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From Heritage to Design: Pattern Extraction and Landscape Interpretation of the Alaca (Painted) Mosque, Tetovo, North Macedonia

Marija Miloshevska Janakieska, Faton Kalisi and Harika Shehabi

Abstract

This study is focused on cultural heritage and how it can influence the contemporary spatial design through a design oriented educational workshop focused on the Alaca Mosque in Tetovo, North Macedonia. The research aims to analyze the historical development, visual identity, and ornamental language of the mosque and to translate these findings into landscape design proposal for its surrounding urban context. The methodology consists of historical review of the mosque, analytical documentation of architectural details and ornamentation, extraction of geometric and floral patterns, and their reinterpretation into contemporary design elements. The analytical focus includes detailed research of the decorative elements of the mosque, based on the site observation and the literature review – its geometry, rhythm, color palette, texture, and proportional relationships—which served as the conceptual base for the further design translation process. The outcome of the whole process is a landscape concept along nearby river and public park, inspired from patterns found in the mosque, that reflects the symbolic meaning. At the same time, the landscape proposal addresses current spatial needs. By demonstrating how architectural identity from historical structures can be systematically decoded and reinterpreted into modern urban landscape interventions, this research contributes to the field of heritage-based design. Using a simple workshop-based methodology, the study also emphasizes the educational value of engaging students in analyses of cultural heritage as a tool for developing culturally responsive design thinking.

Keywords: Heritage, patterns, landscape interpretation, Alaca Mosque

Introduction

The process of architectural and urban design is very complex and consists of many aspects. Prior to the process of design, there are many analytical phases that should be acquired. Cultural heritage plays a vital role in these analyses, especially in contexts where important historical structures form the local identity (Khazene & Bensliman, 2024). These analyses lead to heritage-based design approaches that connect the past with the present. They often consist of transforming architectural, artistic, and cultural elements into meaningful architectural, urban and landscape interventions that meet contemporary needs. These approaches in the design are one of the most important segments for maintaining the identity of the place and promoting cultural continuity (Kuipers & de Jonge, 2017).

The main object of this study is the Painted Mosque in Tetovo, North Macedonia which dates back from the 15th-century Ottoman era. The location of the Mosque is near Pena River in Tetovo, North Macedonia. The mosque is a unique remarkable structure with richly colored floral and geometric frescoes, painted with a special technique using thousands of eggs. These decorations give a special value to the mosque, since it is one of kind and unique in the region (Ramani Murseli, 2022). Alaca Mosque presents a perfect case study for this research, through which the connection between the heritage and design can be seen. It is a great source of inspiration with beautifully decorated facades, amazing architectural details, and characteristic polychromatic ornamentation. Moreover, the visual and tactile language of the building is phenomenal. The visual elements – geometry, floral motifs, layered compositions, and vibrant color system in combination with the tactile elements – different textures on the walls make the mosque truly unique. The mosque stands not only as a religious monument but also as a symbol of Tetovo's cultural identity, making it a valuable subject for analytical and design-oriented research.

This study is based on an interdisciplinary workshop organized through a collaboration between the Faculty of Art and Design, the Department of Architecture, Faculty of Engineering at International Balkan University and Interior Architecture Department, Faculty of Architecture, at Yeditepe University. The workshop started with a visit to the Alaca Mosque, where students guided by the professors were doing on-site observational exercises, sketching, photographing, and taking notes (Figure 1).

Figure 1

Photos from the visit of the mosque.

Source: Authors.

The workshop continued the second day at the Innox Center with analytical sessions, presentations, and feedback meetings. During the second day, the students analyzed the photographs and sketches, did research on the historical review of the mosque, and offered a design proposal informed by the gathered documentation (Figure 2). In the following weeks, students were working on the design proposal and preparing the graphical representations for the upcoming exhibition.

Figure 2

Photos from the workshop.

Source: Authors.

The workshop concluded with an exhibition where all the works of the students were exhibited (Figure 3). The exhibition consisted of different results from the participants of different departments.

Figure 3

Photos from the exhibition.

Source: Authors.

This study presents the process and outcomes of a workshop-based pedagogical approach in architectural education. Within this framework, students, guided by professors, explored the historical development, visual identity, and ornamental characteristics of the Alaca Mosque, and translated their findings into a contemporary landscape design proposal for the surrounding urban context.

Literature Review

There are several studies which analyze the influence of culture and heritage on architectural design. Previous research by Al-Adilee (2024) indicates that cultural and historical contexts profoundly influence architectural design. This article shows how architects draw on local heritage, materials, and symbols—while navigating globalization—to create culturally sustainable, context-sensitive designs that preserve and revitalize cultural identity.

Ornament in architecture occupies a complex position, shaped by its deep connection to the human body, symbolism, and decorative arts. Thinkers from Ruskin to Sullivan, Semper, and Alberti show that ornament reaches its highest artistic form when figural motifs are reinterpreted and abstracted into a harmonious mathematical unity between part and whole (Durgut & Akalın, 2022). Studies from Mustafa and Hassan (2013) and similar studies are focused on pattern analyses in Islamic and Ottoman architecture. Similar studies explore how local heritage can influence the design of new landscape proposals.

The importance and meaning of the Alaca Mosque should be understood within the context of Ottoman architecture in the Balkans. Early Ottoman architecture represents an initial phase in the development of a rational architectural style. A key study on Ottoman architecture in Europe, particularly in the Balkans, is "Ottoman Architectural Works in Europe, Yugoslavia, Volume 3" by Ekrem Hakki Ayverdi (1981). This study discusses specific cities in Yugoslavia, particularly Tetovo. It examines architectural identity, urban development, and the positioning of Tetovo within its regional context. Tetovo's location at the foot of Sharr Mountain and its possession of a fortress place the Alaca Mosque in a strategic position, a factor further influenced by the architectural triad. In his detailed research, Ayverdi also provides information, old photographs, and detailed drawings regarding the mosque's interior architecture, mimbar, mihrab, and prayer hall. The author provides a detailed analysis of the mosque's architectural elements. Isa Bey commissioned the architecture of the mosque, and he also commissioned the hammam, which is one of the three sections of the mosque complex (Ibrahimgil, 1997).

Tetovo is one of the most important urban centers of the Ottoman Empire in the region of North Macedonia and serves as a significant example where, in some cases, the model of the Islamic triad in architecture and urban organization has been implemented: mosque - hammam - han. This model, which represents a balance between spiritual, physical, and economic life, is clearly reflected in the old part of Tetovo. Although this book (Kumbaradži et al., 1998) focuses heavily on Ottoman

works in Skopje, it systematically and intelligently addresses the Islamic Triad, not only discussing the triads in Skopje but also touching upon the Alaca Mosque complex. It analyzes not only the architectural aspects but also the urban scale, offering a fresh perspective on architectural history and theory, and serving as a supportive work for future studies. Due to its location and cultural orientation, the city of Tetovo has adopted a rural and provincial architectural style. The most important and impactful aspect of the Alaca Mosque is its architecture and stance, which are in harmony with the city's fabric and nature. In this book, the author conveys all these contexts to the reader (Kumbaradži et al., 1998).

The mosque follows a central prayer hall organization, with the mihrab positioned on the qibla wall and the minbar located adjacent to it. The spatial composition is defined by a symmetrical arrangement of structural and ornamental elements. Another element that presents us with today's Alaca Mosque and makes it such a valuable and accepted structure is the ornamentation and wall paintings of its facade. Perhaps this is why the mosque is so valuable and meaningful, as it was originally a foundation established by two women. The 19th century certainly plays an important role in this; in this research, we see the most beautiful interpretation of the integration of wall art and painting art with a mosque, and how the Baroque and Rococo periods, which we will discuss later, come together with Andalusian influences and miniature-like art to create a place of worship (Demirarslan, 2016).

Methodology

The methodology of this study is structured, heritage-based design approach combined with field visit and observation, research of the historical overview, pattern analyses, and design translation, based on the literature review.

The first step was the field observation and visual documentation. The field observation was performed on 31st of October, 2025. Students performed on-site sketching, photographing, and pattern tracing to record architectural details, ornamentation, materials, textures, and colors. In addition, spatial relationships, circulation and connection with context were also documented.

A chronological timeline of the Alaca Mosque was created using archive sources, historical texts, and visual documentation. The students identified the key construction and renovation phases so that the evolution of the building could be understood. Findings were represented as sketches of different details and elements on one poster.

Moreover, analyses were performed where students were researching concepts such as geometric composition, repetition, rhythm, symmetry, texture and color relationship. The analyzed patterns were converted and translated into conceptual landscape design elements. The analyzed details and elements were used, transformed and implemented into landscape design.

This methodological framework allowed the research to move systematically from heritage documentation to the creation of a contemporary, pattern-inspired landscape design proposal.

Discussion

Historical Review of the Alaca Mosque Construction Origins and Cultural Context

One of the most magnificent examples of Islamic architecture from Tetovo's Ottoman era is the Painted Mosque (Alaca Mosque), which is located near the town centre on the left bank of the Pena River, which is one of the most important remains of Islamic culture and civilisation in the Balkans. The locals call this mosque *Pasha's Mosque* because Abdurrahman Pasha rebuilt it from the base in 1833. Its original name, *"Alaca,"* means *"Painted"* in the ancient Ottoman language (Lewis, 1979, pp. 322).

Early Ottoman works evolved as Ottoman control stretched over the Balkans. Based on a waqf (endowment) foundation, this mosque has played a major role in the region's urban growth. Tetovo is one of the earliest examples of rural and provincial architecture, given its urban scale and location at the base of the mountain. The mosque has maintained its basic provincial architecture and its harmony with the urban fabric over time, despite restorations in the 17th and 18th centuries and the addition of Modern and Baroque elements to its facade, which gave the edifice a European air and served not only as a place of worship but also as a social and symbolic centre of the Ottoman city (Pavlov, 2009, pp. 108-110).

