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E-State: A Multilingual and Explainable AI Framework for Real Estate Decision Support

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Abstract: The real-estate discovery and investment ecosystem in emerging regional markets is characterized by fragmented listings, language barriers, limited transparency, and weak decision support, making property selection and valuation difficult for both buyers and brokers. Existing platforms typically offer isolated search or listing workflows and lack integrated intelligence for multilingual query understanding, price estimation, and investment analysis. This paper presents E-State (Alaska Property), a comprehensive AI-enabled real-estate decision support framework that unifies property discovery, broker-side listing management, financial analytics, and subscription-aware access control in a single web platform. The proposed system combines a dual-mode search pipeline with structured filtering and relevance-scored natural-language matching, an explainable price prediction module driven by location, property type, age, and amenity factors, and an investment calculator that estimates EMI, ROI, future value, and rental yield. In addition, E-State incorporates multilingual interaction support for English and major Indian regional languages to improve accessibility across diverse user populations. The framework is implemented with a modern three-layer architecture using React and TypeScript on the client side and Firebase services for authentication, data persistence, and analytics, enabling scalable real-time property operations. E-State addresses key gaps in current literature by integrating multilingual usability, interpretable AI-assisted valuation, and role-based monetization workflows into a unified, deployable platform for practical real-estate decision intelligence.

I. INTRODUCTION

A. Background

The real estate sector is undergoing rapid digital transformation, yet property discovery and investment decision-making remain fragmented, opaque, and highly manual in many emerging markets [1]. Prospective buyers and investors often depend on disconnected listing portals, informal broker networks, and non-standardized valuation practices, which increases search cost and decision uncertainty [2]. These challenges are amplified in multilingual regions, where language barriers limit accessibility and reduce trust in digital platforms [3].

Recent advances in artificial intelligence have enabled data-driven support for recommendation, valuation, and user-personalized experiences across multiple domains [4]. However, in real estate, many deployed systems still provide isolated capabilities, such as listing search without explainable valuation, or financial calculators without integrated market context [5]. A robust platform for modern property ecosystems should combine intelligent search, interpretable price estimation, and investment analytics within a single operational workflow [6].

B. Problem Statement

Current digital real estate solutions face several critical limitations:

1) Fragmented decision workflow: Existing platforms typically separate property search, price understanding, and investment planning, forcing users to switch across tools and reducing decision coherence [7].
2) Limited intelligence in search: Many systems rely on rigid filters and keyword matching without adaptive relevance scoring for user intent and property characteristics [8].
3) Poor explainability in valuation support: Available valuation features often provide outputs without transparent factor-level interpretation, limiting user confidence and practical adoption [9].
4) Inadequate inclusion for regional users: Monolingual interfaces and non-localized content reduce accessibility for non-English-speaking populations in high-growth property markets [10].
5) Weak integration between stakeholder roles: Buyer-facing and broker-facing workflows are frequently disconnected, creating inefficiencies in listing management, lead conversion, and service monetization [11].

C. Research Motivation

This research is motivated by the need for an integrated, practical, and explainable real estate intelligence system that supports end-to-end decision-making for both users and brokers. Real-world property decisions require simultaneous reasoning across multiple dimensions: affordability, location quality, expected appreciation, and investment returns.

To operationalize this in a deployable platform, the system must:

1) Support multilingual interaction for broader market accessibility
2) Provide dual-mode intelligent search that combines structured filtering with intent-aware ranking
3) Generate explainable price prediction based on interpretable market and property factors
4) Offer financial analytics (e.g., EMI, ROI, rental yield) to improve investment literacy
5) Enable role-based workflows and subscription-aware access for sustainable platform operations

D. Contributions

This paper makes the following contributions:

1) Unified real estate decision intelligence framework: A comprehensive architecture that integrates property discovery, valuation support, investment analytics, and role-based platform services within a single web ecosystem.
2) Dual-mode AI-assisted property search: An intelligent retrieval strategy combining conventional constraint filtering with relevance-scored natural-language query handling for improved property matching.
3) Explainable price prediction module: A transparent valuation mechanism that estimates future price movement using interpretable features such as location profile, property type, age, and amenities.
4) Integrated investment analytics engine: A decision-support component that computes EMI, return on investment, future value, and rental yield to assist financially grounded property choices.
5) Multilingual and role-aware platform design: A practical implementation that improves accessibility through regional language support while aligning user and broker workflows under subscription-enabled service governance.

