organization different from the traditional room-corridor relationship: depth, density, and interconnectedness In addition to new space boundaries and spatial relationships, it presents contemporary space types in spatial design, including group space characteristics such as day and night compartments, individual space characteristics such as service compartments, and new space types such as; liminal, dual, repetitive, intermediate, niche, and open spaces. This study aims to introduce spatial design in all its dynamics and reveal them through examples. It presents contemporary, flexible, user-friendly, changeable and transformable, and highly adaptable to different scenarios.

**Keywords:** Spatial design, Flexibility, Contemporary spaces

## 1. INTRODUCTION

Accordingly Ulrich Exner and Dietrich Pressel spatial design is defined as; ‘’*Spatial design can be generally defined as any type of active spatial appropriation, whether it is a room or a landscape. At the center of this group is space as a relationship, perceived sensorially and cognitively, between things, bodies or elements of the activated nature. Below, we discuss human perception of the built and natural environment, the characteristic phenomena of space, and the means and elements available for designing it’’(Exner&Pressel,2021).*



Thus as defined by Exner and Pressel, spatial design is the art of occupying spaces, differently from traditional cell-to-cell type configurations, spatial design aims to create contemporary, flexible, adaptable, multi-functional, human-based space design. Spaces can be quickly respond to changing user and usage scenarios and re-produced again again. Spatial design is a perception based design, it has close relation with gestalt design laws, such as; similarity, proximity, symmetry, good continuity, figure-ground relations. As highlighted by Exner and Pressel (2021) spatial design and perception relations which is called spatial perception defined as; *‘’The prerequisite for any spatial design and its effect is the human sensory and cognitive perception of the surrounding environment. All of the sensory stimuli conveyed by space are processed by the brain, which influences how an individual feels, behaves, and moves. Humans are believed to possess up to thirteen senses, including the five main senses of sight, hearing, touch, smell, and taste, as well as balance. Some people do not have access to all of the senses or are not able to perceive or fully perceive certain sensory stimuli such as light or sound. The sense of equilibrioception is responsible for perceiving gravity, and therefore spatial verticality, as the constant orientation in space’ (Exner&Pressel,2021).*

Spatial perception serves our basic orientation without our need to absorb all the spatial characteristics completely. We are constantly using new spaces in our daily lives. Much of a space’s information is processed so quickly by the senses and the cognitive system that it automatically influences our behavior without the need to first activate our thinking process. The human processing of perception and information quickly allows space to appear cozy or uncomfortable, claustrophobic or protective, without perceiving the spatial characteristics

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individually. We know the moment we enter a café whether we like the atmosphere or not.

### 1.1.Perception

Our visual field normally consists of heterogeneous elements that differ in shape, size, color, or orientation. To better comprehend the structure of a visual field, we tend to organize its elements which are perceived as figures and negative elements which provide a background for the figures. At the scale of a building, we tend to read the configurations of walls as the positive elements of a plan. The white space in between should not be seen simply as background for the walls, but also as figures in the drawing that have shape and form. The form and enclosure of each space in a building either determines or is determined by the form of the spaces around it. In the theater in Seinajoki by Alvar Aalto, we can distinguish several categories of spatial forms and analyze how they interact. Each category has an active or passive role in defining space. (Ching,1996) (Figure 1)

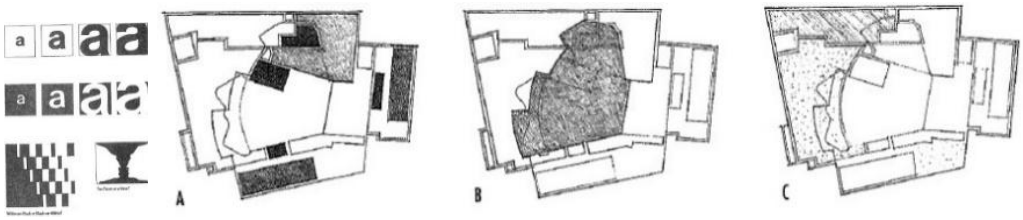


Figure 1. a) Letters are seen as dark figures against the White background of the paper surface, b) Alvar A. Alto,Theather in Seinajoki

### 1.2.Form Defining Space

This part illusturates space identifiers both horizontally and vertically such as; all sort of horizontal and vertical planes.



**1.2.1. Horizontal elements defining space:** a) Base Plane: A horizontal plane lying as a figure on a contrasting background defines a simple field of space. This field can be visually reinforced in the following ways. b) Elevated base plan: A horizontal plane elevated above the ground plane establishes vertical surfaces along its edges that reinforce the visual separation between its field and the surrounding ground. Section of Farnsworth house: Piona Illinois, 1950, Mies van Der Rohe. The Farnsworth house was constructed to rise above the flood plain of the Fox River. This elevated floor plans, together with an overhead roof plane, define a volume of space that hovers delicately above the surface of its site. (Ching,1996) (Fig.2)

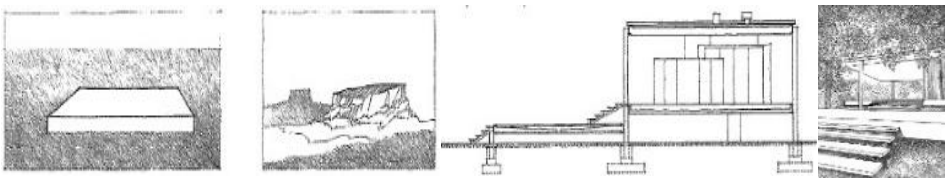

Figure 2. a) Base Plane, b) Elevated base plan

c) Depressed Base Plan:A horizontal plane depressed into the ground plane utilizes the vertical surfaces of the lowered area to define a volume of space. The degree of spatial continuity between a depressed field and the raised area surrounding it depends on the scale of the level change. d) Overhead Plane: A horizontal plane located overhead defines a volume of space between itself and the ground plane. Since the edges of the overhead plane establish the boundaries of this field, its shape, size and height above the ground plane determines the formal qualities of the space. Glass house, New Canaan, Connection, 1949, Philip Johnson. The roof plane can be the major space-defining element of a building and visually organize a series of forms and spaces beneath its sheltering canopy. (Figure 3)

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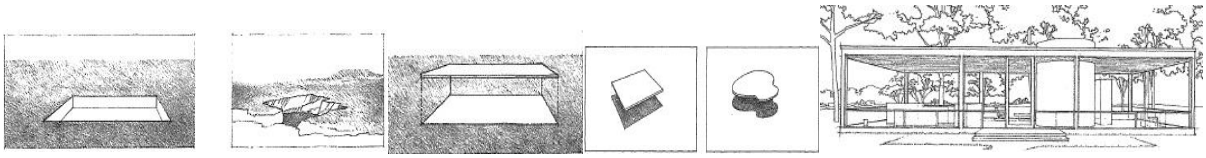

Figure 3. a) Depressed Base Plan, b) Overhead Plane, c) Glass house

**1.2.2. Vertical elements defining space- space as a 3-dimensional architectural element**

Vertical forms have a greater presence in our visual field than horizontal planes and are more instrumental in defining a discrete volume of space and providing a sense of enclosure and privacy for those within it. a) Vertical linear elements; define the perpendicular edges of a volume of space. b) Single Vertical Plane; articulates the space on which it fronts. c)L-shaped plane; a L-shaped configuration of vertical planes generates a field of space from its corner outward along diagonal axis. (Ching,1996) (Figure 4-5)

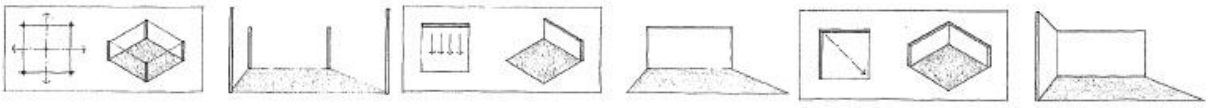

Figure 4.a) Vertical linear elements, b) Single Vertical Plane, c) L-shaped plane

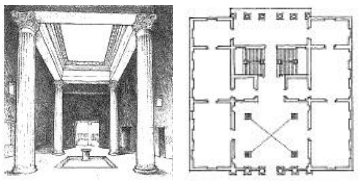

Figure 5. a) The four columns not only supported the vaulted ceiling, and the floor above but also adjusted the dimensions of the rooms to Palladian proportions.



**1.3. Organization of Form and Space**

This part presents the basic ways the spaces of a building can be related to one another and organized into coherent patterns of form and space. a. Space within a space: A large space can envelope and contain a smaller space within its volume. Visual and spatial continuity between the two spaces can be easily accommodated, Moore house, Orinda, California,1961, Charles Moore, Glass house, New Canaan, Connecticut,1949, Philip Johnson. b. Interlocking spaces: An interlocking spatial relationship results from the overlapping of two spatial fields and the emergence of a zone of shared space. When two spaces interlock their volumes in this manner, each retains its identity and definition as a space. Villa at Carthage, Tunisia 1928, Le Corbusier. c. Adjacent spaces Adjacency is the most common type of spatial relationship; it allows each space to be clearly defined and to respond, each in its own way, to specific functional or symbolic requirements. (Ching,1996) (Figure 6)

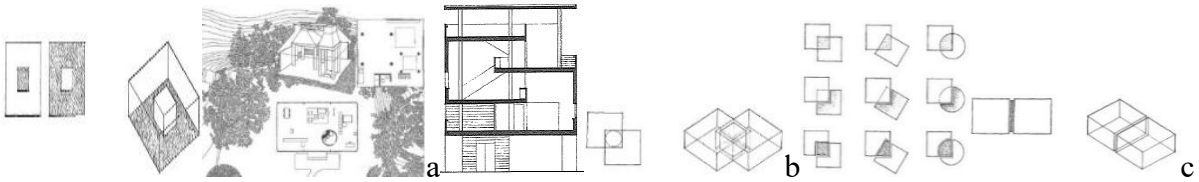


Figure 6. a) space within a space, b) interlocking spaces, c) adjacent spaces

d. Spaces linked by a common space: a) Two spaces which are separated by distance can be linked or related to each other by a third, intermediate, space. b) The visual and spatial relationship between the two spaces depends on the nature of the third space with which they share a common bond. The intermediate space can differ in form and orientation from the two

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spaces to express its linking function. c)One-half house (project) ,1966, John Hejduk.(Ching,1996) (Figure 7)

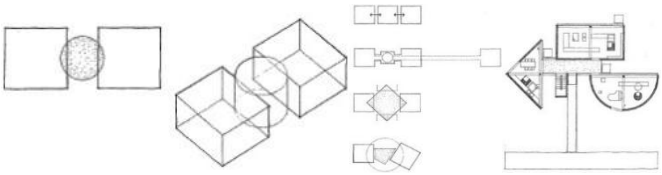

Figure 7. Spaces linked with a common space relation illustrations

## 2. SPATIALITY DEFINITIONS

Aristotle defined space as a container of things; we would thus be occupying a succession of all-embracing envelopes ranging rather like Russian dolls from those that are 'within the limits of the sky' to the very smallest. Hence space is necessarily a hollow limited externally and filled internally. There is no empty space; everything has its position, its location, and its place.