This took place in the larger framework of Ottoman modernization and the integration of Western influence into provincial architecture, especially Ottoman Baroque and Rococo aesthetics. A stunning and varied example of both Islamic oriental art and Western painting, the rich, multi-coloured paintings included plant murals, architectural panoramas, and miniature-like drawings. In this way, the mosque contributed significantly to Tetovo's multi-layered architectural character as a fresh example of an eclectic style as well as a religious structure in the city center adjacent to the Pasha's home. While studying these scenarios, another architectural and cultural

theme catches our eye: the "Islamic Triad." The Islamic Triad can be defined both as an architectural trilogy and as an indicator of a cultural and life ritual. The Alaca Mosque is one part of this trilogy; immediately across the river is the Cifte Hamam (public bath), and behind the Pasha's mansion (konak) is the inn(han). This trilogy was conceived as a complex, where visitors would first wash and cleanse themselves in the baths, perform their prayers in the mosque, and rest in the inn. This trilogy is a design frequently encountered in the Ottoman Balkans (Ibrahimgil, 1997).

Timeline of Modifications and Restorations

According to the vakıfname of the mosque, as reported in secondary sources, the foundation is attributed to the sisters Hürşide and Mensure (Pavlov, 2009; Ibrahimgil, 1997). The founding charter specifies who creates the vakıf, what it is endowed with, and how it must operate indefinitely). In the meantime, it was reconstructed in the eighteenth century. The Vakifname adds that the Hurside and Mensure sisters also constructed the "Cifte Hamam," a public bath, close to the Alaca Mosque. The sisters Hurside and Mensure, who relocated to Tetovo from Anatolia, commissioned the construction of the Painted Mosque. The year of Hurside's passing is still uncertain; however, she was buried in the mosque garden. Other scholars claim that the sisters Hurside and Mensure restored the Alaca Mosque in 1564. According to the inscription on the mosque, Abdurahman Pasha built it, and its current architectural style originates from the first part of the 19th century. Its design is similar to the foundation of another building, most likely the mosque with the same name, Alaca, that was destroyed in the town's late 17th-century fire. Therefore, contrary to what certain academic publications state, the current Painted Mosque in Tetovo was not constructed in the 17th century. In such a scenario, this date would relate to a different mosque that was destroyed to the ground, as the lines mentioned in the inscription tell us (Pavlov, 2009, pp. 108-110).

In 1991, the Islamic Union took the initiative to restore these walls. Due to its exceptional architectural and artistic qualities, this mosque is protected by UNESCO.

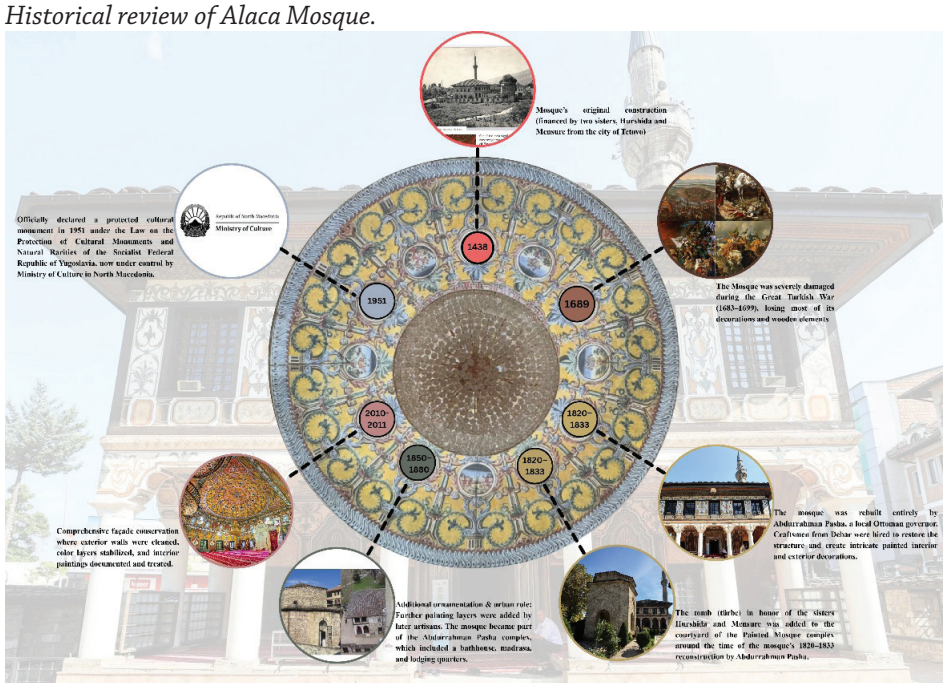
During the conflict that began in April 2001, the mosque was attacked, damaging the building's main wall. The walls had nine gunshot holes, and the windowsills were damaged.

Following this assault, the mosque was the target of three further attacks, which caused minor structural damage. Additionally, a bronze inscription pointing to the mosque's status as a cultural and religious landmark is stolen (Shehapi, 2002, 00. 34).

The foundation of its current appearance is based on the restorations carried out in 2010-11. The main goal of the 2010–2011 restoration project at the Alaca (Painted) Mosque in Tetovo was to preserve the painted surfaces and outside fabric, which had been damaged by ageing, moisture intrusion, and material deterioration. A rare example of late Ottoman painted architecture in the Balkans, the intervention sought to stabilise the building while maintaining its unique polychrome ornamental program. Stabilisation of the facade, restoration of degraded surfaces, and protective coatings for the external paintings were examples of conservation measures. International funding for the project in 2011 allowed for a more methodical approach in line with modern conservation standards. The pieces avoided stylistic reconstruction in favour of minimal intervention and visual continuity. All things considered, the restoration made a substantial contribution to the mosque's long-term preservation and ongoing use as a place of religious and cultural significance. The historical review of the mosque, as well as the timeline of the modifications and restorations, is presented graphically on Figure 4.

Figure 4

Historical review of Alaca Mosque.



Source: Authors, based on workshop outputs (2025).

Architectural Character and Key Stylistic Phases

The interior of the Painted Mosque has a nearly square plan, measuring approximately 10 × 10 meters. The praying hall is covered in domes and has a distinctive volume. This hall has a square layout and is accessible through the gate, which has an inscription in Ottoman script. The dome defines the interior space, while the exterior is covered by a pitched roof structure. Thirty lights, fifteen up and fifteen down, illuminate the inside of the mosque.

The structural system includes supporting elements along the northern façade, consisting of multiple piers and columns that reinforce the wall construction. On the north side, a series of supporting elements contributes to the stability of the structure.

The mosque is of the Early Constantinople style of Ottoman construction, which is characterised by a single dome with a porch on the side of its entry. The square foundation of the central area is hidden from view from the outside by a dome. The mihrab is positioned on the qibla (southern) wall, indicating the direction of prayer toward Mecca, and the minbar is placed adjacent to it, in accordance with standard mosque architectural principles. The mihrab is richly decorated, with its upper section composed of circular fields containing verses from the Quran.

On the western side of the interior is the mahvil (elevated gallery), consisting of semi-circular projections and extending across the width of the structure. The gallery is supported by profiled columns and is integrated into the two-story porch system. Decorative niches and inscription panels are present on the northern and western walls, and should not be interpreted as functional mihrabs.

Turkish tiles are used to create a four-ridged roof that covers the entire structure. On the south side is a minaret with a hexagonal base and one serefe (balcony). The four window openings, set in two rows, provide light. They are enclosed on the inside as well as the outside, and they are elaborately adorned with slabs of perforated stone that add to the building's overall splendour.

This mosque stands out because of its 19th-century painted ornamentation. For this aim, Abdurahman Pasha hired skilled workers from Debar to paint the decoration using oil paints; these artists were most likely the same ones who painted the Arabati Baba Tekke. The façade has been extravagantly painted using a fresco technique that resembles marble. Four rows of vertically organised rectangular fields with circular star-shaped motifs are painted on the east, north, and south facades.

These fields are divided by painted columns that end in an "S" shape below the roof in the last row. The porch is decorated with stylised geometric and floral decorations. The mosque's interior is very vibrant since it features landscape elements in addition to geometric and floral decoration. The representation of Mekka, a unique and possibly unique example of the picture of this monument of the Prophet in Southeast Europe, is particularly appealing among the pictorial decorations (Mediu-Dushi, 2010, pp. 21-23).

The türbe (mausoleum), where Hurside Hanum is buried, is located northwest of the mosque. It is a sort of open türbes, with a stone base shaped like an uneven octagon. It is thought to have been constructed in the sixteenth century, despite the lack of written evidence. It adds to the Painted Mosque's urban atmosphere with its balanced proportions. The structure was originally covered by a dome, and its balanced proportions contribute to the overall urban composition of the Painted Mosque complex.