II. LITERATURE REVIEW

A. Digital Real Estate Platforms and PropTech Evolution

Recent PropTech research shows that digital real estate systems have significantly improved listing visibility, customer reach, and transaction efficiency; however, most platforms remain marketplace-centric rather than decision-centric [1]. Existing systems typically prioritize listing aggregation, static filters, and lead routing, with limited support for integrated valuation and investment decision workflows [2]. Studies on online property portals also note persistent issues of data asymmetry, inconsistent listing quality, and weak transparency in pricing rationale, especially in emerging markets [3]. These findings indicate that platform maturity in user interface design has not always translated into intelligence maturity in decision support.

B. Ai and Machine Learning for Property Valuation

Automated Valuation Models (AVMs) using linear regression, hedonic pricing, random forests, gradient boosting, and deep learning have demonstrated strong predictive potential for real estate price estimation [4], [5]. Nevertheless, model transferability across regions remains challenging due to heterogeneity in micro-location effects, local regulations, and neighbourhood amenities [6]. A recurring concern in this literature is explainability: black-box predictors can produce accurate outputs but fail to provide factor-level reasoning useful for end users and non-technical stakeholders [7]. Recent work therefore emphasizes interpretable or hybrid approaches that balance predictive strength with transparent feature influence [8], directly motivating explainable valuation support in deployable platforms.

C. Intelligent Property Search and Recommendation

Property retrieval research has progressed from rule-based filtering to ML-based recommendation and, more recently, semantic retrieval methods [9]. Traditional faceted filtering is computationally efficient but often fails to capture user intent when queries are vague, contextual, or preference-rich [10]. Recommendation-based approaches improve personalization but may suffer from cold-start and sparse behavioural signals in new or low-traffic platforms [11]. Emerging studies suggest that practical systems can benefit from hybrid search pipelines that combine deterministic constraints (budget, location, type) with relevance-aware scoring for higher retrieval quality [12]. This motivates dual-mode search designs that preserve user control while improving intent matching.

D. Multilingual Human-Centred Design in Real Estate Services
Multilingual UX and localization research consistently reports improved accessibility, trust, and task completion when platforms adapt to native language use, especially in linguistically diverse populations [13]. In real estate contexts, language barriers can increase interpretation errors around legal, financial, and location-specific terms, directly affecting high-stakes decisions [14]. While multilingual support is common in e-commerce and public-service systems, its adoption in real estate decision platforms remains limited and often superficial (partial translation, inconsistent terminology, weak persistence across workflows) [15]. This gap is particularly relevant for regional markets where local-language discoverability is critical for digital inclusion and market participation.

E. Financial Decision Support for Real Estate Investment
Prior literature on property investment tools highlights the practical importance of integrated financial indicators such as EMI, ROI, net yield, and projected appreciation [16]. Many consumer-facing systems provide standalone calculators, but they are rarely connected with live property discovery and valuation outputs, limiting contextual usefulness [17]. Decision science studies indicate that integrated analytical workflows reduce cognitive load and improve confidence by allowing users to compare affordability and return trade-offs in one environment [18]. This supports the need for tightly coupled search-valuation-investment modules rather than isolated utilities.

F. Role-Based Platform Architectures and Monetization
Platform engineering research emphasizes role-based access control (RBAC), workflow separation, and service-tier gating as key enablers of scalable two-sided ecosystems [19]. In real estate applications, broker and buyer journeys have distinct requirements: brokers need listing lifecycle management, while users need trustworthy information, contact transparency, and actionable analytics [20]. Subscription-based feature gating has been studied as a sustainability mechanism, but prior work reports risks when gating is not aligned with perceived value or transparent communication [21]. This suggests that monetization should be integrated with user trust and utility design, not treated as a detached business layer.

G. Research Gap and Positioning of E-State
From the reviewed literature, five gaps remain insufficiently addressed in combination:
1) Lack of unified platforms that jointly support intelligent search, explainable valuation, and investment analytics.
2) Limited multilingual depth in real estate decision workflows for emerging regional markets.
3) Insufficient integration between user-side decision support and broker-side operational tooling.
4) Weak explainability in valuation outputs for practical trust and adoption.
5) Incomplete coupling of role-aware monetization with decision-centric platform design.
6) E-State is positioned to address these gaps through an integrated real estate decision intelligence framework that combines multilingual interaction, dual-mode AI-assisted search, explainable pricing logic, financial analytics, and role-aware platform workflows in a single deployable architecture.