### 2.1. Elements of Spatial Definition

Architectural space is born of the relationship between objects or between boundaries and planes which do not themselves have the character of object, but which define limits. In modern architecture, the principle of regular, parallel, interrupted walls and spaces has been applied to the main perpendicular space. It is one of the ways in which architectural space is created. (Figure 8)

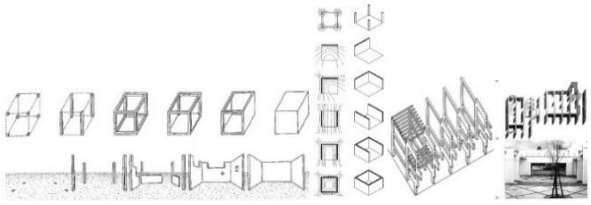



Figure 8. Different spatial fields on the same square plan produced by varying spatial elements.

**a. Depth of space**

The most common and effective indicators of depth perception are; on the one hand, the effect of perspective with, notably texture gradient, on the other, phenomenon which tells us that an object partially hiding another must be front of it. Working with frontal planes wherein respective distance is small and ambiguous, certain architects of the Modern movement exploited not only the effects of shallow space but also the phenomenon of transparency resulting from the disappearance and fragmentary reappearance of one plane behind another.(Ching,1996)(Figure 9)

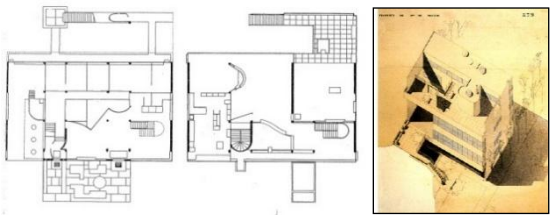

Figure 9. Le Corbusier (1887-1965). Villa Stein-de Monzei, Garches, first-and second-floor plan study, b)Le Corbusier's Villa Stein-de Monzie , Garches, axonometric, 1927.

**b. Density of space**

Space does not only have depth: it is also more or less dense. When greater density is the goal,

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we can modulate distances by intermediary ‘stages of depth’ brought closer together. This is generally the case when we work with shallow space, but we can also create density in deep space: the Cordoba Mosque with its ‘forest’ of columns is a deep space of extraordinary density. Conversely, the design for extension of the Bibliothèque Nationale by Boullee characterized the absence of density with a sparse, unitary space. (Figure 10)

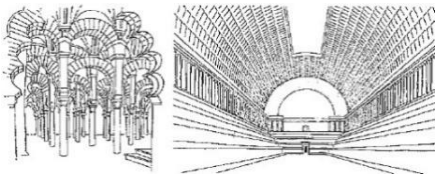

Figure 10. (Left) Dense space: interior of the Cordoba Mosque, (Right) sparse unitary space: design for the reading room of the Bibliotheque Nationale, E.L.Boutte, 1785

**c. Opening space**

One of the fundamental oppositions making it possible to distinguish types of architectural space is that they can either be closed/introverted and concentrated upon themselves, or open/extroverted and centrifugal. While mass is concentrated, space is closed. The degree of its enclosure depends on more than the quantity and size of openings; when we wish to create a space opening to the exterior, we try to make it less explicit. Hence, there is direct connection between notions of explicit and implicit space and the degree of opening or closure. We can use the principles of one to achieve the other. (Figure 11)

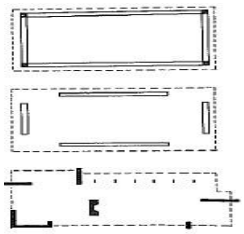



Figure 11. These instructional diagrams by Allen Brooks show Frank Lloyd Wright’s contribution to a new spatial conception: starting with the elimination of corners, he continues by altering the initial spatial geometry, displacing or pivoting segments of the geometric envelope by 90 degrees in order to organize the spatial continuity to his liking.

**d. Spatial juxtaposition and interpenetration**

Elements of spatial definition and openings characterize type of spatial relationships; indeed, they determine the degree to which a given space is autonomous or linked to other spaces. We can pick out two basic types: juxtaposition and interpretation. Juxtaposition insists of autonomy. Our language has a great number of terms that are, in principle, only applicable to a relatively well-defined closed space-room, bedroom, cell, hall and corridor all tied to the notion of privacy and exclusion from other spaces. Spatial interpenetration creates continuity from one space to another from the moment an important element of definition-wall, ceiling, floor-appears to belong to two or more spaces. (Ching,1996) (Figure 11-12)

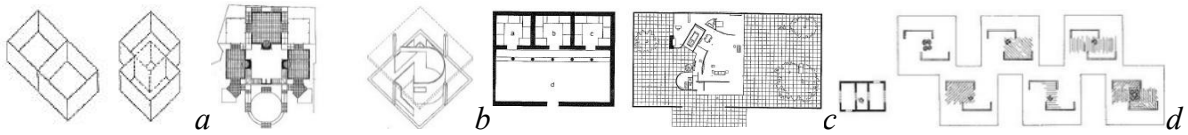


Figure 11. a)Juxtaposition and interpenetration, b) Spatial juxtaposition c) Juxtaposition, d) Spatial juxtaposition and interpenetration

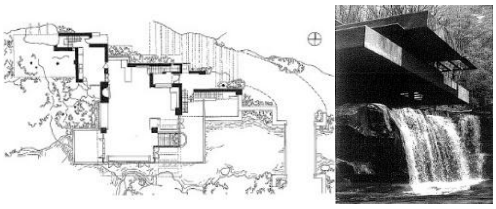

Figure 12. Deconstruction of the box',Kaufmann House (falling water), Frank Llloyd Wright,1936.

## 3. EXPLORATION OF SPATIAL DESIGN

### 3.1.**Dynamics of Space: Use / Usage / User Triology**

| USER/HOUSEHOLD/CLIENT CHARACTERISTICS AND LIFESTYLES | NECESSARY EQUIPMENT AND ACCESSORIES FOR SPACES | ACTIVITIES AND REQUIRED SPACES |
|---|---|---|
| USER | USAGE | USE |

**Table 1.**USER-USAGE-USE interaction

As can be seen from the scheme, space organization is a complement which; *subject /user* is human motivations and aims, *complement/usage* is space elements and components, and *predicate/use* is human activities. In other words, *space organization* is the place where subject's activities due to subject's aims and motivations have been realized under proper space conditions. Responsible systems of space organization alternately ensure interior harmony. So, it can be said that system of space balance can be provided with dynamic process. Here the space elements and components such as light, color, texture, furniture, decoration, form the proper and identical interior space for subject. (Oyman Ş.,1996)



As indicated in the table-2, space organization that develops over 'subject-complement-activity' concept;

1st one human factor on space organization includes important topics such as; social-cultural arrangements individuals place in general orders, socio economic status of subject's /individuals, the education level, and professional area and lastly lifestyle, philosophy of life and expectations of the individual/user,

2nd one focuses on complement includes analyses of; fixed, semi-fixed, mobile, technological features, anthropometric/ergonomic and prosemik features, number of elements, required areas, standards, and formal and symbolic values,

Lastly 3rd part of space organization concept 'activity' includes, cultural-social significance of the activity, performer of the activity, interaction between individuals, routine of activity, required area for activity, and activity period-time-session. As understood from the table, space organization and creation is a dynamic process affected by 'human, activity and components.

| HUMAN | ACTIVITY | NECESSARY EQUIPMENTS AND ACCESSORIES FOR ACTIVITY |
|---|---|---|
| a) social-cultural arrangement and place in general order, ethnic groups etc | a) cultural social significance of the event.<br>b) who perform the activity, role | a) attribute can be fixed, mobile, semi-mobile<br>b) technological order and level |

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| | | |
|---|---|---|
| b) social-economic status (income level-education-professional area-age-gender etc)<br>c) Philosophy of life, lifestyle, values & attitudes, expectations, level in the process of cultural change. | distribution, role definition<br>c) quality of activity individual, physical interaction<br>d) routine of activity, density, communication quality<br>e) necessary space/areas and standards<br>f) activity period, time, session | c) number of elements, required area and standards<br>d) anthropometric/ergonomic and procsemic features<br>e) formal and symbolic values |

**Table 2**. Dynamic balance definition of space: 'space: user-complement/usage-predicate/use' relationship

### 3.2.Group Characteristics of Spaces and Contemporary Space Types

Group spaces are; public compartments that are defined with spaces which strongly have integration relations that all daily activities occur in one place such as; entrance, kitchen, living room, terraces, whilst private compartments exhibit spaces for night and individual usages generally such as; 'bedroom, dressing room, bathroom'. Public compartments exhibit multi-functional spaces together in an open plan. These spaces are implicitly defined and consist of different functional spaces with semi-transparent partitions and mobile furniture. For example, public compartments are formed by implicitly integration of; 'entrance + kitchen + living room + dining room + study room' spaces without any walls between. (Figure 12 a-b)


Figure 12. a)38.7m2 My-Via 414 Mix-Use Project Izmir


Figure 12. b)Next Level B59 1+1 70-100 m2 category

On the other hand, contemporary (new) space types create group zones and compartment organizations as public/private and there are six space types totally in the study: liminal, dual, niche, repetitive, in-between and open spaces. These space types gather in the spatial organizations and create compartments as space groups and each space type has a different feature. Liminal spaces work like passages, at especially the smallest houses that connect outside with inside and at larger types they become halls with closets and bathroom connections. Dual spaces exist in public compartments and act as multifunctional spaces such as, a dining room transforms into a study room, or living room transforms to bedroom from time to time. In-between spaces exhibit fold in and fold out features, thereby they can be disappeared in the organization, in addition, they are used at both public and private

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compartments. Niche spaces are open version of enclosed spaces and repetitive spaces show similarities with sizes and forms; lastly open spaces are terraces that can integrate with the house's interiors with sliding doors.(Figure 13 a-b)

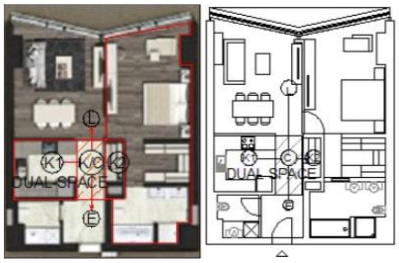


Figure 13. a) Dual Function and In-between Spaces that Act as Circulations


Figure 13. b) In-between Space

### 3.3. Spatial Identifiers

These identifiers act as interior walls of traditional space organizations which able to create sub spaces in one big open space implicitly, without cutting fluidity of spaces increases flexibility of interiors with highly integrated spaces instead of segregated closed spaces of traditional organizations.