Analysis of Architectural Details and Ornamentation

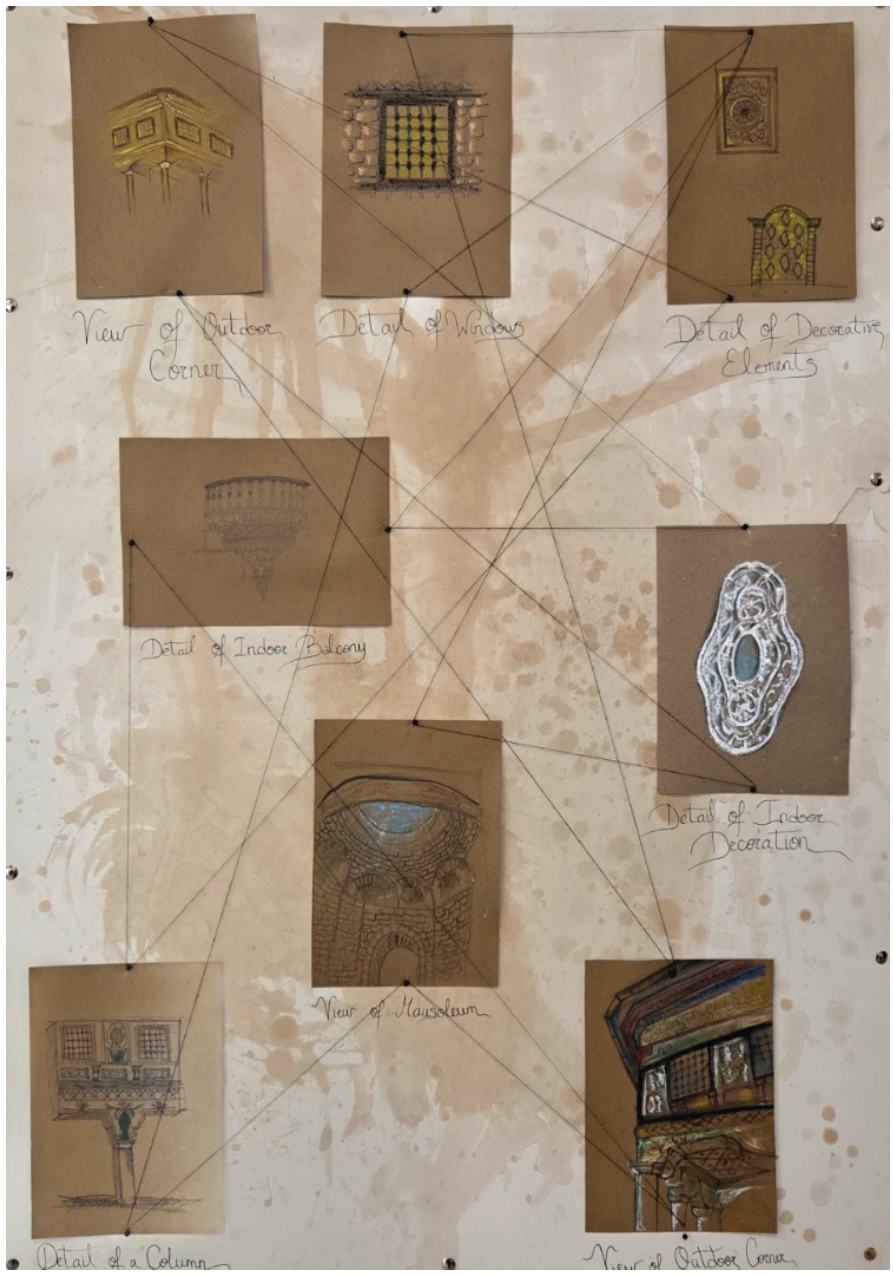
As part of the workshop, students were analyzing the architectural details and ornamentation of the mosque, both on the exterior and in the interior. Figure 5 is the final result of this phase – a poster with the most important details and elements.

As part of this phase, the following elements were analyzed:

- Geometric patterns: types, mathematical logic, repetition systems
- Floral and vegetal motifs
- Color palette: symbolism, relationships, layering techniques
- Decorative compositions: façade, interior frescoes, ceiling details
- Spatial characteristics: light, proportion, rhythm, transitions
- Patterns as carriers of cultural meaning

Figure 5

Analysis of Architectural Details and Ornamentation.

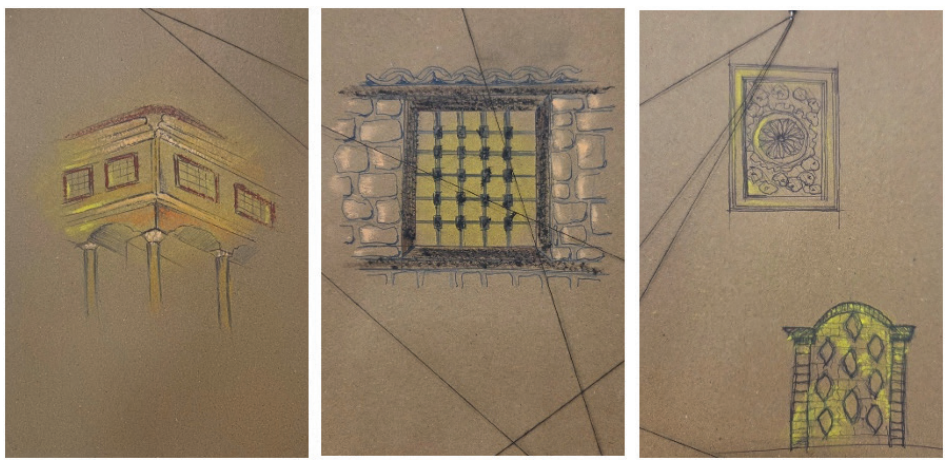


Source: Authors, based on workshop outputs (2025).

Figures 6 and 7 show the architectural details and ornamentation, outside views, structural and non-structural elements, windows and opening details and decorative elements with rich geometrical and floral motifs.

Figure 6

Architectural details and ornamentation: a. View of outdoors; b. Corner detail of window; c. Detail of decorative elements.



Source: Authors, based on workshop outputs (2025).

Figure 7

Architectural details and ornamentation: a. Detail of indoor decoration; b. View of Mausoleum; c. Detail of a column; d. View of outdoor corner.

Source: Authors, based on workshop outputs (2025).

Results

The decomposition of the identity of the Alaca Mosque in the architectural, ornamental, and spatial context turns out to be the main source of materialization of the proposed landscape plan. Through the transformation of the conceptual decomposition of the identity of this cultural heritage, a new spatial narrative resulted, where design principles are intertwined in a contemporary spirit, with the aim of being used as a mediator of cultural memory and current urban needs.

Site Description: River and Park Context

The surrounding area of the mosque and the riverbank has not been exploited adequately. The current circulation system is formed naturally, while there is no visual or symbolic link with the monument. The area is a transit place, failing to provide meaning and active engagement of visitors. There is a lack of appropriate green space organization, opportunities for entertainment, and leisure activities for pedestrians. Although it has the potential to become an attractive and resting zone with low intervention, this is not being used. The connection of this zone with the neighboring ones makes this zone self-isolated and distinct from the urban dynamics. This results in the loss of opportunity to become an active and cohesive centre.

Conceptual Landscape Strategy

The conceptual landscape strategy is built on the principle of pattern as a generative language of spatial organization. Geometric and floral patterns, derived from the ornamentation of the mosque, were analysed as systems of rules rather than forms to be replicated, being interpreted as rhythmic structures that articulate the relationship between parts and the whole. These systems were translated into a contemporary geometric order that structures paths, squares, and spaces of standing, creating spatial hierarchies, axialities, and experiential sequences. The materiality and chromaticity of the design are conceived as a continuation of the visual and cultural memory of the historical object. The synergy of colours, tactility, and the ornamental identity of the monument, we use as an abstract design system to convert it into a contemporary landscape (Figure 8).

Figure 8

Conceptual Landscape Design.

Source: Authors, based on workshop outputs (2025).

Spatial and Visual Outcomes

In the selected location near Alaca Mosque, we redesign a promenade along the river that functions as a connecting axis between the monument and the city. For the redesign of this promenade, we have implemented the fragmentary heterogeneity of the decomposition of the identity system of the mosque, both at the functional and perceptual levels. We create spaces with geometric rules, with versatile and spontaneous pedestrian circulation, where the activity itself catalyses the visual and symbolic relationship of the location. The implementation of the axis, symmetry, hierarchy, whether visual or functional, and rhythm reflects the semiotic transformation of the location. Through this narrative we have a transformation of the current landscape and create a new identity. Through an analytical and critical approach to landscape, the potential of the location itself was exploited to the

maximum, with existing natural elements, architectural heritage values that exist around the area, and the community as a coherent urban structure.

Educational Output

In terms of pedagogical outcomes, the workshop produced results that go beyond the final design product itself, affirming itself as a structured learning and research process. Analytical diagrams, physical models, and conceptual drawings document a working methodology where analysis and design develop as interconnected and mutually generative phases. Students were involved in a continuous reflective practice, moving from empirical observation and reading of the context to theoretical abstraction and then to spatial articulation and synthesis. These results highlight the value of a pedagogical methodology based on cultural heritage as a research and investigation tool, where design is understood as a form of knowledge production (design as research). The overall process highlighted the potential of ornament and patterns not only as aesthetic components but also as conceptual structures and instruments of thought that can inform and enrich contemporary practices of architecture and urban and landscape design.

Conclusions

This study shows how a landscape design can be inspired by a significant cultural heritage through a pattern-based analytical approach. Alaca Mosque in Tetovo is used as a case study to show how a strong cultural identity can influence a design expressed through geometry, ornament, color, rhythm, and proportion. The inspiration is not used only as a decorative reference, but it is decoded and interpreted into the design language of the landscape.

The methodology based on a workshop was effective both as a research and educational tool. Several methods such as site observation, historical analyses, pattern extraction, and design translation, were used.

The result was a landscape proposal which strengthens the cultural significance of the place. This approach can be used and transferred to similar historically significant buildings, as a heritage-based design and urban regeneration. Further research could include implementing patterns-inspired design on a wider context, even within a wider urban context.