III. PROPOSED METHODOLOGY

A. System Architecture
E-State employs a three-tier architecture designed for usability, maintainability, and real-time decision support in property discovery and investment planning. The system components interact as illustrated in Fig. 1. The frontend layer (React + TypeScript) delivers multilingual UI, role-based navigation (User/Broker), and interactive modules for Smart Search, Price Estimation, and Investment Analytics. The application logic layer executes hybrid retrieval (filter + intent scoring), explainable valuation, and financial computations (EMI, ROI, rental yield). The cloud services layer (Firebase Authentication, Cloud Firestore, Firebase Analytics) provides identity management, persistent storage of listings/user profiles/subscriptions, and telemetry for monitoring feature usage and improving ranking heuristics.

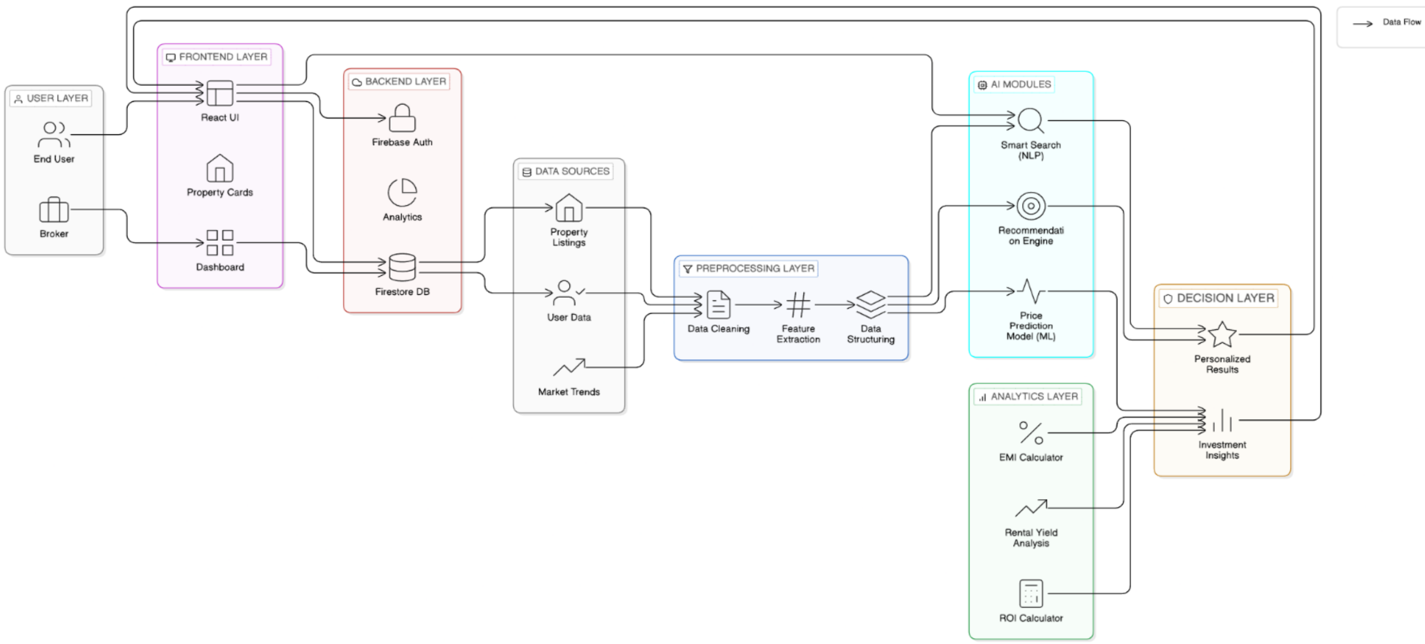

Fig. 1. E-State System Architecture

B. Research Gaps and E-State Solutions

TABLE I
RESEARCH GAPS AND E-State SOLUTIONS

Gap	Existing Limitation	E-State Solution
Workflow fragmentation	Search, valuation, and finance handled via separate portals/tools	Unified end-to-end pipeline (discover → value → analyze returns)
Search quality	Rigid filter-only retrieval misses intent	Hybrid retrieval: strict filters + intent-aware relevance scoring
Valuation trust	Black-box or opaque estimates reduce confidence	Explainable factor-based pricing with visible drivers
Regional accessibility	Monolingual interfaces reduce adoption	Multilingual UI layer with consistent terminology
Role integration	Weak broker/user workflow separation	Role-aware flows (broker dashboard + user discovery)
Platform sustainability	Limited monetization for premium data	Subscription gating for sensitive listing details

C. Data Modeling and Acquisition Strategy

E-State uses a structured schema so the same property record can support search, valuation, and analytics consistently.