The spatial identifiers have been classified under 6 in the study as;

1.Nodal partitions (columns) (flexibility)

2.Vertical planes (flexibility + expandability)

3.Fix-furniture (convexity)

4.Level changes (flexibility + expandability)

5.Material differences (flexibility + expandability)

6.Three dimensional (3d) space modules/structures

7.Over head plane (ceilings) & Artificial Lighting & Acoustics

#### 3.3.1. Nodal partitions (columns)

A vertical linear element, column or tower, establishes a point on the ground plane and makes it visible in space. When centered in space, a column will assert itself as the center of the field and define equivalent zones of space between itself and the surrounding wall planes. (Ching, 1996)

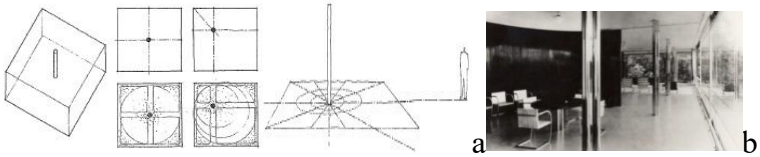


Figure 14. a) A column in the space, When offset, the columns will define hierarchical zones

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of space differently by size form, and location.b) Steel columns and glass made façade from dining room view

### 3.3.2. Vertical planes (free standing walls)

A single vertical plane, standing alone in space, has visual qualities uniquely different from those of a freestanding column. A vertical plane has frontal qualities, its two surfaces or faces front on and establish the edges of two separate and distinct spatial fields. (Figure 15)

Figure 15. a) Vertical Plane, b) Barcelona Pavilion, Mies van der Rohe

### 3.3.3 Fix-Furniture

Furniture has space definition ability in open spaces and creates sub-spaces in which different functions occur. As seen at figure 23, Philip Johnson's glass house project, there is one open space and there are sub-spaces such as; dining, working, sleeping, and cooking, living spaces in that one big space which is made of glass facades. Here the separation of different functional spaces is achieved just by using fix-furniture in a very weak way. (Figure.16)

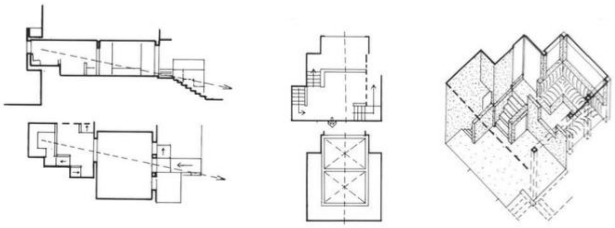



a)Multi-functional fix furniture, they separate spaces and have functions, b) Glass house, New Canaan, Connecticut, 1949, Philip; Sub spaces are formed with in one big open space with fixed furniture

Space defining fixed furniture: bathroom, table, study desk, bed closet, floor material of the living area, rectangle and circler columns

### 3.3.4. Level Changes

Raising a horizontal base plane makes a big difference in a large spatial organization. By elevation differences, edges are formed, spatial flow obstacles thereby spatial boundaries are determined. (Ching, 1996). Adolf Loos' raum plan dwellings are marked by a maximum of three-dimensional compactness and a concentration of length, width and height.(Figure 17 a-b)



a b

Figure 17. a) Raum Plan, Adolf Loos, Moller house, Vienna, b) Raum Plan _Moller House Adolf Loos

### 3.3.5. Material Differences

The surface articulation of the ground or floor plane is often used in architecture to define a zone of a space within a larger context. A. Different floor and ground coverings define different spaces. (Ching F., 1996), B. Different floor and ground coverings that define different spaces. (Ching, 1996) (Figure 18)

Figure 18. material differences can define circulation and main zones

### 3.3.6. 3D_Three-Dimensional Space Modules Structures

3-dimensional space structures can be also degrees from weak to strong, its difference from other space identifiers is to exhibiting floor, wall, ceiling borders all together. Thereby, space structures are the strongest space identifiers weakly, they can be developed from pure geometric forms such as; cube, core, prism, domes, vaults, etc. and they can create 3 dimensional sub-spaces in one big space.(Figure 19)

Figure 19. Three-Dimensional Space modules/structures, Source: www.koleksiyon.com., www.nurus.com.



### 3.3.7. Overhead plane (ceilings) & Artificial Lighting

Overhead plane can define very simply a different functional space by its form visually. The ceiling plane can also be detached from the floor or roof plane and become a visually active element in space. (Figure 20)

Figure 20. Ceilings and lightings that define the space.

## 4. CASE STUDIES

### 4.1. Households Characteristics & Housing space

This part consists of households' characteristics and housing space such as;

(1) Household characteristics & lifestyles

(2) Activities & required space

(3) Necessary equipment & accessories

To reveal spatiality of recent day's small housing units, firstly, household characteristics have been investigated by their 'dynamic, diverse, dual' features variegated in recent decades. Johnston (1970) described dynamics of small households as; flexible, changeable,

transformable living cycle which is connected to age, family life cycle, distance between work & house and migrant character.

Diverse characteristics as mentioned by Balamir (1995) are household typologies such as; 'one person, two people, two friends, a couple, a male parent with a child, a female parent with a child, three people sharing a house, a couple and a child'. Thirdly, dual characteristics appear as 'female/male, working/non-working, old/young, poor/rich, student/graduated, technologic/traditional, native/tourist. Diversity changes due to number, relationship, gender, age and social status of households such as one/two/three, family/couple/housemates, male/female, young/old, student/worker high/medium/low income.

### 4.2. Spaces of Recent Day's Diverse Small Housing Units

Today's small houses are accommodated; living space, dining space, bedroom/s, kitchen, bathroom, guest wc/bath, storage spaces and terraces with diverse typologies for diverse scenarios (table.2-3). These typologies can be classified as; '1+0, 1+1, 1+1+1, 1+1.5, 1+2'.

**(1) 1+0 type;** small house spaces; open plan living space with dining/studying/sleeping activities, with open kitchen, bathroom with/without terrace.

**(2) 1+1 type;** living space with dining/studying/resting activities, 1-bedroom, open kitchen, bathroom with/without terrace.

**(3) 1+1.5 type;** living space with dining/resting activities, 1 bedroom, a niche space for study, and open kitchen, bathroom with /without terrace.

**(4) 1+1+1 type;** common use open plan living space with dining/study/resting activities, 1st bedroom , 2nd bedroom, and open kitchen, bathroom with/without terrace.

**(5) 1+2 type;** living space with dining/studying/resting activities, 1st bedroom, 2nd bedroom and open kitchen, bathroom with /without terrace.(Table 3)



| **Households Characteristics & Housing space relationship** | | | | | |
|---|---|---|---|---|---|
| | **Scenario of the small housing unit** | **Household characteristics and lifestyles** | **Required Space for Activities** | **Equipment & accessories** | **Spatiality** |
| 1 | Female/male Student,<br>Alone living young adult | One household<br>careerism +consumerism | 1+0<br>1+1 | Camouflage units<br>Adaptable furniture<br>Permeable partitions | flexible spaces<br>union spaces |
| 2 | A couple,<br>Two students/friend, | Two households<br>Familism+ careerism+ consumerism | 1+1.5,<br>1+2,<br>1+1+1 | Solid partitions<br>Permeable partitions | multi-purpose spaces<br>union spaces<br>niche spaces |
| 3 | A couple and a child,<br>Three friends', Housemates | Three households<br>Familism+ careerism+ consumerism | 1+2 | Solid partitions<br>Permeable partitions | compartment spaces<br>union spaces<br>niche spaces |

**Table 3.** Households Characteristics & Housing space relationship

### 4.3. Spatial Characteristics Recent Day's Diverse Small Housing Units

Spaces of small housing units, today, gain some spatial characteristics by usage of necessary equipment and accessories such as;

(1) Living spaces transform to flexible spaces by usage of disappearing and kinetic units such as, living space/bedroom

(2) Kitchens/bathrooms/guest wc/bath/closet rooms transform to compact spaces by usage of fix equipment,

(3) Living/dining spaces and open kitchen become union spaces by permeable partitions and low-height furniture arrangement due to not blocking contact in the space,

(4) Dining spaces with table can be used as assembly/study space and become multi-purpose spaces by usage of adaptable furniture,

(5) Bedrooms become compartment spaces by usage of solid partitions and includes more than one space, act as mono-space such as master bedroom of unusual types are connections of three spaces: bedroom, closet room, bathroom' .

(6) Kitchens/bathrooms/laundries/guest wc/baths are serving spaces as; it is the separation between 'served' and 'serving' spaces that the order imposed on space creates stable nuclei that allow flexibility in the determination of the served, inhabited spaces, which are free from accessory spaces, whether technical or functional.' (pg.112), [31]

(7) Living spaces gain temporal characteristics by modifying itself and providing a different and reversible use such as 1+0 type living spaces used as bedroom at nighttime.

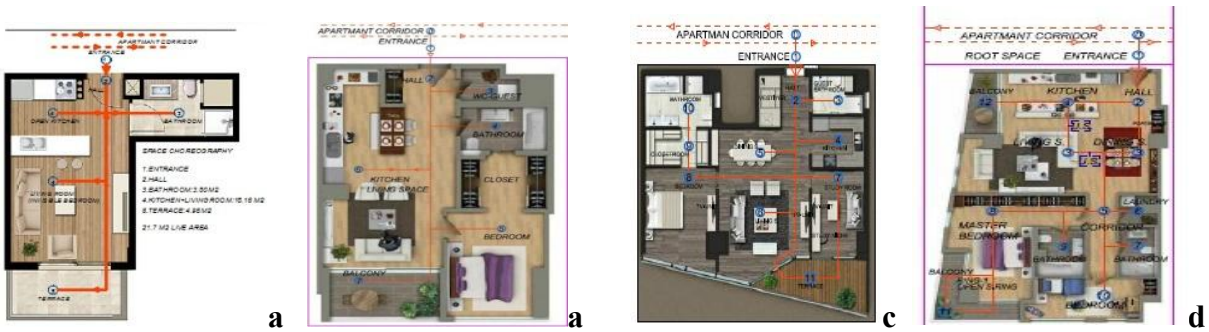
(8) Rings between spaces: As Hillier and friends (1996) indicated each spatial or architectural unit, through its topologic border features must be 'closed surface' or 'ring'. Units that have their own borders are named 'closed', without borders are named as 'open'. [36]



(9) Private/public spaces: As Avi Friedman indicated, public zones are used by household members and their guests and typically include the dining room and living room. Semi-private zones consist of areas that are used by the household and occasionally by guests such as the kitchen and the powder room. Finally, private zones such as bedrooms and bathrooms are only used by households and placed in far zones. (pg.65)

### 4.4. Exploration of the Spatial Design Over 4 Different 1+1 Type Houses

#### 4.4.1. Plans of the selected 4 houses




**a** **a** **c** **d**

**a.**Myvia 414 1+0, **b.**Bomonti-Modern 1+1**, c.**Next Level 1+1.5, **d.**Bomonti-Modern Palas 1+2

#### 4.4.2. Spaces

**a. My-via 414 1+0**, 22 net area ; Living space + kitchen: 16 , Bathroom: 3.7 , Hall: 2, terrace:4, Total minimum dwell space: 21.95 m2, One household

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**b.Bomonti-Modern 1+1**: 78.45 m2 net area, Gross area 92.93,Antre:4.0,Kitchen:10.63,Living space:25.11, Bedroom:22.39, Bathroom:6.72, Laundry:2.76, Balcony:6.23, One-two-three households can accommodate

**c.Next Level 1+1.5** : 112.5 m2 net area net area113.05 , Gross area 151, Open area 10.97, Walls 37.95, Hall:8.4, Guestbath:7.16, Kitchen:8.17, Living space:36.61, Studyroom:14.07, Masterbedroom:11.19, Terrace:10.97, One-two-three households can accommodate.