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Database-as-a-Service (DaaB) Sector Expansion: MongoDB's Acquisition of Voyage AI Tech Startup to Moderate Hallucination

Netra Pal Singh

Abstract

Invention is the crucial source of development and competitive gains in tech segment of the industry specifically artificial intelligence domain. In the context of aggressive hi-tech rivalry, augmenting innovation competencies is strategic factor to accomplish even for mature big tech firms. To enhance innovation capabilities the big tech companies are following the path of mergers and acquisitions to get hold of external technologies. In this context, this deal in Database-as-a-Service (DBaaS) domain is a landmark deal. The research contents of this article present the motivation (acquiring external technologies in short time) of MongoDB which has grown organically in the past, acquiring a high-tech startup Voyage AI at a very high exit evaluation cost. The research article concluded that the acquisition strategy of MongoDB is more similar to horizontal acquisition. Post-merger integration model of MongoDB is in sync with theories such as Resource Based View, Knowledge Based View, Open Innovation Theory, and Absorption Capacity Theory. This is because of technological, financial capabilities, and market reach of MongoDB (Colombo et al., 2021). The integration of technologies of two firms will reduce hallucination in AI applications and provide a platform for future innovations in AI domain. It will fill the technological gaps for MongoDB and may create technological disruption in future if MongoDB able to innovate with acquired new skills.

Keywords: Absorptive capacity**,** text embeddings, multi-model embeddings, rerankers, RAG.

Introduction

Voyage AI is based in Palo Alto, California, USA. It was founded in 2023 with a backing of venture capital investors. Its valuation was $ 11.64 million per employee during 2025. Its exit valuation was $ 220 million during the same period. It is developing Retrieval-Augmented Generation (RAG) tools to reduce AI hallucination. RAG tools and fine tuning will come over the limitations such as lack of updated knowledge and outdated public knowledge of Large Language models (LLM) such as ChatGPT-3 (Sourabhkv, 2024). Its application domain of activities is AI and data management. It has developed algorithms for exploration and retrieval of data/ information from unstructured big or small databases of text, images, audio, video etc. Its models are used by tech companies such as Anthropic PBC, Lang Chain Inc., Harvey.AI, and Replit Inc. Its core competency is in building embedding models, customized for specific domains of application and specific firms, for enhancing retrieval correctness and RAG applications that enhancing accuracy and reliability of governance AI models with information from specific and relevant data sources (Merritt, 2025). Voyage AI offers high-precision data vectorization, production-ready models tailored for domains such as finance, healthcare, and legal. It had also developed capabilities of integration with existing information systems. With the help of Voyage AI tools businesses can improve their AI-driven processes while developing framework for intelligent data retrieval and analysis as per their needs (PitchBook, 2025). Voyage AI had developed API endpoints for embedding and reranking algorithms that take users' data (such as documents, queries, or query-document pairs) as an input and gives their embeddings or relevance scores as an output. Further, embedding models and rerankers can be integrated with other parts of a RAG (a general purpose fine-tuning recipe that can be used nearly any LLM to connect with external resource) stack as a module, together with vector stores and generative Large Language Models with the help of Voyage AI models/ tools for LLMs (Merritt, 2025).

Voyage AI offers high precision data vectorization, production ready models for finance, healthcare, and legal as mentioned earlier. In addition, it also provides integration capabilities with existing systems that enable business to improve their AI driven processes by providing a framework for intelligent data retrieval and analysis. Basically, Voyage AI has major three capabilities. These are (i) text embeddings, (ii) multi-model embeddings, and (iii) rerankers that can boost the relevance and quality of retrieved result of RAG pipelines by deploying two stage retrieval processes that is initial retrieval and reranking (Ism, 2024).

MongoDB basically has grown organically but had acquired companies of smaller valuation as evident from the data given in table 1. To fill gaps of internal innovation in technology MongoDB acquired WiredTiger an open-source, NoSQL data management platform known for its high-performance storage engine in 2014. It has acquired Objectlabs Corporation later on known as MongoLab for $68 million in 2018. It is a cloud based database service. It is hosted with fully-managed MongoDB databases, operating on platforms like AWS, Google Cloud, and Microsoft Azure (Marketscreener, 2018), MongoDB acquired Realm, a mobile-focused database company to strengthen MongoDB's mobile database solutions in 2019 for $ 39 million (Chan, 2019). Very recently on February 24, 2025 MongoDB acquired Voyage AI for harvesting benefit of its core technology and brilliant team of developers in AI & data management segment.

The objective of these acquisitions are (i) WiredTiger was acquired to enhance the high quality manpower and capabilities of MongoDB 3.0 (Solarwinds, 2017), (ii) ObjectLabs was acquired to compete in global cloud database technology market (Genig, 2018), and (iii) Realm was acquired to strengthen mobile offerings (Dineshwori, 2019). Its objective to acquire Voyage AI was to improve accuracy of Generative AI models as stated by Aiello (2025).

Table 1:

Market Cap at the end of years & Buyouts of MongoDB

Year	Market Cap	Change	Buyouts	Value
2025	$15.38 B	-19.43%	Voyage AI	$220 Million
2024	$19.09 B	-35.28%	Nil	Nil
2023	$29.50 B	116.38%	Nil	Nil
2022	$13.63 B	-61.40%	Nil	Nil
2021	$35.33 B	63.30%	Nil	Nil
2020	$21.63 B	189.74%	Nil	Nil
2019	$07.46 B	66.37%	Realm	$ 39 Million
2018	$04.48 B	199.00%	ObjectLabs	$ 68 Million (Marketscreener, 2018)
2017	$01.50 B		Nil	Nil
2014	-	-	WiredTiger	Undisclosed (MongoDB, 2014)

Source: https://companiesmarketcap.com/mongodb/marketcap/#google_vignette

The main objective of present research is to analyse the key strategy of growth of MongoDB to enter in high-tech domain inorganically with small and gradual

investment to mitigate risk of failures of merger and acquisition approach (Singh & Singh, 2020; Folta, 1998; Vassolo et al., 2004). Second objective is to extend literature on integration of technologies and skills of startup high tech companies. It may not be easy, however, may be quick due to size of startup in terms of product range which are not monolithic and skilled manpower. This may be in line with existing absorptive capacity theory (Cohen & Levinthal, 1990; Hagedoorn & Duysters, 2002). A third objective is to analyse the acquisition of Voyage AI which is unique in many ways. The domain of technology of Voyage AI is full of disruption, innovations are core philosophy of startups, large tech companies acquire innovators to fill the unique skill and technological gaps provided objective is not to kill competition.

Based on the insight of data available just after acquisition news, this study is an effort to investigate MongoDB acquisition of Voyage AI in all-inclusive manner in relation to strategic and behavioral theories and the stated research objectives and propositions identified and narrowed down based on overall objectives as listed in earlier paragraph. The research paper consists of 7 segments starting introduction of the companies and also includes acquisition of small firms by MongoDB. This makes section 1 of introduction. The next section 2 presents the assessment of works of other researchers in the tech domain followed by section 3 which embodies the methods/ processes used in the study. The next section 4, presents the statistics of top 10 tech acquisitions of quarter 1 of 2025, mergers and acquisitions in technology segment during 2021 to 2024 and funding of Voyage AI. The section 5 embodies a brief of deal, and similar deals between other companies for the same objectives, business models of Voyage AI, and impacts of acquisition in the ecosystems of Technology. The reasons for acquiring Voyage AI by MongoDB, Voyage customers and competitors, analysis of seven propositions in the context Voyage AI acquisition are presented in section 6. The last section 7 offers the closing explanations on the purchase of Voyage AI.

Analysis of past literature on the subject

This section presents a brief review of the tech acquisition in the segment of AI segment in the recent past with almost similar objectives. Researchers in the recent past highlighted the shift in technology innovation strategies of established corporations. The terms such as open innovation v/s traditional internal innovation of big corporation have created interest among academics and also encouraged start-

ups. Singh (2019) analyzed acquisition of DataFox by Oracle. He concluded that Oracle acquired DataFox to augment AI driven abilities, enlarge accessible data bases for its business intelligence tools. This deal was $33 million approximately. Prado & Bauer (2022) considered a set of 32,367 venture capital deals between 2010 and 2020. They also included 392 tech start-up acquisitions in their study. These acquisitions were by Google, Facebook, Amazon, Apple, and Microsoft. They concluded that there is a statistically significant positive normal effect of Big Tech start-up acquisitions across world, on venture capital movements/ investments. Their outcomes were based on fixed effects panel data and statistical method, i.e., differences-in-differences (DiD) estimators of causal effect. They also concluded that positive effects of big tech start-up acquisitions are short lived in the context of more venture capital investments.

de Barsy & Gautier (2024) investigated whether an acquisition of startup focused on innovation, by a big tech contributes to the development of technologies in the form patents. Similarly, Gugler et al. (2025) studied several hundred acquisition made by Google, Apple, Facebook, Microsoft and Amazon and discovered that about 14% of acquisitions negatively affected innovation and venture capital investment. There are large variations in innovation outcomes across the acquisition.

Gap 1: Venture capital investments are in directly related to merger and acquisition. Many authors have studied large number of mergers & acquisitions in relation to venture capital investment which indirectly drive innovation by startups. However, this results in to summarization of data from diverse tech domain which results in to findings of generic nature. Summarization also results in to loss of information. Generalization may be out of context for many mergers and acquisitions. The analysis of Voyage AI startup acquisition by a big tech company will fill gap of knowledge of high-tech domain specific merger and acquisition.

Kak et al. (2023) mentioned that there is no AI without big techies. Every startup, new entrant, and even AI research lab are non-existent without large technology companies. Their dependence is because they do not have computing infrastructure at par with Microsoft, Amazon, and Google to train their best models. AI startups depend on large technology companies to reach out to the consumers to deploy and sell their AI products. Therefore, it is good for these startups to be acquired as early as possible.