- Core attributes: title, description, price, area, type/subtype, age/age bracket
- Location attributes: state, city, locality
- Amenities: standardized amenity set (parking, security, lift, etc.)
- Role metadata: broker/user ownership and timestamps
- Optional signals: engagement (views/likes) for contextual boosting

Data Sources

- Seeded dataset for reproducibility and demos
- Broker-created listings via dashboard workflow

Preprocessing

- text normalization (lowercase, trimming)
- label standardization (type/subtype/amenities)
- numeric validation (price, area)
- missing data handling (safe defaults; exclude only if critical fields are absent)

H. Hybrid Retrieval and Ranking Formulation

E-State ranks properties using a hybrid score that combines deterministic constraints with intent relevance.

$$S(p,q) = \alpha S_f(p,q) + \beta S_k(p,q) + \gamma S_c(p)$$

$S_f(p,q)$: filter compliance score (budget, state/location, type, area).
$S_k(p,q)$: keyword/intent relevance computed from matches across title, description, location, subtype, and amenities.
$S_c(p)$: contextual booster (e.g., “luxury”, “affordable”, “spacious”, subtype cues; optional popularity if available).
(α,β,γ): tunable weights.
This formulation preserves strict constraint satisfaction while improving relevance for natural-language intent.

I. Algorithm--Dual-Mode Property Retrieval

Input: constraints (C), query (q), dataset (P)
Output: ranked results (R)

- Filter: $P' = \{ p \in P \mid p \; satisfies \; C \}$
- Process query: tokenize, remove stopwords, extract intent terms
- Score: S(p,q) = α S_f(p,q) + β S_k(p,q) + γ S_c(p)
- Rank: R = sort(P', S(p,q), descending)→ return (R)

J. Explainable Price Estimation and Projection

E-State uses an interpretable factor-based price model to improve user trust.

$$\hat{P} = A \times \rho_{loc} \times M_{type} \times M_{subtype} \times M_{age} \times M_{amen}$$

Where:

- A = area
- ρ_{loc}= location base rate
- $M_{type}, M_{subtype}, M_{age}, M_{amen}$= multipliers

Future Price Projection:

$$P_t = \hat{P}(1 + r)^t$$

Where:

- r = annual appreciation rate
- t = time (years)

K. Investment Decision Analytics

E-State computes real-time affordability and return indicators for shortlisted properties.
EMI Calculation:

$$EMI = \frac{(L \times i \times (1 + i)^n)}{((1 + i)^n - 1)}$$

Return on Investment (ROI):

$$ROI(\%) = \left[\frac{(V_{future} - C_{total})}{C_{total}}\right] \times 100$$

Rental Yield:

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$$Yield(\%) = \left[12 \times \frac{R_{monthly}}{P_{purchase}}\right] \times 100$$

These metrics allow comparison based on affordability (EMI) and profitability (ROI/yield).

L. Role-Based Access and Subscription Control

- End users: search, view explainable pricing, run investment analytics
- Brokers: create/manage listings via dashboard
- Subscription gating: restricts access to sensitive details (e.g., contact info) while keeping core discovery and analytics accessible.

M. Module Specifications

TABLEII
MODELSPECIFICATIONS

Module	Method	Output
Filtering	rule-based constraints	candidate set
Intent Scoring	keyword matching + heuristics	relevance score
Ranking	weighted aggregation	ranked results
Explainable Pricing	factor-based model	price + explanation
Projection	compound growth	future value
Investment Analytics	formulas	EMI, ROI, yield
Access Control	role + subscription	gated visibility

IV. IMPLEMENTATION

A. Technology Stack

TABLE III
IMPLEMENTATION TECHNOLOGIES

Layer	Component	Technology
Frontend	Framework	React + TypeScript
Frontend	Build Tooling	Vite
Frontend	UI & Styling	Tailwind CSS + reusable UI components
Frontend	State/Context	React Context (Auth/Language/Theme)
Cloud	Authentication	Firebase Authentication
Cloud	Database	Cloud Firestore
Cloud	Telemetry	Firebase Analytics

B. Core Modules and Implementation Design

1) Authentication and User Profile Management

E-State implements secure identity and role handling using Firebase Authentication. After login/registration, a user profile document is stored in Firestore containing:

- user identity (uid, email, name)
- role: user or broker

- subscription status and plan metadata (if enabled)

This enables role-aware navigation and feature access control across the application.