**d.Bomonti-Modern Palas 1+2**, Net area 135.5 , Hall 8.06, Corridor 7.52, Kitchen 15.63, Livingspace 38.37, Masterbedroom:27, Masterbathroom:6.5, Bedroom-2:13.42, Bathroom:5.34, Balcony-1:4.58, Balcony-2:6.01, One-two-three households can accommodate.

**4.4.3.Activities**

**1.**Open plan, one room concept. Living, resting, dining, sleeping, tv watching studying activities at one room. Serving spaces: Open kitchen bathroom

**2.** Living, dining, studying at living space. Cooking, preparing food at open kitchen. Sleeping at bedroom.

**3.** Open plan living space with 1 bedroom., U type semi-open kitchen, dining space, living space in one open space, and study in 0.5 space. Bedroom with a bathroom and closet room. Serving spaces are high quality concept: laundry, open kitchen, guest wc/bath.

4. Open plan living space with 2 bedrooms, master and kids' bathrooms. Open kitchen ,dining space, living space, study space in one open space. Master bedroom with a master bathroom and closet room. Bedroom with study and closet niches. Serving spaces: laundry, open kitchen, guest wc/bath.



**4.4.2.Equipment&Furniture:**

**1. Open kitchen with compact units**; storages, and tops. Camouflage bed unit hidden in the wall.

**2. Furniture**: Flexible, compact, multi-functional. Serving spaces: compact units as storage, closet room, kitchen modules. Served spaces: flexible units' beds, coaches. Multi-functional units: tv module, dining/studying table **Clothing's:** Floors: coffee wood, dark grey granite. **Partitions:** solid walls between spaces, furniture between living-dining-kitchen. **Lighting:** daylight and artificial light.

**3. Furniture:** Flexible, compact, Multi-functional furniture. Serving spaces: compact units as storage, closet room, kitchen modules. Served spaces: flexible units' beds, coaches. Multi-functional units: tv module, dining/studying table **Clothing's:** Floors: dark grey wood, white granite, **Partitions:** solid walls between spaces Furniture between living-dining Sliding wall/door between 0.5 space and living space. **Lighting:** daylight and artificial light.

**4. Furniture**: Flexible, compact, multi-functional furniture. Serving spaces: compact units as storage, closet room, kitchen modules. Served spaces: flexible units' beds, coaches, kids bed & study niche. Multi-functional units: tv module, dining/studying table. **Clothing: Floors:** Light coffee wood, grey granite, **Partitions:** Solid walls between spaces, furniture between living-dining. **Lighting:** Daylight and artificial light.

## 5. CONCLUSIONS

In the article, spatial design has been introduced by highlighting main design principles such as; gestalt perception theory,human based design principle as adapatation to diverse changing scenarios, flexible design that ensures quick transformations of spaces, multifunctional usage patterns and transformations,new spatial identifiers instead of walls-door-corridor relations, permeable, soft, camouflouge space equipments that create sub-spaces in one big space, this spatial identifiers mainly differ from traditional borderssuch as especially at public spaces; art installations, spatial scenarios, color-material usages, perception based identifiers. new space types introduced in the paper as the multifunctional,dual usages, niche spaces. compartment characteristics of spaces formed by soft spatial identifiers and new space types , mainly public-private and work compartments. As a conclusions, in the study , contemporary space design titled as **'spatial design'** has been explored by basic principles, samples and theories. And its aimed to shed a light for future architectural space designs.

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# Oracle PL/SQL Sorgularının Yapay Zekâ Tabanlı Performans Optimizasyonu

Artificial Intelligence-Based Performance Optimization of Oracle PL/SQL Queries

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## Özet

Bu çalışma, Oracle PL/SQL ve Forms tabanlı uygulamalarda yavaş çalışan sorguları analiz ederek performansı artırmayı amaçlayan yapay zekâ destekli bir optimizasyon sistemi geliştirmeyi hedeflemektedir. Araştırmada, Oracle veri tabanında çalıştırılan sorguların performans verileri SQL_TRACE ve EXPLAIN PLAN kullanılarak toplanmış, Python ortamında analiz edilmiştir. Çalışma süresi, mantıksal okuma ve I/O işlemleri gibi metriklere dayalı özellik seçimiyle veri seti oluşturulmuş; sorgu yavaşlığının nedenlerini belirlemek için Random Forest ve XGBoost algoritmaları uygulanmıştır. Tarihsel performans kayıtlarıyla eğitilen modellerin doğruluğu çeşitli metriklerle değerlendirilmiş, sistem gerçek ortamdan alınan yeni sorgularla test edilerek öneri yeteneği geliştirilmiştir. Sonuçlar, önerilen sistemin sorgu yürütme süresini %82,4, mantıksal okuma oranını %84,8, fiziksel okuma oranını %90,9 ve toplam Oracle maliyetini %97 oranında iyileştirdiğini göstermektedir. Model karşılaştırmasında XGBoost, %96,1 doğruluk ve F1 skoru ile daha yüksek sınıflandırma başarısı sergilerken, Random Forest daha hızlı tahmin süreleri sağlamıştır. Bu çalışma, Oracle PL/SQL performans sorunlarını yapay zekâ ile analiz eden özgün bir sistem sunarak veri tabanı yöneticilerine karar desteği sağlamaktadır.

**Anahtar kelimeler:** Oracle, PL/SQL, Performans Optimizasyonu, Yapay Zeka, SQL Analizi.

## Abstract

This study aims to develop an artificial intelligence–based optimization system to analyze and improve the performance of slow-running queries in Oracle PL/SQL and Forms-based applications. Performance data from Oracle queries were collected using SQL_TRACE and EXPLAIN PLAN and analyzed in a Python environment. A dataset was constructed through feature selection based on metrics such as execution time, logical reads, and I/O operations. Random Forest and XGBoost algorithms were applied to identify factors contributing to query slowness, with historical performance records used for model training and evaluation through standard performance metrics. The system was further refined and validated using real-world queries to enhance its recommendation capability. Results indicate substantial improvements: execution time reduced by 82.4%, consistent read rate by 84.8%, physical read rate by 90.9%, and total Oracle cost by 97%. In model comparison, XGBoost achieved superior classification accuracy with 96.1% accuracy and F1-score, while Random Forest provided faster prediction times. This research introduces a novel AI-driven system for diagnosing and optimizing Oracle

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PL/SQL performance issues, offering decision support for database administrators and contributing to improved query efficiency.

**Keywords:** Oracle, PL/SQL, Performance Optimization, AI, SQL Analysis

## 1. GİRİŞ

Dijital dönüşüm çağında, veri yönetimi ile verilerin etkin ve güvenilir bir şekilde işlenmesi, kuruluşlar için stratejik açıdan kritik bir önem kazanmıştır. Artan veri hacmi, iş süreçlerinin giderek karmaşıklaşması ve erişilebilirlik talebinin yükselmesi, ilişkisel veritabanı yönetim sistemlerinin (RDBMS) performansını hayati bir unsur haline getirmiştir. Oracle gibi kurumsal düzeydeki sistemlerde, sorgu yürütme süresinin azaltılması ve sistem kaynaklarının verimli kullanılması, uygulamaların genel başarısını doğrudan etkilemektedir.

Oracle PL/SQL ve Oracle Forms, kurumsal uygulamalarda veri işleme ve iş mantığının kontrolünde temel bir rol üstlenmekte, bu yapılar sistemin omurgasını oluşturmaktadır. Ancak, sistem mimarilerinin zamanla genişlemesiyle birlikte performans sorunlarının ortaya çıkması kaçınılmazdır. Yavaş sorgular, tam tablo taramaları ve verimsiz indeks kullanımı gibi problemler, hem kullanıcı deneyimini hem de sistemin genel verimliliğini olumsuz yönde etkileyebilmektedir.

Bu çalışma, Oracle PL/SQL ve Forms ortamlarında karşılaşılan performans darboğazlarını belirlemek, analiz etmek ve iyileştirmek amacıyla gerçekleştirilmiştir. Geleneksel performans iyileştirme yöntemlerinin ötesine geçilerek, yapay zeka (YZ) ve makine öğrenmesi (ML) teknikleriyle desteklenen bir sistem geliştirilmiştir. Bu yapı, Python programlama dili ile entegre edilerek SQL sorgu performans izlerini analiz etmekte ve otomatik optimizasyon önerileri üretmektedir.



Araştırmanın temel amacı, Oracle tabanlı uygulamalarda performansı artırmaya yönelik bilimsel temelli ve pratik olarak uygulanabilir bir çözüm önermek ve bu çözümü, veritabanı performans optimizasyonu için YZ destekli bir karar destek mekanizmasına dönüştürmektir.

## 2. LİTERATÜR TARAMASI

Bu bölümde, ilişkisel veritabanı yönetim sistemlerinde performans optimizasyonu, Oracle PL/SQL ve Forms tabanlı uygulamalarda karşılaşılan yaygın performans sorunları ile bu sorunların giderilmesine yönelik geliştirilen yöntemler ele alınmıştır. Ayrıca, son yıllarda veritabanı performans yönetiminde yapay zeka ve makine öğrenmesi tekniklerinin kullanımına odaklanan çalışmalar incelenerek, mevcut yaklaşımların güçlü ve sınırlı yönleri ortaya konmuştur. Bu bağlamda, çalışmanın konumlandığı bilimsel çerçeve belirlenmiş ve önerilen yaklaşımın literatürdeki yeri değerlendirilmiştir.

(Zongheng Yang, 2022) geliştirdiği Balsa adlı sistemde olduğu gibi, klasik sorgu optimizasyon süreçleri yerine makine öğrenmesine dayalı yeni nesil yaklaşımlarla, veritabanı sorgularının yapısal örüntüleri üzerinden optimizasyon stratejileri öğrenilebilmekte ve bu stratejiler uzman müdahalesi olmaksızın sistemler tarafından uygulanabilmektedir. Böylece, hem manuel hatalar en aza indirgenmekte hem de veri tabanı sistemlerinin adaptif ve dinamik şekilde kendini optimize edebilmesi mümkün hale gelmektedir.

Bu yaklaşım sayesinde, veritabanı yöneticilerinin veya geliştiricilerin manuel müdahalesine gerek kalmaksızın; veritabanı sorgularının gerçek zamanlı performans değerleri üzerinden değerlendirilmesi, potansiyel darboğazların önceden belirlenmesi ve iyileştirme yollarının önerilmesi hedeflenmektedir.