Singh (2011) studied the expansion strategies of the big tech companies in Business Intelligence domain and concluded that big techs acquired not only startups

but good size companies to fill the technological gaps also to become free from internal innovation stagnation in addition to kill competition and certainly to acquire skilled workforce of niche companies and none the less markets/customers. Singh & Singh (2020) highlighted the importance startups to not only big tech companies but also to manufacturers in Indian auto segment. They study acquisition of startups of IoT and Machine Learning domain by one of the two wheeler manufacturer, TVS India Limited and concluded startups are the key components of innovation in technology development.

Koi-Akrofi (2016) researched and mentioned that during post-merger/acquisition early stage of integration, the acquiring firms are employing major strategies to achieve stated goals of acquisition vis-a-vis organizational performance. In this stage major management and strategic decisions are taken aimed to achieve gains for shareholders, employees, and customers. He reviewed these strategies with a view to know that how the actual integration era should be. Petković et al. (2023) concluded that the key determinants that are accountable for success of investments in AI startups are technical competences, market prospective of their innovation, commercial process to market, and premeditated alliances to survive or grow, a startup can make in the short run. Colombo et al. (2021) mentioned that firm with better absorbing capabilities are able to understand technologies of acquired company, integrate research and innovation activities, able to retain skilled employees, and convert acquired knowledge for competitive advantage.

Gap 2: There are many theories of high tech mergers and acquisitions. In addition, there are many factors/reasons for high tech companies to acquire technologies and skills by acquiring small startups or group of skilled scientists. Past studies studied mergers and acquisition with a view to create theories based on specific data. There is a need of studying a merger and acquisition in relation to existing theories. Further, each acquisition is based on specific reasons on part of the acquirer and acquired company. This study will fill the gap by identifying reasons for acquisition under study.

Review suggests that there are studies which are based on the analysis of data of large number of acquisitions by big tech companies which in many ways impact innovation and venture capital investments. These studies are based on analysis of quantitative data of patents before and after merger and acquisitions. The studies based on individual acquisition of high-tech startups are not too many. This study will fill this gap.

Research Methodology

The Context

Methodology of the current research can be called as mix method. It is based of secondary data, therefore, qualified as exploratory in nature. It based on sizable data to draw inference and linkages with existing strategic and behavioral theories, therefore, can be also termed as descriptive. Secondary data for current study are collected from the different sources such as websites of Voyage AI, and its competitors, MongoDB, and research reports of companies in AI domain specifically in the domain of Voyage AI, etc.

Research Objectives & Propositions

The objectives and research propositions of this research study are identified by analyzing the views of different experts in the merger and acquisition field as expressed in media and underlying theories of merger and acquisitions of high tech companies.

The major theories that can be linked with this high-tech mergers taken in to account in this study are (i) Resource-Based View (RBV) and its extension, the Knowledge-Based View (KBV), (ii) Absorptive Capacity Theory (ACT), (iii) Open Innovation Theory, (iv) Real Options Theory (ROT), (v) Dynamic Capabilities Theory (DCT), and (vi) The Hubris Hypothesis and Agency Theory (HHA) (Behavioral Perspectives). A brief description of these theories is presented in the following.

RBV & KBV theories assumed that acquirer will absorb the acquired firm's exceedingly specialized R&D competencies and human capital to expand its own technological boundaries (Ranft & Lord, 2002). Absorbing capacity theory (ACT) is basically state that successful merger depends on the acquirer prior knowledge related to acquired firm's technology. In many ways both theories support each other (Cohen & Levinthal, 1990; Hagedoorn & Duysters, 2002). Open Innovation theory (OIT) assumed that mergers and acquisition serves as a structured model of inorganic growth. It further states that merger and acquisitions is speedy channel for cross-organizational knowledge boundaries, allowing large incumbents to capture agile, small-scale startup innovation, market, and highly skilled manpower (Chesbrough, 2003; Van de Vrande, et al., 2006).

According to Real Options Theory (ROT), high-tech markets are full of technological disruptions and market uncertainty. Therefore, as a strategy, acquirers start with smaller investments as part of continuing tech acquisitions. A tech giant

might acquire a minority stake or buy an early-stage startup as a "call option" to enter a promising domain such as AI and quantum computing technologies. Committing massive investment in unproven technologies or firms could be risky proposition (Folta, 1998; Vassolo et al., 2004).

Competitive advantages are transitory in high-tech domain. According to Dynamic Capabilities Theory (DCT), merger and acquisitions is acquirer's capability to integrate, build, and reconfigure internal and external competences to address fast changing technologies (Teece et al., 1997; Graebner, 2004). In many cases it is an end result of internal innovation stagnation also (Singh, 2011).

The five strategic theories assume that mergers and acquisitions is a rational journey for tech concerted effort. This journey creates synergies between acquirer and acquired firm. On the other hand behavioral theories (HHA) believe that high-tech domains are famous for bidding conflicts where acquiring executives, driven by managerial overconfidence (Hubris) often overvalue the prospective target's unproven tech stack. This leads to massive value destruction during post-acquisition period in many cases. These executives are paid destructive premiums. It works due to information asymmetry about potential of new technologies) and "FOMO" (Fear of Missing Out) among high tech firms in the next big technology wave. Therefore, in many cases it does not result in to actual economic synergies rather than kill investment in other sector of economy (Roll, 1986; McCarthy & Aalbers, 2016). Based on analysis of available of data and theoretical advancements, the objectives and propositions of this study are identified and listed in the next sub-section.

Research Objectives

The main research objectives of this research based on the views of acquirer and acquired firm and strategic and behavioral theories are as under.

Research Objective 1: To analyse the growth trajectory of Voyage AI from its inception to its acquisition by MongoDB.

Research Objective 2: To examine the role of venture capital in enhancing Voyage AI's technological capabilities and innovation prior to the acquisition.

Research Objective 3: To analyse similar tech acquisition in the recent past and during 2025 having valuation of more than US$ 100 million.

Research Question 4: To assess the technological, social, and competitive impact of the Voyage AI acquisition on MongoDB & other stakeholders.

Research Objective 5: To map the acquisition of Voyage AI by MongoDB with strategic and behavioral theories.

Research Propositions

The secondary data collected from these sources are subjected to mainly content analysis to some extent trend analysis. With a view to draw meaningful conclusions of the transaction between MongoDB and Voyage AI in the context of research objectives, 7 propositions are identified. These are listed in the following paragraph with brief justification.

Proposition 1: MongoDB acquired Voyage AI to enhance its technological capabilities. This is aligned Open Innovation Theory.

Proposition 2: MongoDB acquired Voyage AI to fill the technology gap in its offerings (Singh, 2011; Singh, 2019).

Proposition 3: Acquisition of Voyage AI created disruption in RAG domain. The proposition is aligned to Real Option Theory which supports investment in disruptive technologies.

Proposition 4: The theoretical intent of the post-merger integration (PMI) of Voyage AI acquisition by MongoDB of Voyage AI is in line of absorptive capacity theory (Colombo et al., 2021; Bae et al., 2020; Carbone, 2011).

Proposition 5: MongoDB acquired Voyage AI to reduce hallucination in AI application. Capabilities of MongoDB fit in the definition of RBV & KBV theories.

Proposition 6: Voyage AI merged with MongoDB to take its cutting age technology to the larger customer group (Singh, 2011).

Proposition 7: MongoDB is investing in Voyage AI startups to be competitive in retrieval and RAG (Singh & Singh, 2020).

The Research Process Architecture

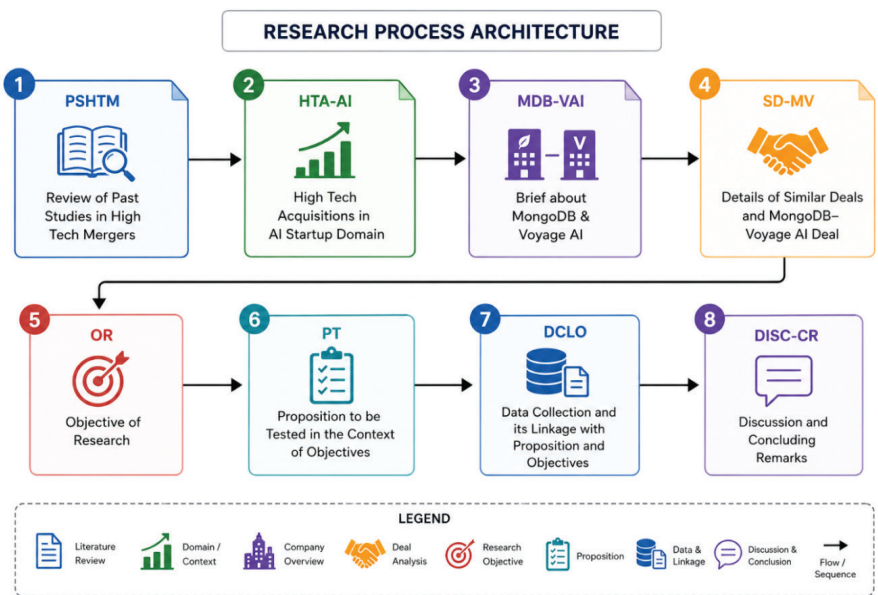
The process of conducting the present study is summarized in the fig 1. It consists of mainly eight steps starting with review of past studies is relation to the theories of high tech mergers and acquisition, analysis of high tech acquisition of startups in AI domain, a brief of MongoDB and Voyage AI, similar deals in the similar high-tech domain of the recent past in relation to Hallucination. It is followed with documentation of five research objectives and seven research propositions. Research process framework as given in fig 1 also includes the stage of secondary data collection and its analysis in the context of present research objectives and propositions.