2) Property Listing Management (Broker Workflow)

Broker operations are implemented as a structured dashboard workflow that supports:

- create listing (standardized schema: location, price, area, type/subtype, amenities, description)
- update listing (editing and corrections)
- persistence to Firestore with timestamps and broker ownership metadata

This ensures consistent data quality and improves downstream retrieval and pricing reliability.

3) Property Discovery (Basic + Smart Search)

E-State provides dual-mode retrieval:

- Basic Search: rule-based filtering over Firestore-loaded property data using budget, state, type, and area constraints to generate candidate set (P').
- Smart Search (AI-assisted intent scoring): query is tokenized, normalized, and scored against listing fields (title, description, location, subtype). Domain boosters are applied for intents such as luxury/affordable/spacious and subtype matches. Results are sorted by the final score (S(p,q)).

This hybrid design improves both precision (filters) and relevance (intent).

4) Explainable Price Estimation

The pricing module implements an interpretable valuation function that provides:

- Estimated price $\hat{P}$
- Factor-wise contribution (location, type, subtype, age, amenities)

Price Estimation Formula:

$$\hat{P} = A \times \rho_{loc} \times M_{type} \times M_{subtype} \times M_{age} \times M_{amen}$$

Where:

- A = area
- ρ_{loc}= location base rate
- $M_{type}, M_{subtype}, M_{age}, M_{amen}$= multipliers

5) Investment Calculator

The investment module computes affordability and profitability metrics in real time:

EMI Calculation:

$$EMI = \frac{(L \times i \times (1 + i)^n)}{((1 + i)^n - 1)}$$

Return on Investment (ROI):

$$ROI(\%) = \left[\frac{(V_{future} - C_{total})}{C_{total}}\right] \times 100$$

Rental Yield:

$$Yield(\%) = \left[12 \times \frac{R_{monthly}}{P_{purchase}}\right] \times 100$$

C. Database Design and Data Integration

Firestore Collections (logical organization)

E-State persists structured data in Firestore collections such as:

- users: role, subscription state, profile info
- properties: listings with searchable fields (type/subtype, location, price, area, amenities)

- subscriptionPlans (optional): plan definitions and limits
- aiFeatures / services / lawyers (optional): auxiliary feature metadata and services directory

Data Flow

- User/Broker authenticates via Firebase Auth
- App fetches user profile from Firestore
- Properties are fetched from Firestore for search/ranking
- Selected properties feed into pricing explanation and investment analytics
- Analytics events are logged to Firebase Analytics

D. Access Control and Security

E-State enforces access control at two levels:

- Application level: role-aware routing (broker dashboard accessible only to broker role)
- Feature level: subscription gating for sensitive details (e.g., contact information)

This approach supports sustainability while keeping core discovery and analytics accessible.

E. Operational Telemetry

Firebase Analytics captures feature usage signals such as:

- search mode usage (basic vs smart search)
- valuation tool usage
- investment calculator usage
- plan/subscription interactions

Telemetry supports iterative tuning of ranking weights (α, β, γ)and UX improvements based on observed behavior.

V. EXPERIMENTAL METHODOLOGY

A. Evaluation Metrics

The proposed system should be evaluated using the following metrics:

1) Search / Ranking Quality

- Precision@K: proportion of relevant properties in the top-K results
- Recall@K: proportion of all relevant properties retrieved within top-K (if ground truth set is defined)
- NDCG@K: ranking quality with graded relevance (rewards correct ordering)
- MRR: reciprocal rank of the first relevant result (measures how quickly a user finds a good match)

2) Valuation / Price Estimation Quality

- MAE: mean absolute difference between estimated price and reference price
- RMSE: penalizes large estimation errors more strongly
- MAPE (optional): percentage error for interpretability across price ranges
- Explainability Consistency Checks: monotonic behavior (price increases with area, decreases with higher age bracket, increases with more amenities)

3) Investment Analytics Correctness

- EMI deviation: absolute error vs standard EMI formula (should be near-zero within rounding)
- ROI/yield deviation: correctness of computed ROI and rental yield against formula-based calculations