Özellikle (Ryan Marcus, 2020) Learning to Steer Query Optimizers çalışmasında, karmaşık sorgu iyileştirme sürecine makine öğrenmesi (takviye öğrenmesi ve sinir ağları) uygulanarak büyük performans kazanımları elde edildiği görülmektedir. Makine öğrenmesi sınıflandırma modellerini kullanarak youtube verileri üzerinde duygu analizi yapabilen başarılı bir örnek çalışmadır(Şahinaslan, 2022).

(Asokan, 2025) Veri tabanı performansı üzerinde yapay zekâ destekli optimizasyonun, otomatik indeksleme ve anomalilerin tespitiyle birlikte organizasyonlara hem hız hem de verimlilik kazandırdığını belirtmektedir. Makine öğrenmesi algoritmalarının gerçek bir süreçte uygulanmasını incelemiş ve metodolojik olarak YZ-tabanlı sistemlerin performans kazanımlarına dair kanıtlar ortaya koymuştur(Şahinaslan, 2023.

Random Forest, birden fazla karar ağacının (decision tree) birleşiminden oluşan topluluk öğrenme (ensemble learning) yöntemidir. Her bir karar ağacı, rastgele örneklenen veri alt kümeleri üzerinde eğitilir ve modelin çıktısı, tüm ağaçların oylamasıyla belirlenir. Bu algoritma, overfitting riskini minimize ederken yüksek doğruluk sağlar. SQL sorgularının sahip olduğu çeşitli performans metrikleri (örneğin: elapsed_time, buffer_gets, physical_reads) modelin giriş değişkenleri olarak kullanılmış, etiket ise "optimizasyon önerisi gerektiriyor mu?" sorusunun cevabı olarak belirlenmiştir.

Bu çalışma kapsamında kullanılan Random Forest tabanlı sınıflandırma yaklaşımı, (Dhanara, 2021)tarafından önerilen "Random Forest Bagging X-Means SQL Query Clustering" yöntemine dayanmaktadır. Bu yöntem, SQL günlüklerinden anomali sorguları başarılı biçimde belirlemek amacıyla Random Forest ile öğrenme sağlamakta, ardından X-Means kümelemesi ve majority voting ile kötü yapılandırılmış sorguları ayırt edebilmektedir. XGBoost, Chen ve Guestrin (2016) tarafından geliştirilen, denetimli öğrenme problemlerinde yüksek doğruluk sunan, ağaç tabanlı bir topluluk (ensemble) makine öğrenmesi yöntemidir. Özellikle büyük veri setlerinde ve yüksek boyutlu problemlerde hızlı çalışması ve overfitting'e karşı direnci sayesinde günümüzde akademik ve endüstriyel birçok çalışmada tercih edilmektedir. XGBoost algoritması, karar ağaçları üzerinde gradyan artırma (gradient boosting) tekniğini optimize eden, paralel işlemeye uygun, düzenlileştirme (regularization) içeren gelişmiş bir versiyonudur. Bu sayede hem eğitim süresi kısalmakta hem de modelin genellenebilirliği artmaktadır. (Chen, XGBoost: A Scalable Tree Boosting System., 2016), çalışmada XGBoost'un temel algoritması sunulmuş, GBM (Gradient Boosting Machine) algoritmasına yapılan optimizasyonlar detaylı olarak açıklanmıştır. Özellikle sparse veri yapıları, paralel işleme kabiliyeti ve düzenlileştirme mekanizmaları gibi performans artırıcı teknikler ön plana çıkarılmıştır.



2021 yılında yapılan bir tez çalışmasında, ağ tabanlı saldırı tespiti problemlerinde XGBoost ve Rastgele Orman algoritmaları karşılaştırılmıştır. XGBoost'un daha yüksek doğruluk ve F1-Skoru sağladığı, ancak eğitim süresi bakımından biraz daha fazla kaynak tükettiği vurgulanmıştır (Buldu, 2021). Veritabanı yönetimi ve kurtarma tekniklerini ele alan ve ilişkisel veritabanlarının kritik operasyonlarına odaklanan bir diğer çalışma da veri kaybı-önleme/pratik sorun çözümleri sunmuştur(Sahinaslan, 2022)

Özetle, literatürde yer alan çalışmalar; veritabanı sorgu optimizasyonu ve performans yönetimi alanında yapay zeka ve makine öğrenmesi tabanlı yaklaşımların, geleneksel kural tabanlı ve manuel yöntemlere kıyasla daha ölçeklenebilir, adaptif ve yüksek doğruluklu çözümler sunduğunu ortaya koymaktadır. Özellikle Random Forest ve XGBoost gibi ağaç tabanlı topluluk öğrenme yöntemlerinin, sorgu performans metriklerini etkin biçimde analiz ederek anomali tespiti ve optimizasyon kararlarında başarılı sonuçlar verdiği görülmektedir. Bu bağlamda, mevcut literatürden elde edilen bulgular ışığında, bu çalışmada Oracle PL/SQL ve Forms ortamlarına özgü performans izlerinin YZ destekli modellerle analiz edilmesi ve otomatik optimizasyon önerileri üretilmesi hedeflenerek, literatürdeki yaklaşımları kurumsal

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veritabanı sistemlerine uyarlayan bütüncül ve uygulanabilir bir çözüm sunulması amaçlanmaktadır.

## 3. MATERYAL

Çalışmanın deneysel altyapısı, kullanılan yazılım ve donanım bileşenleri ile performans ölçüm ve veri toplama sürecine ilişkin ayrıntılar sunulmaktadır. Oracle tabanlı kurumsal veritabanı sistemlerinde sorgu performansının gerçekçi ve tekrarlanabilir koşullar altında değerlendirilebilmesi amacıyla, kontrollü bir deneysel ortam oluşturulmuş ve bu ortamda farklı sorgu senaryoları sistematik olarak test edilmiştir. Elde edilen performans izleri, yapay zeka ve makine öğrenmesi tabanlı modellerin eğitimi ve değerlendirilmesi için girdi verisi olarak kullanılmıştır. Bu kapsamda, deneysel ortamda kullanılan teknolojiler ve bileşenler Tablo 1'de özetlenmektedir. Bu çalışma kapsamında Oracle 18c Express Edition üzerinde yapılandırılmış bir veritabanı ortamı kullanılmıştır. Bu ortamda oluşturulan tablolar, sorgu performansının gerçekçi koşullar altında gözlemlenebilmesi için milyonlarca kayıtla doldurulmuştur. Performans ölçümleri, Oracle'ın SQL_TRACE çıktıları ve EXPLAIN PLAN komutları kullanılarak elde edilmiştir. Ölçümler sırasında Elapsed Time, Consistent Reads (CR), Physical Reads (PR) ve Total Cost gibi temel performans metrikleri değerlendirilmiştir. Python ile Oracle arasında oracledb kütüphanesi aracılığıyla bağlantı kurulmuş ve toplanan performans verileri makine öğrenmesi modellerinin eğitimi için kullanılmıştır.

Veritabanı şeması, aşağıdaki tabloları birincil veri kaynakları olarak içermektedir:

T1_CUSTOMERS (500.000 kayıt)

T2_ORDERS (500.000 kayıt)

T3_PRODUCTS (500.000 kayıt)

T4_ORDER_DETAILS (1.000.000 kayıt)

Bu tablolar; müşteri, sipariş, ürün ve sipariş detaylarını kapsayarak gerçekçi iş senaryolarının simülasyonunu mümkün kılmıştır.

Testlerin Oracle'ın standart yapılandırmaları (bellek, listener, arka plan süreçleri vb.) altında gerçekleştirilmesinin, diğer sürümlerde benzer sonuçlar vereceği varsayılmıştır. Ayrıca, SQL_TRACE ve EXPLAIN PLAN çıktılarının sorgu performansını doğru şekilde yansıttığı kabul edilmiştir. Modelleme sürecinde, Random Forest ve XGBoost algoritmalarının yeterli çeşitlilikte yavaş ve hızlı sorgu örnekleriyle eğitildiği varsayılmıştır. Bu varsayım, yapay zeka modellerinin yeni sorgular için güvenilir tahminler sunabileceği beklentisini desteklemektedir.



**Tablo 1.** Deneysel ortamlar

| Teknoloji | Açıklama |
|---|---|
| **Oracle XE 18c** | Deneysel Veritabanı Ortamı |
| **Python 3.11+** | Veri İşleme ve Model Eğitimi |
| **Pandas** | Trace Verilerinin İşlenmesi |
| **Scikit-learn** | Makine Öğrenmesi Algoritmaları |

| | |
|---|---|
| **Oracledb (cx_Oracle)** | Oracle ile Bağlantı Kurulması |
| **SQL Developer** | Sorgu Analizi ve Plan İzleme |

Arka planda Oracle veritabanı performansı izlenmiş ve analiz edilmiştir. Python programlama dili, veri işleme, analiz ve makine öğrenmesi modellerinin geliştirilmesi için kullanılmıştır. Performans analizleri Scikit-learn, pandas ve matplotlib gibi kütüphaneler aracılığıyla gerçekleştirilirken, veritabanı bağlantısı için oracledb kütüphanesi kullanılmıştır. Tablo 1, deneysel ortamda gerekli teknolojileri özetlemektedir.

### 3.1. Yöntem

Bu çalışmada, Oracle veritabanı üzerinde SQL sorgularının performans analizi gerçekleştirilmiştir. Analiz süreci aşağıdaki adımlardan oluşmaktadır:

**Veri Toplama**

SQL sorgularının çalıştırılması sırasında, ALTER SESSION SET SQL_TRACE = TRUE komutu kullanılarak izleme etkinleştirilmiş ve oluşturulan iz dosyaları kaydedilmiştir. Ayrıca, sorguların yürütme planları EXPLAIN PLAN komutu ile elde edilmiştir. Bu verilerden aşağıdaki performans metrikleri çıkarılmıştır:

Elapsed Time

Consistent Reads (CR)

Physical Reads (PR)

Estimated Query Cost

Full Table Scan

Join Count



**İz Dosyalarının Analizi**

Oluşturulan .trc uzantılı iz dosyaları Python betikleri kullanılarak işlenmiş, performans metrikleri ayrıştırılmış ve bir veri kümesine dönüştürülmüştür. Bu süreçte Elapsed Time, CR, PR, Executions, Plan Cost, Join Count ve Full Table Scan Count gibi özellikler çıkarılmıştır.

**Oracle İz Dosyalarının Oluşturulması ve Analizi**

Oracle iz dosyalarının (.trc) oluşturulması ve TKPROF gibi araçlarla analiz edilmesi, sorgu yürütme süresi (elapsed time), yürütme sayısı ve tam tablo taramaları gibi kritik performans metriklerinin elde edilmesini sağlar (Oracle Corporation, 2023). Bu çalışmada benzer şekilde, Oracle PL/SQL ortamında üretilen iz dosyaları Python betikleri ile işlenmiş; Elapsed Time, Executions ve Full Table Scan Count gibi metrikler çıkarılarak modelleme amacıyla bir veri kümesine dönüştürülmüştür.