Data Collection and Analysis

To formalize the assessment of seven propositions, qualitative data are transformed on 1 to 10-point scale. "1" means proposition is not at all true or does not have supportive data with respect to acquisition and "10" indicates that a particular proposition is out rightly supported with available secondary data. To support strategic and behavioral theories in the context of acquisition of Voyage AI, the available secondary qualitative data contents are mapped with the core definitions of theories. To mention, it is reported that MongoDB had capabilities to integrate new technological features (Algorithms of Voyage AI) along with absorbing highly skilled scientific manpower with a view to create a unique selling proposition to its existing and new customers in the high-tech market. It is line with the theory of Cohen and Levinthal (1990).

Figure 1.

Research Processes of the Present Study Consisting Eight Steps



Tech Acquisitions & Funding of Voyage AI

This section presents recent tech acquisition in Q1 of 2025 having exit valuation more than $100 million. Section also presents the data of tech services companies' acquisition during 2021 to 2024. Further, the section presents the large tech acquisition of recent past and expected to conclude during 2025 including failed acquisition deals. It also includes the analysis of Voyage AI funding starting with seed money to series A.

Tech Acquisition in Recent past & 2025

Technology in general and information technology in particular is the hot segment for the merger & acquisition activities during recent past as can be seen from the statistics given in table 2.The numbers of deals are increasing continuously during Q1 2021 to Q4 2024. However volume in terms of the $ value had decreased drastically. This is an indication that investments are made by companies to mainly acquire startups or smaller companies having niche technology. The notable completed and abandoned big acquisitions of recent past are (i) Broadcom completes the acquisition worth of US$ 61 billion of VMware (Gonsalves, 2023), (ii) Adobe finalizes the acquisition of Figma for $ 20 billion (Mali, 2025), (iii) Intel acquired Tower semiconductor for $ 5.4 billion which was later on cancelled during the negotiations (Kharpal, 2023), and (iv) Microsoft concludes purchase of Activision Blizzard with valuation of $68.7 billion (Roush, 2023).

In addition to these four big ticket acquisitions, information technology segment had witnessed many small acquisitions in the first quarter of 2025.These acquisitions are given in table 3. It is apparent from the data presented in table 3 that Voyage AI acquisition by MongoDB is of highest volume, i.e., $220 million. It is evident from the data that Voyage AI exit valuation after 17th month of its launch is on the top for first quarter of the year 2025. Another company Aerodome was acquired by Flock Safety within a year time for $300 million. Both these companies, i.e., Aerodome and Voyage AI have raised $ 28 million each and were backed by common investor CRV (MacColl, 2024).

Further, expected deals in coming quarters are (i) Swisscom acquisition of Vodafone Italia for $8.6 billion, (ii) Private equity firm Permira (https://www.permira.com) is set to acquire Squarespace, a software company for $ 6.9 billion, (iii) T-Mobile acquisition of US Cellular for $4.4 billion, (iv) Engineering simulation ANSYS (https://www.ansys.com/) acquisition by Synopsys (https://www.synopsys.com) for $35 billion,

and (v) Hewlett Packard Enterprise's (https://www.hpe.com/) acquisition of Juniper Networks, a front-runner in AI built-in systems for $14 billion in all cash transaction (MacDowell, 2024; Patel, 2025).

Table 2:

Monthly Merger & Acquisition deals in Technology Services from Q1 21 to Q4 24.

	Year			
Quarter	2021	2022	2023	2024
Quarter 1	183	229	198	223
Quarter 2	136	173	132	212
Quarter 3	128	186	201	212
Quarter 4	206	171	191	210
Total	653	759	722	857
Volume ($ Billion)	56.7	34.0	7.0	32.2

Source: EY (2025)

Table 3:

Top 10 Tech Acquisition worth $100 Million in Q1 2025

Rank	Company	Year of Establishment	Valuation/ Employee	Exit Valuation	Head-count	Acquirer	Focus
1	Voyage AI	2023	$11.6M	$220M	19	Mon-goDB	AI data man-age-ment
2	Helio	2022	$8.8M	$175M	20	MoonPay	Web3 pay-ments
3	Dealer-Club	2024	$7.5M	$113M	15	Cars.com	Whole-sale auto retail
4	Genera-tionGe-nius	2017	$7.1M	$100M	14	Newsela	K-8 edtech

5	Zilla Security	2019	$3.7M	$175M	47	CyberArk	Cloud data security
6	Kinara	2015	$3.5M	$307M	88	NXP Semiconductors	Chips for edge AI
6	Liquidity-Book	2005	$3.5M	$247M	71	FactSet	Financial trading
8	SafeBase	2020	$2.7M	$250M	92	Drata	Compliance automation
9	Mavely	2018	$2.6M	$250M	95	Later	Influencer marketing
10	Oosto	2015	$1.3M	$125M	98	Metropolis	Facial Recognition
11	Aerodome	2023 October	$15M	$ 300 M+	20	Flock Safety	Drones Technology

Source: CN Insights. Data as on 3/10/25, Aerodome was acquired on October 16, 2024.

Funding Raised by Voyage AI

Voyage AI raised $28 Million in two rounds from 9 investors and two partner investors (Brian Zhan and Murat Bicer) of CRV (Voyage AI, 2024). It is worth to mention that MongoDB was not backers of Voyage AI in any of the funding round (Strechay, 2025). This is in contradiction to Indian automakers wherein they are financially supporting startups or a group of techies in developing new technologies including AI domain (Singh & Singh, 2020).

$8 Million: Seed Money

Voyage AI seed money round investment of $ 8 million was from two investors, i.e., Wing VC (https://www.wing.vc) and Conviction (https://www.conviction-vc.com). These two investors were also the part of series-A funding of Voyage AI.

$20 Million- Series A

The series A investment was headed by CRV (https://www.crv.com) with involvement from Wing VC (https://www.wing.vc), Conviction (https://www.conviction-vc.com), Snowflake (https://www.snowflake.com), Databricks (https://www.databricks.com), Pear VC (https://pear.vc), Mayfield Fund (https://www.mayfield.com), Tectonic Ventures (https://www.tectonicventures.com), and Fusion Fund (https://www.fusionfund.com). Voyage AI intend to use this fund to expand offerings. It is also reported that CRV raised $1 billion fund for startups and $500 million for the more mature companies (Griffith, 2024).

Result & Discussion

The deal

MongoDB, the prominent database for contemporary applications, made a statement on February 24, 2025 that it has assimilated Voyage AI, an innovator of ultramodern embedding and reranking models that may control next-generation AI applications (MongoDB, 2025). The value of exist evaluation was $220 Million (ODSC Team, 2025). It is in Cash and stock deal (Eastland, 2025). Even before Voyage AI acquisition by MongoDB, Databricks and Snowflake are reportedly that they are in talks with Voyage AI to acquire it. It is an ample proof of growing competition to dominate the generative AI space which is equipped with new capabilities. Though Databricks and Snow flake are rivals in the domain of data management, but aligning with each other on leveraging generation generative AI capabilities. Their objective is to help businesses to navigate and extract value from their data. Even this was their main motive to be with each other in targeting/ acquiring Voyage AI (Louise, 2025b).

Here are two set of contrasting examples of companies in developing capabilities for hallucination reduction markets. Two companies are following the straggles similar to MongoDB acquiring Voyage AI and another set of two companies developing these capability with internal innovations.

- **Databricks + MosaicML**: Databricks, and data and AI Company acquired MosaicML, a generative AI platform known for Mosaic Pretrained Transformers (MPT) large language models (LLMs). The core objective was to reduce hallucination by fine tuning the model on proprietary data to build data intelligence. The deal was worth 1.3 billion US$ (Datta & Hu, 2023, Louise, 2025a).

- **Snowflake + TruEra:** Snowflake acquired TruEra, an AI startup having tools to test, debug and monitor machine learning models and LLM apps in making for unknown amount (Sharma, 2024). This deal is a part of strategy "catch the hallucination before it reaches to user. TruEra's AI observability platform is a managed offering that can be deployed as software-as-a-service (SaaS) or hybrid SaaS via virtual private cloud, and public cloud (Ghoshal, 2024).
- **Elastic+ ESRE (Elasticsearch Relevance Engine):** Elastic developed Elasticsearch Relevance Engine powered by built-in vector search and transformer models. The objective is to apply AI innovations to proprietary enterprise databases (Business Wire, 2023). ESRE provide unified APIs for vector search, BM25f search and hybrid search, plus a new transformer model small enough to fit on a laptop's memory mean businesses and teams are now able to optimize infrastructure and talent resources more efficiently.
- **Microsoft+ GraphRAG:** Microsoft had developed an open source advanced RAG (GraphRAG) that relays on knowledge graphs to understand complex relation between entities and concepts by LLMs. It was release as python library in July 2024 (Larson & Truitt. 2024). GraphRAG is an essential paradigm shift from simple similarities of the documents to the understanding of complex relationships that drive business understandings. Microsoft claimed that traditional RAG achieved 23% accuracy on multi-hop reasoning tasks as compared to 87% of GraphRAG (Richards, 2025).

Business Model of Voyage AI[1]

Its business model has four sets of price offerings as per its four unique capabilities. These business models are classified as text embeddings pricing, multi model embeddings, rerankers, and fine-tuned models. The pricing models of Voyage AI were premium models. The major features of business models are technology based models, number of tokens, number of free tokens, number of pixels, number of free pixels, number of requests, and amount of services.