4) System Performance

- End-to-end latency: time from user query submission to ranked results display
- Throughput: number of queries/rankings processed per second (for batch tests)
- Availability: uptime and successful query completion rate under Firebase/network issues

B. Baseline Comparisons

Evaluation should compare E-State against the following baselines:

1) Filter-Only Search: strict constraint filtering without intent scoring

2) Keyword-Only Search: simple text match without structured filtering or boosters
3) No-Booster Hybrid Ranking: hybrid score with contextual booster disabled ((γ=0))
4) Black-Box Pricing Baseline: a simple regression model without factor explanations (used only to show trust/interpretability advantage)
5) Manual Sorting Baseline: ranking by lowest price / highest area as naive heuristics

C. Dataset Description

Evaluation data comprises structured real-estate listings with at least the following fields: price, area, type/subtype, state/city/locality, amenities, title/description, and timestamps.

1) Primary dataset: seeded property dataset for reproducible experiments
2) Supplementary dataset: broker-created listings collected through the dashboard workflow
3) Query set: user-style search queries covering constraint-heavy, intent-heavy, and mixed intents (minimum 50–100 queries recommended)
4) Labeling: top-K results per query are human-judged as Relevant/Partially/Not Relevant to compute ranking metrics
5) Splits (if needed): separate sets for tuning weights ((α, β, γ)) and final reporting (development vs test queries).

VI. CONCLUSION AND FUTURE WORK

A. Conclusion

This paper presented E-State, an AI-assisted real-estate decision support platform that integrates property discovery, explainable pricing, and investment analytics into a single unified workflow. Unlike fragmented property portals that separate search and financial evaluation, E-State provides an end-to-end pipeline where users can filter and rank listings using intent-aware relevance scoring, understand valuation through transparent factor contributions, and estimate affordability and returns through real-time financial metrics. The proposed three-tier architecture (React + TypeScript frontend, application logic layer, and Firebase cloud services) demonstrates that intelligent ranking, interpretable pricing, and investment computations can be deployed in a practical, user-friendly system.

The main contributions of E-State are:

1) Hybrid retrieval and ranking formulation that combines strict constraint satisfaction with intent-aware relevance scoring using

$$S(p,q) = \alpha\, S_f(p,q) + \beta\, S_k(p,q) + \gamma\, S_c(p)$$

enabling better search quality than filter-only approaches.

2) Explainable price estimation module based on a factorized valuation model that provides both an estimated price and a breakdown of contributing factors (location, type/subtype, age, amenities, area), improving transparency and user trust.
3) Investment decision analytics engine that computes essential affordability and profitability metrics (EMI, ROI, rental yield, future value) to support data-driven property comparison.
4) Role-aware and subscription-aware platform design that supports both end users and brokers, enabling sustainable access control while maintaining core search and analytics usability.

B. Limitations

Despite its usefulness as a decision-support platform, E-State has several limitations:

1) Pricing reference limitation: The valuation model may rely on listing prices or region-level base rates as reference signals, which may not fully match true transaction prices due to negotiation, market shocks, and local micro-factors.
2) Data quality dependency: Search relevance and valuation accuracy depend strongly on the completeness and correctness of listing data (missing amenities, incorrect area, inconsistent locality names).
3) Limited external market integration: The current scope may not include integration with official government guidance values, registry transaction histories, or third-party real estate indices, which could improve calibration.
4) Heuristic intent scoring constraints: Intent-aware scoring is lightweight and may not capture deeper semantics (e.g., “near metro”, “good connectivity”) unless explicitly encoded or supported by richer NLP.

C. Future Work

Future research and development directions include:

1) Integration of real market reference data (registry/indices)

Incorporate verified transaction-level references (where available) or locality price indices to better calibrate (\rho_{loc}) and reduce valuation error across cities and submarkets.

2) Advanced NLP for semantic intent understanding

Upgrade from keyword-based matching to semantic retrieval (embedding-based ranking) to better interpret natural language queries such as “near hospital”, “family friendly area”, or “good connectivity”, while still preserving hard constraint compliance.

3) Automated tuning of ranking weights

Use telemetry and offline evaluation sets to systematically tune $(\alpha, \beta, \gamma)$and booster rules, including A/B testing or multi-armed bandit tuning to improve relevance continuously.

4) Explainability enhancements and user trust evaluation

Provide richer explanations (e.g., “top 3 reasons this listing is recommended” and “factor contribution waterfall for price”), and conduct formal usability studies to quantify trust and decision confidence improvements.