**Makine Öğrenmesi Modeli**

Elde edilen veri kümesi, scikit-learn kütüphanesi aracılığıyla uygulanan Random Forest ve XGBoost algoritmaları kullanılarak eğitilmiştir. Bu modeller, sorgu performansını sınıflandırmakta ve "Yeterli", "Indeks Ekle", "Partition Önerisi" ve "JOIN Optimize Et" gibi optimizasyon önerileri üretmektedir.

Bu çalışmada kullanılan Random Forest tabanlı sınıflandırma yaklaşımı, (Dhanaraj ve ark., 2021) tarafından önerilen Random Forest Bagging X Means SQL Query Clustering yöntemine dayanmaktadır. Bu yöntem, SQL günlüklerinden anormal sorguları Random Forest ile belirlemekte, ardından X-Means kümeleme ve çoğunluk oylaması ile zayıf yapılandırılmış

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sorguları ayırt etmektedir. XGBoost, (Chen & Guestrin, 2016) tarafından geliştirilen, yüksek doğruluk sağlayan ağaç tabanlı bir topluluk makine öğrenmesi yöntemidir. Hızı ve aşırı öğrenmeye karşı dayanıklılığı, özellikle büyük ve yüksek boyutlu veri kümelerinde hem akademik hem de endüstriyel uygulamalarda tercih edilmesini sağlamaktadır. XGBoost algoritması, düzenlileştirme (regularization) ve paralel işlem desteği gibi geliştirmelerle Gradient Boosting yönteminin ileri bir versiyonudur. Bu iyileştirmeler, hem eğitim verimliliğini hem de modelin genellenebilirliğini artırmaktadır.

Bu çalışmada, sınıflandırma modelleri olarak XGBoost ve Random Forest seçilmiştir. Bu tercih, literatürde bu iki algoritmanın güçlü karşılaştırmalı performansını gösteren çalışmalarla desteklenmektedir. Örneğin, (Shao ve ark., 2024) XGBoost'un Random Forest'a kıyasla daha yüksek doğruluk sağladığını rapor etmiştir. Ayrıca, sınıf dengesizliği sorununu ele almak kritik öneme sahiptir; (Imani ve ark., 2025) SMOTE + XGBoost kombinasyonunun yüksek oranda dengesiz veri kümelerinde en iyi performansı sağladığını vurgulamıştır. Bu nedenle, tez kapsamında önce SMOTE uygulanmış, ardından her iki algoritma aynı veri kümesi üzerinde eğitilmiş ve karşılaştırılmıştır.

(Chen & Guestrin, 2016) tarafından sunulan XGBoost: A Scalable Tree Boosting System çalışması, XGBoost'un temel algoritmasını ve Gradient Boosting Machine (GBM) üzerindeki optimizasyonları detaylandırmaktadır. Seyrek veri işleme, paralel işlem yetenekleri ve düzenlileştirme mekanizmaları gibi performans artırıcı teknikler vurgulanmaktadır.

**Tahmin ve Öneri**

Yeni sorgular için aynı performans metrikleri çıkarılmış ve model tarafından analiz edilerek performans iyileştirme önerileri sunulmuştur. Bu öneriler hem istatistiksel analiz hem de yürütme planları ile desteklenmiştir.



**Model Karşılaştırması**

2021 yılında gerçekleştirilen bir tez çalışmasında, ağ tabanlı saldırı tespit problemleri bağlamında XGBoost ve Random Forest algoritmaları karşılaştırılmıştır. Bulgular, XGBoost'un daha yüksek doğruluk ve F1 skoru sağladığını, ancak eğitim sırasında biraz daha fazla hesaplama kaynağı gerektirdiğini göstermiştir (Buldu & Yıldız, 2021). Bu çalışmada, Random Forest ve XGBoost modelleri doğruluk, F1 skoru ve hata oranları açısından karşılaştırılmış ve en iyi performans gösteren model belirlenmiştir.

### 3.1.1. Veri kaynağı

Bu çalışmada kullanılan veri seti, Oracle veritabanı üzerinde gerçekleştirilen gerçek sorgu çalışmaları ve simülasyon verilerinden oluşmaktadır. Performans analizi için SQL sorguları, Oracle 18c Express Edition üzerinde oluşturulan test ortamında çalıştırılmıştır. İzleme sürecinde ALTER SESSION SET SQL_TRACE = TRUE komutu ile sorguların yürütülme detaylarını içeren trace dosyaları elde edilmiştir. Ayrıca, sorguların yürütme planları EXPLAIN PLAN komutu ile kaydedilmiştir. Bu kaynaklardan elde edilen veriler arasında sorgu çalışma süresi (Elapsed Time), mantıksal okuma (Consistent Reads), fiziksel okuma (Physical Reads), maliyet (Cost), tam tablo taraması (Full Table Scan) ve JOIN sayısı gibi performans metrikleri bulunmaktadır. Toplanan bu veriler, Python betikleri ile işlenerek makine öğrenmesi modellerinin eğitimi için kullanılacak veri kümesine dönüştürülmüştür.

### 3.1.2 Veri toplama

Çalışmada kullanılan veriler dört ana tablodan oluşan ve sorgu performansını ölçmeye olanak sağlayacak kadar veri ile yapılmıştır. Tablo ve veri sayıları tablo 2' de verilmiştir.

**Tablo 2.** DB Tablo Veri Seti

| Tablo İsimleri | Kayıt Sayısı | İndex |
|---|---|---|
| **T1_CUSTOMERS** | 500.000 | Yok |
| **T2_ORDERS** | 500.000 | Yok |
| **T3_PRODUCTS** | 500.000 | Yok |
| **T4_ORDER_DETAILS** | 1.000.000 | Yok |

### 3.1.3 Makine Öğrenmesi ile Model Eğitimi

Bu çalışmada, Oracle veritabanında gerçekleştirilen SQL sorgularının performansını analiz etmek ve iyileştirme önerileri sunmak amacıyla gözetimli öğrenme yöntemi tercih edilmiştir. Özellikle düşük performans gösteren sorguların karakteristiklerinden yola çıkarak, hangi durumlarda optimizasyon gerektiğini belirlemek üzere Random Forest algoritması kullanılarak bir sınıflandırma modeli oluşturulmuştur.

Modelin eğitimi için kullanılan veri seti, çeşitli sorguların performans özelliklerini içermektedir. Bu özellikler arasında; sorgunun tam tablo taraması yapıp yapmadığı (0 veya 1), sorguda yer alan join sayısı, tahmini yürütme maliyeti (cost) ve indeks kullanım durumu gibi parametreler bulunmaktadır. Her bir veri noktası, bu dört özelliği içeren bir vektör şeklinde temsil edilmiştir. Şekil 1'de örnek veri seti gösterilmektedir.

```
X = [
    [1, 3, 1500, 0],  # full scan var, 3 join, yüksek cost, index yok
    [0, 2, 500, 1],   # index var, düşük cost
    [1, 1, 1300, 0],  # full scan, az join, yüksek cost
    [0, 0, 300, 1],   # index var, simple query
    [1, 2, 1600, 0],  # full scan, orta karmaşa
    [0, 3, 800, 1],   # index var, çok join ama iyi optimizasyon
]

```



**Şekil 1.** Model Eğitim Girdileri

Sorgulara ait sınıf etiketleri (y), alan uzmanlarının değerlendirmeleri doğrultusunda belirlenmiştir. Bu etiketler, sorgunun mevcut haliyle yeterli olup olmadığını veya ek optimizasyona ihtiyaç duyup duymadığını ifade etmektedir. Şekil 1'de bu sınıflandırma etiketleri görselleştirilmiştir.

```
y = [
    'index ekle',
    'yeterli',
    'index ekle',
    'yeterli',
    'index ekle',
    'yeterli'
    ]

```

**Şekil 2.** Model Eğitim Çıktıları

Modelin eğitimi sürecinde RandomForestClassifier sınıfı kullanılmıştır. Bu algoritma, çok sayıda karar ağacından oluşan bir topluluk (ensemble) yapısı ile çalışarak sınıflandırma işlemini gerçekleştirir. Bu yöntem, hem aşırı öğrenmeyi (overfitting) azaltmakta hem de modelin doğruluk oranını artırmaktadır. Şekil 2'da modelin eğitilmesi ve kalıcı olarak saklanması süreci yer almaktadır.

```
1  from sklearn.ensemble import RandomForestClassifier
2  import joblib
3  model = RandomForestClassifier(n_estimators=100, random_state=42)
4  model.fit(X, y)
5  joblib.dump(model, "model.pkl")
6
```

**Şekil 3.** Model Eğitim Kütüphanesi

Şekil 3'da görüldüğü üzere, n_estimators=100 parametresi ile 100 adet karar ağacı oluşturulmuştur. Ayrıca random_state=42 parametresi, modelin tekrar üretilebilirliğini sağlamak amacıyla kullanılmıştır. Eğitim tamamlandıktan sonra model, joblib kütüphanesi aracılığıyla. pkl uzantılı bir dosya olarak kaydedilmiştir. Bu sayede model, ilerleyen aşamalarda yeni sorgular üzerinde gerçek zamanlı tahminler yapmak üzere tekrar kullanılabilir hale gelmiştir.

Sonuç olarak, bu aşamada geliştirilen sınıflandırma modeli, geçmiş sorgu verilerine dayanarak yeni sorguların performansını analiz edebilmekte ve gerektiğinde "indeks ekleme" gibi optimizasyon önerileri sunabilmektedir. Bu yapı, performans iyileştirme sürecinde yapay zekâ destekli karar verme mekanizmasının temelini oluşturmaktadır.



### 3.2. İyileştirme Önerisi ve Uygulama

Modelin aldığı girdiler doğrultusunda, sorgunun Total Cost ve Consistent Reads değerlerinin oldukça yüksek olduğu, ayrıca üç tabloya da Full Table Scan yöntemiyle erişim sağlandığı tespit edilmiştir. Bu analiz sonucunda, model tarafından ilgili tabloya indeks eklenmesi yönünde bir performans iyileştirme önerisi sunulmuştur. Gerçekleştirilen müdahale, öneriye uygun olarak tabloya indeks eklenmesi şeklinde uygulanmıştır. Şekil 4'de görüldüğü gibi T4_ORDER_DETAILS tablosuna Index eklenmiştir.

```
37
38 •  CREATE INDEX IDX_UNIT_PRICE ON OPT.T4_ORDER_DETAILS(UNIT_PRICE);
```

**Şekil 4.** Index Oluşturulması

Model tarafından önerilen indeks eklendikten sonra, sorgu üzerinde yeniden Trace ve SQL Execution Plan alınmıştır. Yapılan analiz sonucunda, Total Cost ve Consistent Reads değerlerinde belirgin bir düşüş gözlemlenmiş; ayrıca sorgunun artık Full Table Scan gerçekleştirmediği tespit edilmiştir. Çıktılar aşağıdaki gibidir.