Price for Text Embedding = f (model, no. of tokens, no. of free tokens)

Price for Multi-model embeddings = f (models, no. of tokens, no of pixels, no of free tokens and pixels, no of images)

1 https://docs.voyageai.com/docs/pricing

Price for Rerankers= f (Rerankers model, no of free tokens, no of tokens, no of request)

Price for fine-tuned models = f (amount of services, negotiations with Voyage AI and its client)

Impact on MongoDB offerings of this Acquisition

With Voyage AI, MongoDB will empower establishments to effortlessly build dependable, AI-powered applications by offering highly precise and appropriate information retrieval that is intensely integrated with operational data with Voyage AI Technology (MongoDB, 2025). Strechay (2025) mentioned that the acquisition of Voyage AI will make MongoDB as a leader in AI-powered retrieval within the database market

Financial Impact: The acquisition has noteworthy potential economic influence particularly in relation to the valuation of future AI segment. MongoDB's invested $220 million in a young company; it means there is a demand and competition among big techs for cutting-edge AI technologies. This will increase the valuations for startups which are innovating to improve accuracy of their models and preventing AI models from hallucination. Big tech companies are willing to embed these capabilities into their offerings within a short period. These trends will see more aggressive mergers and acquisitions. To support these outlooks, Neeva's AI search technology acquisition by Snowflake at the cost of $185 million is another case in Q1 of 2025 (Ferguson, 2025).

Social impact: Voyage AI's technology integration with MongoDB is anticipated to assist broader enterprise AI adoption, mainly for improving the trustworthiness and accurateness of AI applications. The capability of Voyage AI to significantly reduce AI hallucinations is predominantly pivotal in multifaceted industries with complex processes. Two industries, i.e., healthcare and finance that have high dependency on trustworthiness of AI tools will witness a paradigm shift in operations and decision-making processes. The innovators such as Voyage AI will be setting a new benchmark for AI application accuracy. The integration of Voyage AI with MongoDB will uplift the users trust in AI systems and promote extensive recognition of AI technologies. In summary, MongoDB had drawn a bigger mission by embedding Voyage AI's technology into its database abilities to offer more trustworthy AI solutions for communities of developers which in turn transferred to a wider social impact (Ferguson, 2025).

Technological Impact: Voyage AI did not mention about patents but MongoDB is certainly acquiring improved algorithm which in turn increase its competitive edge. It will generate value for MongoDB in searching and retrieval of its huge database. Due to probabilistic nature of AI, it can hallucinate. Hallucinates are due to wrong retrieval and lack of access to the right data. In turn it results in to incorrect information. If accuracy is non-negotiable in mission critical application AI model adoption is not worth. Voyage AI capabilities will prevent hallucinates and will have huge impact on the competitors to innovate (Ittycheria, 2025).

Industry and Competitive Impact: MongoDB being a high tech company which may provide better platform for innovation to the employees of Voyage AI. In turn, it may result in to concentration of talented workers with MongoDB for better career opportunities. This is based on the past trends which are indicative of the fact that talented skilled workers pool concentrate with biggies that in turn will certainly impact the growth of startups. It may convert in to a scenario of sluggish growth of innovations in the long run. It will further enhance the concentration of talented workforce and may become impediment for the growth of startups. It may redefine the landscape of databases with AI capabilities.

Voyage AI is also presently competing with many competitors for Large Language Model Operationalization (LLMOps) software. These competitors are (i) Vertex by Google, (ii) Botpress from Botpress (fund raised $15 million), (iii) Kong API gateway from Kong Inc. (Fund raised $ 345 million and valued at 2 billion), (iv) Tune AI from NimbleBox.ai, (v) SuperAnnotate from SuperAnnotate[2] ($60.5 million in 5 rounds from 15 investors), (vi) Azure Machine Learning from Microsoft, (vii) Aporia from Coralogix (Aporia is acquired by Coralogix for US$ 50 million (Orbach, 2023), (viii) Clarifi from Clarifi, (ix) Dataiku from Dataiku (Fund raised $1.04 billion in 9 rounds), and (x) TrueFoundry from TrueFoundry (Fund Raised $21.3 million from 15 investors) (Kong Inc., 2024), Some of these competitors may follow the path of Voyage AI at the earliest due to their dependency for training models, commercialization of their technology, and marketing of their technologies.

2 https://tracxn.com/d/companies/superannotate/__CYkGxumXxYNfmgAkgkxcG-9eIFCvwcCZZD-cAuLmqd1A/funding-and-investors

Voyage AI Acquisitions, Competitors and Propositions

This section presents the reasons for MongoDB to acquire Voyage AI and select list of competitors of Voyage AI. In additions, grounded on available secondary data composed from diverse sources on net, this section also presents a measurement index on 10-point scale in support of seven propositions.

The reasons for acquiring Voyage AI by MongoDB

There is no specific data is available with respect to reasons for MongoDB to acquire Voyage AI. However, there is enough reporting of the facts that MongoDB acquired Voyage AI due to improved performance of its algorithm and to assured customers that MongoDB at the forefront in innovating technology to create value for money of its customers.

Competitors of Voyage AI.

Traxcn.com listed 36 competitors of the Voyage AI including the competitors listed in section 5. The competitors are classified based on the locations and raised funds. The competitors which had raised more funds are Tamr ($69.2 million), Paxata ($ 68.8 Million, Acquired), DatologyAI ($57.6 million), Lattice (US$ 20 million, acquired), Forge AI ($ 11 million). Most of the competitors of Voyage AI are from USA.

Propositions & conclusions

The deal to acquire Voyage AI by MongoDB is not a big ticket buyout; therefore, media was active for a short period. Still there is sufficient data available to draw meaningful conclusions.

Proposition 1: MongoDB acquired Voyage AI to enhance to enhance its capabilities.

Aiello (2025) mentioned that 60% to 70% accuracy of the predicted results with existing applications is not enough for highly sensitive sectors such as finance and healthcare. According to founder of Voyage AI, the models of Voyage AI and massive storage of structured, unstructured and semi-structured data in databases of MongoDB will have unlimited potential in enhancing the accuracy. Combined technologies of two companies under reference can offer a “clean, simple solution” to developers of AI-powered apps (Aiello, 2025), reduction in cost of development and manpower and high skill competencies needed to stitch up together multi-

ple components. MongoDB also shares his strategic vision for the future of AI. It is predicted by expert that the next generation AI applications will be built on MongoDB data base platform (Ma, 2025). Sahm Capital (2025) also mentioned that buyout of Voyage AI will reinforce AI product roadmap of MongoDB and position within the modern data stack. It will help organization to build trustworthy AI applications (MongoDB, 2025). By integrating Voyage 4 AI models, MongoDB introduced automated embeddings in MongoDB vector search (Gluck & Agarwal, 2026). These postings are an ample proof that Voyage AI had enhanced the technological capabilities of MongoDB hence the proposition support score is 9 on 10 point scale. It is not a heavy investment on part of MongoDB but it is startup tech acquisition and therefore in line with Open Innovation Theory (Chesbrough, 2003; Van de Vrande, et al., 2006).

Proposition 2: MongoDB acquired Voyage AI to fill the technology gap in its offerings.

PR Newswire (2025) reported that MongoDB had acquired Voyage AI to fill the technological gap by integrating technology of Voyage AI. In the present day context, Voyage AI technology is treated as leading embedding and reranking models technology that provide highly accurate information and applicable information retrieval systems to power sophisticated AI use case in its existing technology stack. Voyage AI's advanced text embedding and reranking models will add technology to the stack of MongoDB that will help customers of MongoDB in developing RAG-enabled AI applications with three features. These are improved contextual relevance, cost efficiency, and reduction in latency (Sahm Capital, 2025). This is the case with many big tech companies that they had still many gaps in their existing AI models & fill such gaps external technologies are acquired. MongoDB is not exception. Whiting (2026) mentioned that Voyage AI will fill the gap between experimentation and operating reliably. Incorporating these competencies in to databases, MongoDB will transform its storage engine in to full retrieval stack. These citations are in support of the proposition and can be assigned a score of 9 on 10-point scale and it is in line with finding of other studies of merger and acquisition in high-tech merger domain (Singh, 2011; Singh, 2019).

The data collected from different sources suggests that there is a reduction in number of patent application filing by MongoDB (Table 4). It can be seen from data given in table 4 collected from different sources that MongoDB granted by 2025 only 92 patents and up to May 2026 102 patents. This data suggests that innovation

activities of MongoDB are not at par with many high tech companies. Voyage AI technology is heavily protected with trade secrets, open weights release, exclusive machine learning architecture. The Voyage AI technology may enhance innovation at MongoDB and fill the skill & technological gaps. Finally results in to more patent filing to compete in era of AI innovations.

Table 4:

MongoDB's Year wise Patents applications and Patent Granted

Year	Applications Filed	Patents Granted	Cumulative Total
2026 (iDiyas, n.d.)		102	-
2015-2025 (PlainPatent, n.d.)		92	-
2023 (GreyB, n.d.)	–	4	69
2022 (GreyB, n.d.)	9	14	65
2021 (GreyB, n.d.)	5	7	51
2020 (GreyB, n.d.)	12	19	44
2019 (GreyB, n.d.)	5	10	25
2018 (GreyB, n.d.)	7	3	15
2017 (GreyB, n.d.)	25	6	12
2016 (GreyB, n.d.)	11	2	6
2015 (GreyB, n.d.)	4	3	4
2014 (GreyB, n.d.)	1	–	1
2013 (GreyB, n.d.)	6	1	1
2012 (GreyB, n.d.)	1	–	-
2011 (GreyB, n.d.)	2	–	-
Sources: https://insights.greyb.com/mongodb-patents https://idiyas.com/company/mongodb https://plainpatent.com/company/mongodb-inc/			

It is further mentioned that MongoDB sets a new standard for retrieval accuracy with Voyage 4 models for production-ready AI applications after integrating Voyage AI technologies (PR Newswire, 2026). The datasets provided by the articles on this section and additional data available on net support this proposition. Support may be ranked as 9 on a 10 point scale.

Proposition 3: Acquisition of Voyage AI created disruption in RAG domain.