5) Risk-aware investment planning

Add configurable investment profiles (low/medium/high) that adjust appreciation assumptions, minimum rental yield thresholds, and affordability constraints to personalize recommendations for different buyer/investor risk preferences.

6) Scalability and reliability upgrades

Introduce caching, pagination, and query optimization for large Firestore datasets and implement graceful degradation strategies so core discovery features remain available even under partial cloud failures.

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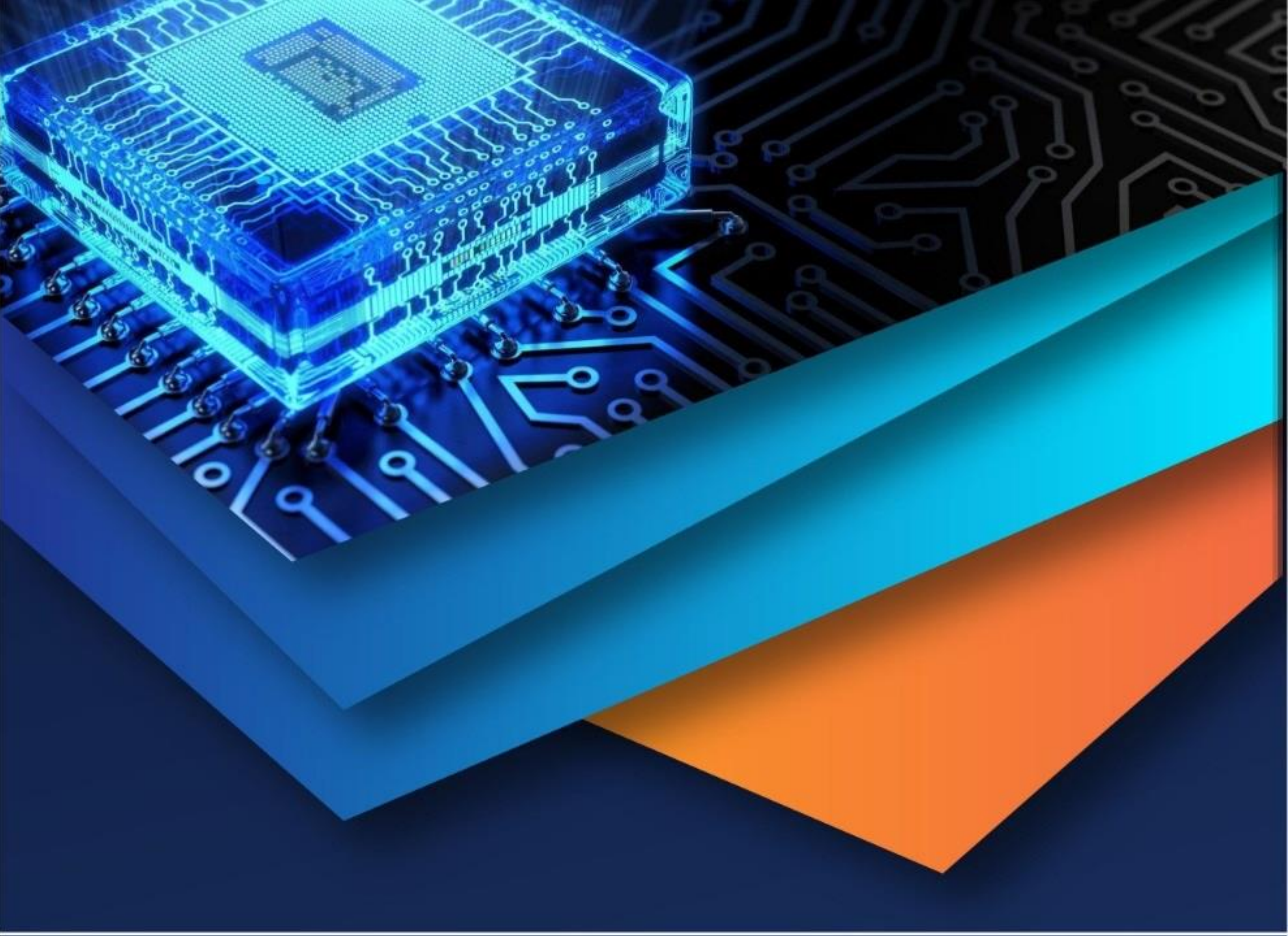

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