- Elapsed Time: 0,49 saniye
- Consistent Reads: 789
- Physical Reads: 13

- Full Table Scan: 0
- Total Cost: 78

### 3.2.1 Performans İyileştirme Oranı

Performans iyileştirme yüzdesi Şekil 5'de olduğu gibi formülle hesaplanmıştır:

**İyileştirme (%) = ((Eski Süre- Yeni Süre) / Eski Süre) * 100**

```
eski_sure = 2.78
yeni_sure = 0.49
                iyilesme_orani = ((eski_sure - yeni_sure) / eski_sure) * 100
print(f"%{iyilesme_orani:.2f} performans artışı")
```

*Şekil 5.* ***Performans İyileştirme oranı***

Sonuç: %82,37 performans artışı.

### 3.2.2 Elapsed Time Karşılaştırması

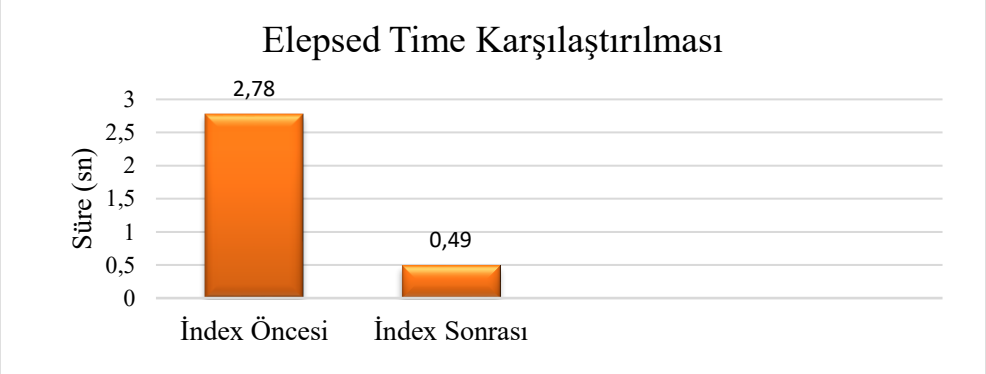
Index öncesi: 2,78 saniye, Index sonrası: 0,49 saniye.

Yaklaşık %82 azalma (iyileşme) sağlanmıştır.

Formül: İyileştirme Yüzdesi = ((2.78- 0.49) / 2.78) × 100 ≈ 82.37%

Şekil 6'da ise sorgu performansı artırılmadan önce ve sorası içim grafik gösterilmiştir.






**Şekil 6.** Elepsed Time Grafiği

### 3.2.3 Consistent Reads Karşılaştırması

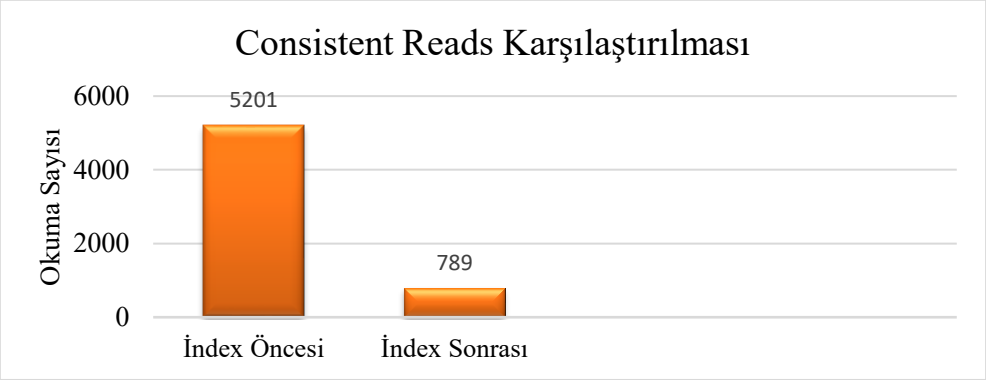
Index öncesi: 5201

Index sonrası: 789

Yaklaşık %84,8 azalma sağlanmıştır.

Şekil 7 'de sorgu performans artırımı yapıldıktan sonra Consistent Reads okuma grafiği gösterilmiş, Consisten Reads okumasında ciddi performans artırımı gözlemlenmiştir.

İyileştirme Yüzdesi = ((5201- 789) / 5201) × 100 ≈ 84.83%




**Şekil 7.** Consistent Reads Grafiği

### 3.2.4 Total Cost Karşılaştırması

Index öncesi: 2670

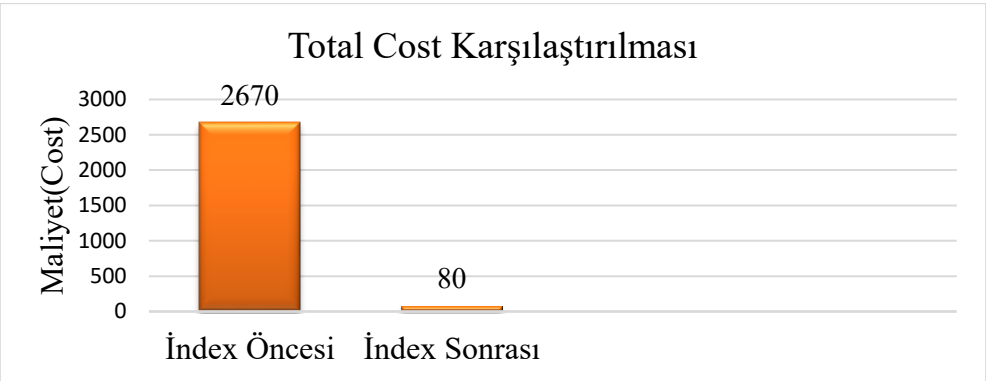
Index sonrası: 78

Yaklaşık %97,1 maliyet düşüşü gözlemlenmiştir.

Total Cost maliyeti Python kodu şekil 37'de gösterilmiştir. Performans artırımı öncesi ve sorası şekil 8'de görüleceği gibi grafik oluşturulmuştur. Performans artırımı sonrası ciddi Total Cost azalması gözlemlenmiştir.

İyileştirme Yüzdesi = ((2670- 78) / 2670) × 100 ≈ 97.08%






**Şekil 8.**Total Cost Grafiği

### 3.3 Random Forest ve XGBoost Algoritmalarının Performanslarının Karşılaştırılması

Bu bölümde, Oracle SQL sorgularının performans verileri üzerinde kullanılan iki farklı makine öğrenmesi algoritması olan Random Forest ve XGBoost'un tahmin başarıları karşılaştırmalı olarak incelenmiştir. Temel amaç, her iki algoritmanın sorgu süresi tahmini ve performans göstergelerine dayalı optimizasyon önerileri üretme konusundaki etkinliğini değerlendirmektir.

Makine öğrenmesi tabanlı sınıflandırma modellerinin başarımı yalnızca genel doğruluk oranı (accuracy) ile sınırlı kalmamalı; aynı zamanda F1 skoru, duyarlılık (recall), hassasiyet (precision), eğitim süresi ve tahmin süresi gibi farklı ölçütler üzerinden de analiz edilmelidir. Bu çerçevede, çalışmada kullanılan Random Forest ve XGBoost algoritmaları çeşitli performans kriterleri doğrultusunda karşılaştırılmıştır. Aşağıda bu metriklerin tanımları ve hesaplama yöntemleri sunulmuştur.

### 3.3.1 Kullanılan Performans Ölçütleri ve Hesaplama Yöntemleri

Sınıflandırma algoritmalarının başarısını değerlendirmek için en yaygın kullanılan yöntemlerden biri karışıklık matrisi (confusion matrix)'dir. Bu matris, modelin tahmin ettiği sınıflarla gerçek sınıfların karşılaştırılması sonucunda elde edilen dört temel bileşeni içerir: Doğru Pozitif (DP), Yanlış Pozitif (YP), Doğru Negatif (DN) ve Yanlış Negatif (YN). Tablo 3'de bu bileşenler görsel olarak sunulmuştur.

**Tablo 3.** F1 Skor Karşılaştırma Matrisi

| Matris Başlıkları | | Gerçek Değer | |
|---|---|---|---|
| | | Pozitif | Negatif |
| Tahmin Edilen | Pozitif | Doğru Pozitif (DP) | Yanlış Pozitif (YP) |
| | Negatif | Yanlış Negatif (YN) | Doğru Negatif (DN) |

- Doğru Pozitif (DP): Modelin pozitif olarak tahmin ettiği ve gerçekten pozitif olan örneklerdir.
- Yanlış Pozitif (YP): Modelin pozitif olarak tahmin ettiği fakat gerçekte negatif olan örneklerdir.
- Doğru Negatif (DN): Modelin negatif olarak tahmin ettiği ve gerçekten negatif olan örneklerdir.
- Yanlış Negatif (YN): Modelin negatif olarak tahmin ettiği fakat gerçekte pozitif olan örneklerdir.



Bu dört değer yardımıyla çeşitli performans metrikleri hesaplanabilir.

- Doğruluk (Accuracy): Tüm doğru tahminlerin toplam tahmin sayısına oranıdır. Doğruluk = (DP +DN)/ (DP+DN+YP+ YN)
- Hassasiyet (Precision): Pozitif olarak tahmin edilenlerin ne kadarının gerçekten pozitif olduğunu gösterir.

Precision= DP / (DP+YP)

- Duyarlılık (Recall): Gerçek pozitif örneklerin ne kadarının doğru tahmin edildiğini gösterir.
  Recall= DP / (DP+YN)
- F1-Skoru (F1 Score): Precision ve Recall değerlerinin harmonik ortalamasıdır. F1-Skoru= 2*(Kesinlik * Duyarlılık) / (Kesinlik + Duyarlılık)

Bu metrikler sayesinde farklı modellerin sınıflandırma başarımı karşılaştırmalı olarak analiz edilebilir. Örneğin bu çalışma kapsamında kullanılan Random Forest ve XGBoost algoritmalarının değerlendirilmesinde bu matris ve türev metrikleri temel alınmıştır. Bu yöntem, (Yıldırım, 2020) ağ tabanlı saldırı tespiti üzerine gerçekleştirdikleri çalışmada da tercih edilmiştir. Onların çalışmasında, benzer şekilde karışıklık matrisinden türetilen metrikler kullanılarak algoritmaların doğrulukları karşılaştırılmıştır.

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## 4. DENEYSEL ÇALIŞMA

Bu bölümde, Oracle veritabanı sorgu performans verileri üzerinde geliştirilen makine öğrenmesi modellerinin eğitimi, değerlendirilmesi ve karşılaştırmalı analizleri sunulmaktadır. Çalışma kapsamında, literatürde veritabanı performans tahmini ve sınıflandırma problemlerinde yaygın olarak kullanılan iki farklı ağaç tabanlı topluluk öğrenme algoritması tercih edilmiştir:

- **Random Forest modeli:** Aşırı öğrenmenin (overfitting) önlenmesi ve genelleme kabiliyetinin artırılması amacıyla GridSearchCV yöntemi kullanılarak optimize edilmiştir. Bu kapsamda, n_estimators=100, max_depth=10, min_samples_split=5 ve min_samples_leaf=2 gibi hiperparametreler en uygun değerler olarak belirlenmiştir.
- **XGBoost Modeli:** Literatürde sıklıkla kullanılan varsayılan parametreler (n_estimators=100, learning_rate=0.3, reg_alpha=0, reg_lambda=1) ile eğitilmiş ve karşılaştırma açısından referans bir model olarak değerlendirilmiştir.

Her iki model de Python ortamında **scikit-learn** ve **xgboost** kütüphaneleri kullanılarak eğitilmiş olup, Oracle SQL_TRACE çıktılarından elde edilen ve *oracle_perf_data.csv* dosyasında yer alan performans metrikleri üzerinde test edilmiştir. Model performansları; doğruluk (accuracy), hassasiyet (precision), duyarlılık (recall), F1-skoru, eğitim süresi ve tahmin süresi gibi hem istatistiksel hem de operasyonel ölçütler üzerinden değerlendirilmiştir.

**Tablo 4.** Algoritma Performansı

| Model | Doğruluk | Hassasiyet | Duyarlılık | F1-Skor | Eğitim Süresi (sn) | Tahmin Süresi(sn) |
|---|---|---|---|---|---|---|
| **Random Forest** | %94.3 | %94.0 | %95.0 | %94.5 | 0.36 | 0.05 |
| **XGBoost** | %96.1 | %96.3 | %96.0 | %96.1 | 0.41 | 0.04 |



Tablo 4'te sunulan sonuçlar incelendiğinde, XGBoost algoritmasının %96.1 doğruluk ve %96.1 F1-skoru ile Random Forest modeline kıyasla daha yüksek sınıflandırma başarısı sağladığı görülmektedir. Bu durum, XGBoost'un gradyan artırma mekanizması ve düzenlileştirme (regularization) yetenekleri sayesinde karmaşık ve yüksek boyutlu performans verilerindeki örüntüleri daha etkin biçimde öğrenebilmesine bağlanabilir. Random Forest modeli ise %94.3 doğruluk ve %94.5 F1-skoru ile güçlü bir performans sergilemekle birlikte, özellikle karmaşık sorgu senaryolarında XGBoost'un gerisinde kalmıştır.

Eğitim süresi açısından değerlendirildiğinde, Random Forest modelinin daha kısa sürede eğitildiği, buna karşın XGBoost'un tahmin süresinde daha hızlı sonuç ürettiği gözlemlenmiştir. Bu durum, gerçek zamanlı veya çevrim içi performans izleme ve karar destek sistemlerinde XGBoost algoritmasının daha uygun bir alternatif olabileceğini göstermektedir. Öte yandan, Random Forest modelinin daha düşük eğitim maliyeti, sınırlı kaynaklara sahip ortamlarda tercih edilmesini mümkün kılmaktadır. Deneysel bulgular, her iki algoritmanın da Oracle tabanlı sorgu performans analizi için etkili çözümler sunduğunu, ancak yüksek doğruluk ve hızlı tahmin gereksinimlerinin ön planda olduğu senaryolarda XGBoost algoritmasının daha avantajlı olduğunu ortaya koymaktadır. Bu bulgular, çalışmanın ilerleyen aşamalarında geliştirilecek yapay zeka destekli karar destek mekanizmasının algoritma seçimi açısından önemli bir temel oluşturmaktadır.

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## 5. BULGULAR VE TARTIŞMA

Bu çalışmada geliştirilen entegre otomasyon sistemi, Oracle PL/SQL sorgularının performansını SQL_TRACE ve EXPLAIN PLAN çıktıları üzerinden analiz ederek; elde edilen verileri (örneğin tam tablo tarama sayısı, birleştirme (join) miktarı, yürütme maliyeti gibi) Random Forest algoritması ile değerlendirmektedir. Bu sistemin sunduğu çıktılar aşağıda özetlenmiştir:

- Random Forest algoritması, değişkenler arasındaki karmaşık ilişkileri öğrenme konusunda güçlü bir topluluk (ensemble) yöntemidir.
- Bu algoritmanın tercih edilme nedeni, aşırı öğrenmeyi (overfitting) azaltma yeteneği ve çoklu karar ağaçları üzerinden tutarlı tahminler sunabilmesidir. Bagging ve rastgele özellik seçimi sayesinde model varyansı düşürülerek daha dengeli sonuçlar elde edilmektedir (Breiman, 2001).
- Literatürde yer alan çalışmalar (örneğin Xuanhe Zhou, 2020 - Database Meets AI: A Survey) da SQL performans optimizasyonunda makine öğrenmesi tabanlı yaklaşımların giderek daha fazla kullanıldığını ortaya koymaktadır.

Modelin doğruluğunu ve genel başarımını artırmak amacıyla, Random Forest'a ek olarak XGBoost algoritması da uygulanmış ve iki model çeşitli metrikler üzerinden karşılaştırılmıştır. Bu karşılaştırmada doğruluk oranı (%96.1 vs. %94.3), F1 skoru (%96.1 vs. %94.5), hassasiyet, duyarlılık, eğitim süresi ve tahmin süresi gibi ölçütler dikkate alınmıştır. Elde edilen sonuçlara göre, XGBoost algoritması sınıflandırma başarımı açısından Random Forest'a kıyasla daha yüksek performans sergilemiştir. Özellikle doğruluk ve F1 skoru açısından anlamlı bir iyileşme gözlemlenmiştir. Ancak tahmin süresi bakımından Random Forest daha hızlı çalışmakta ve bu yönüyle bazı uygulamalarda avantaj sağlamaktadır.



Bu bulgular, Oracle veritabanı performans analizinde tek bir algoritmaya bağlı kalmak yerine, farklı makine öğrenmesi yöntemlerinin birlikte değerlendirilmesinin daha sağlıklı sonuçlar vereceğini göstermektedir. Random Forest, yorumlanabilirliği ve işlem hızıyla öne çıkarken; XGBoost daha karmaşık örüntüleri daha isabetli şekilde öğrenme kapasitesiyle dikkat çekmektedir.

Literatürdeki benzer çalışmalar da bu durumu desteklemektedir. Örneğin, Buldu ve arkadaşları (2020), ağ tabanlı saldırı tespitinde XGBoost'un Random Forest'a göre daha yüksek doğruluk ve daha düşük hata oranı sağladığını göstermiştir. Benzer şekilde, Chen ve Guestrin (2016) tarafından geliştirilen XGBoost algoritmasının, karar ağaçlarına dayalı yöntemler arasında en yüksek sınıflandırma doğruluğu ve işlem verimliliği sunduğu ifade edilmiştir.

Sonuç olarak, Oracle PL/SQL ve Forms uygulamalarında performans iyileştirme amacıyla geliştirilen bu sistemde, makine öğrenmesi modelleri hem teorik hem de deneysel olarak değerlendirilmiş; en uygun algoritmanın uygulama bağlamına göre seçilmesi gerektiği sonucuna ulaşılmıştır. Bu doğrultuda, gerçek zamanlılık, kaynak kullanımı ve doğruluk gibi kriterler göz önünde bulundurularak hibrit yaklaşımların geliştirilmesi önerilmektedir.

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## 6. SONUÇ VE DEĞERLENDİRME

Bu çalışmda, Oracle PL/SQL sorgularının performans analizine yönelik bir otomasyon sistemi geliştirilmiş ve bu sistem, geleneksel izleme araçları olan SQL_TRACE ve EXPLAIN PLAN çıktıları ile entegre edilerek sorgu performansına dair kritik verileri toplamıştır. Toplanan veriler, makine öğrenmesi algoritmaları kullanılarak değerlendirilmiş ve sorguların optimizasyon gereksinimleri hakkında öneriler sunulmuştur.

Çalışmanın temel amacı, veritabanı sorgularının performansını analiz edebilen, öğrenen ve öneride bulunabilen bir sistem tasarlamak ve bu sistemin doğruluğunu farklı algoritmalarla test ederek en uygun yaklaşımı belirlemektir. Bu doğrultuda, Random Forest ve XGBoost algoritmaları kullanılarak sınıflandırma modelleri oluşturulmuş ve sorguların performans özelliklerine göre optimizasyon ihtiyacı olup olmadığı tahmin edilmiştir.

Random Forest algoritması, özellikle değişkenler arasındaki karmaşık ilişkileri öğrenme kapasitesi ve aşırı öğrenmeyi azaltma yeteneği ile öne çıkmıştır. XGBoost ise daha yüksek doğruluk ve F1 skoru gibi metriklerde üstün performans sergileyerek, sınıflandırma başarımı açısından daha etkili bir alternatif olarak değerlendirilmiştir. Ancak tahmin süresi bakımından Random Forest daha hızlı sonuçlar üretmiş ve bu yönüyle gerçek zamanlı uygulamalarda avantaj sağlamıştır.

Her iki algoritmanın karşılaştırmalı analizi sonucunda, tek bir makine öğrenmesi yöntemine bağlı kalmak yerine, uygulama bağlamına göre farklı algoritmaların birlikte değerlendirilmesinin daha sağlıklı sonuçlar vereceği anlaşılmıştır. Özellikle büyük ve dinamik veri tabanlarında, sorgu desenlerinin zamanla değişmesi nedeniyle, modellerin periyodik olarak güncellenmesi ve yeniden eğitilmesi gerekliliği ortaya çıkmıştır.

Geliştirilen sistem, SQL sorgularının geçmiş performans izlerinden öğrenerek gelecekteki sorgulara yönelik optimize edici önerilerde bulunabilmekte; bu sayede insan müdahalesine gerek kalmadan performans iyileştirmesi sağlayabilmektedir. Bu yapı, özellikle kurumsal düzeyde büyük veri tabanı sistemlerinde, karar destek mekanizmalarının güçlendirilmesi açısından önemli bir katkı sunmaktadır.



Ayrıca, sorgu iyileştirmesi öncesi ve sonrası elde edilen metriklerin görselleştirilmesi, sistem yöneticilerinin karar alma süreçlerini desteklemekte ve öneri sisteminin doğruluğunu görsel olarak kanıtlamaktadır. Bu bağlamda, karar destek sistemlerine entegre edilebilecek görselleştirme modülleri, sistemin kullanılabilirliğini ve etkinliğini artıracaktır.

Sonuç olarak, bu çalışma, Oracle PL/SQL sorgularının performans analizine yönelik yapay zekâ destekli bir yaklaşım sunmakta hem teorik hem de uygulamalı olarak makine öğrenmesi algoritmalarının veritabanı optimizasyon süreçlerine nasıl entegre edilebileceğini göstermektedir. Geliştirilen sistem, veri tabanı yönetiminde otomasyonun artırılması, insan hatalarının azaltılması ve karar alma süreçlerinin hızlandırılması açısından önemli bir potansiyele sahiptir.

Gelecekte yapılacak çalışmalar için önerilen bu sistem, farklı veritabanı türlerine uyarlanabilir, daha fazla algoritma ile genişletilebilir ve gerçek zamanlı izleme sistemleriyle entegre edilerek daha kapsamlı bir performans yönetim platformuna dönüştürülebilir.

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