High valuation of Voyage AI by MongoDB and quick decision on part of MongoDB to acquire Voyage AI may result in to very high valuation of AI startups in future for mergers and acquisitions domain (Ferguson, 2025). Voyage's flagship general-purpose and multilingual embedding model, voyage-3-large (released January 7, 2025), surpasses retrieval quality by an average value of 9.74% and 20.71%, of its competitors OpenAI-v3-large and Cohere-v3-English respectively. This may be qualified to be a disruptive Technology in future but at present not (Mishra et al., 2025; Gisca et al., 2023). Walter (2025) mentioned that Voyage AI acquisition will be a Database AI's turning point but did not mention disruptive technology in RAG domain. Not much data is available in support of this proposition. Its score is therefore, kept at 3 on 10 point scale. Though the data has intent of Real Option Theory but support is weak.

Proposition 4: The theoretical intent of the post-merger integration (PMI) of Voyage AI acquisition by MongoDB of Voyage AI is in line of absorptive capacity theory, RBV & KBV theories.

According to Bodner and Capron (2018) if acquirer chooses to absorb an acquired firm and the acquired firm does not require high autonomy to pursue its functions and there are strong inter dependencies between acquired firm and acquirer firm, this is termed as absorptive capacity theory of Pre-Merger-Integration (PMI). Based on data composed from diverse sources (such as https://www.mongodb.com/docs/voyageai/quickstart/), it can be concluded that MongoDB will comprehend the technology of Voyage AI which have developed algorithms for search and retrieval across unstructured databases. Voyage AI competency is in building (i) embedding mathematical algorithms, custom-made these models/algorithms for specific domains and companies, for improving retrieval accuracy and RAG applications, (ii) developing APIs endpoints for embedding and reranking models that help in taking operational data (e.g., documents, queries, or query-document pairs) and (iii) yield their embeddings or relevance scores.

Embedding models and rerankers can be integrated with other parts of RAG stack such as vector stores and generative Large Language Models (LLMs). MongoDB will identify these components and have the capacity to merge these components in its existing technologies. For absorbing knowledge of Voyage AI, MongoDB will follow four stages: acquisition (completed by MongoDB), absorption, transformation, and application, and will continue internalize the knowledge & skills of

the workforce of Voyage AI. If done so then it will justify absorptive capacity of MongoDB (Zahra & George, 2002). Secondly, Ma (2025) communicated to the tech world that Voyage AI wish to be with strong and did not mention about Voyage AI autonomy. The score of this proposition is 8 in view of available data. The finding in line with RBV, KBV, and Absorbing Capacity theories.

Proposition 5: MongoDB acquired Voyage AI to reduce hallucination in AI application.

Ghoshal (2025) mentioned that Voyage AI embedding and reranking models used in retrieval-augmented generation (RAG) help in reducing Hallucination by augmenting vector search capabilities. Andre (2024) reported that "Series A funding will help Voyage AI "innovating in the RAG field, coagulating its place as a leader in reducing AI hallucinations and improving the trustworthiness of AI-generated evidences". Wiggers (2024) written that Voyage AI is developing RAG tools to reduce hallucination. Wilde (2025) mentioned that RAG implementations are still grappling with hallucination where in AI generates information that is plausible but incorrect. To mitigate these challenges, MongoDB has taken a strategic decision to augment its database capabilities with acquisition of Voyage AI. Zilliz (2024) reported that Voyage AI RAG will help in reducing hallucination. The score of this proposition is 9 since Voyage AI models will reduce hallucination but it remains as one of the important concern of all developers in the domain.

Proposition 6: Voyage AI merged with MongoDB to take its cutting age technology to the larger customer group.

PR Newswire (2025) stated that promoter of Voyage AI who claimed that MongoDB will enable Voyage AI's cutting-edge AI retrieval technology to reach larger customer base and MongoDB will seamlessly integrate it into mission-critical applications. The know-how of Voyage AI in embeddings and reranking along with MongoDB's best-in-class database, organizations will develop AI applications. These applications will provide more precise and trustworthy output at scale and empower firms to develop AI based use cases.

Chowdhry (2025) mentioned that the competitors of Voyage AI are merging with competitors of MongoDB and will take technology which is in many ways similar to Voyage AI. The small startup competitors are also attracting venture capitalist investment, it may hamper the dream of Voyage AI but it can be compensated with availability of infrastructure and databases of MongoDB and may help further tun-

ing of Voyage AI models. Investing.com (2025) reported that MongoDB anticipated a visible growth in its Atlas Platform. MongoDB expected an increase in its annual recurring revenue from US $2 billion to US$ 4 billion with new technological capabilities. In view of these opportunities and uncertainties the score of this proposition is tagged at 5 out of 10. This is in line of Real Option Theory.

Proposition 7: MongoDB is investing in Voyage AI startups to be competitive in retrieval and RAG.

Voyage AI developers of AI applications will stitch together multiple components, i.e., databases (from vector databases to operational databases), rerankers, and embedding models, to create retrieval-augmented generation (RAG), generative AI models and agent systems with the support from MongoDB in near future to make the models more robust and stable. In particular, the merger of MongoDB and Voyage AI will aid in achieving this integration for operational databases (Ma, 2025; Ghoshal, 2025). Another piece of technology, i.e., Voyage AI's voyage-3-large model had sets a new accuracy-cost benchmark ahead of its competitors. The better techniques like quantization-aware training and Matryoshka Embedding Learning will help MongoDB to reduce storage costs and processing times with minimal impact on retrieval quality (Aarsen et al., 2024; Singh, 2025). These features will make MongoDB more competitive in the domain of retrieval and RAG with the acquisition of Voyage AI. For building a retrieval-augmented generation (RAG) system a fragmented stack is required. The acquisition will provide natively managed pipelines with further scope of improvement. However, not much directly supportive data is available about this proposition but many claims are made by the management team of Voyage AI, therefore this proposition may be given a score of 7 out of 10. This is in line with Dynamic Capability Theory.

Concluding Remarks

Voyage AI technology is considered as highly innovative by MongoDB but not exactly disruptive technology. The existing technologies are 60 to 70 % accurate in predicting outcome of target / dependent variables of health care or finance data. If Voyage AI can increase it by 10% it can be termed as a breakthrough technology as per the CEO of MongoDB (FinSMEs, 2025). These capabilities are also mentioned by promoter of Voyage AI (Ma, 2025).

MongoDB acquisition of Voyage AI ahead of its backers such as Databricks and snowflake at an enormous high value establishes the importance of Voyage AI models. Secondly, irrespective of its acquisition by MongoDB, Snowflake is set to integrate the Voyage AI models into its Cortex AI service which is based on the similar technology from Snowflake's acquisition of AI search vendor Neeva (Kerner, 2024). This further supports the fact that technologies similar to Voyage AI are of utmost importance in the present day context.

Overall, this is a valuable acquisition for MongoDB, both in terms of technology and talent. This acquisition can be put in the category of DataFox acquisition by Oracle to fill the gap in technological capabilities (Singh, 2019). With Voyage AI's models integration in the very near future, MongoDB will be offering top-tier embedding models that provide performance and cost benefits, potentially it will become fast-tracking AI production workloads on MongoDB's platform.

With the acquisition of Voyage AI, MongoDB will augment its capabilities for operational data, search, real-time analytics, and AI-powered retrieval sine it has absorbing capacities (Colombo, et al., 2021; Bae, et al., 2020; Pillay et al., 2021). As per statement of executives of MongoDB, the transaction under reference will benefit organizations ubiquitously in moving faster, innovating more efficiently, and simplifying complex architectures. However, it rest on the results of further training of models on large data bases which are large enough as per the basic requirement of models. The reality is that the data and models are created and/or can be created independent of each other but utility of models depend on the basic nature of data. This is more important for AI models since many of these models did not have backing in mathematical theories.

Based on the features of technologies and size of the acquirer (MongoDB) and acquired company (Voyage AI), the acquisition is in line with many strategic high-tech merger & acquisition theories such as RBV, KBV, Absorptive Capability Theory, Dynamic Capability Theory, and Open Innovative Theory (OIT). The statement of acquired company's executive in praise of Voyage AI technology acquisition impact on MongoDB cannot be said supportive of The Hubris Hypothesis and Agency Theory (HHA). It is not exaggerated to fit in the definition of HHA.

Irrespective of these facts, AI will create models to get rid of hallucinations due to historical inaccuracies, lack of mathematical support to the algorithms, geographical errors, incorrect financial & healthcare data, scientific and engineering inaccuracies, incompetent legal advices, and data poisoning due to 'n' number of factors. These happenings in terms of reduction in hallucination will be in line of

investment made by MongoDB and commitments of the management of merged entities. The emergence of better models with similar functionalities by startups may pose challenges to the MongoDB and Voyage AI models.

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Artificial Intelligence in Orthodontics: From Algorithms to Aligners

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Abstract

Artificial intelligence (AI) has become an important component of modern orthodontics, significantly influencing diagnostics, treatment planning, and patient monitoring. This review paper examines the current applications of artificial intelligence (AI) and digital technologies in orthodontic practice, with particular focus on cephalometric analysis, clear aligner therapy, predictive tooth movement, and digital treatment workflows. Relevant scientific literature was retrieved from PubMed, Scopus, Web of Science, and Google Scholar, focusing on machine learning (ML), deep learning (DL), cone-beam computed tomography (CBCT), intraoral scanning, and artificial intelligence (AI)-assisted orthodontic software systems. The reviewed studies demonstrate that AI improves diagnostic accuracy, accelerates cephalometric analysis, enhances treatment simulations, and supports individualized orthodontic care. AI-assisted aligner systems and remote monitoring technologies also improve treatment efficiency, patient compliance, and communication. Despite these advantages, orthodontic treatment remains dependent on biological variability and clinical expertise. Artificial intelligence (AI) should therefore be regarded as a supportive tool rather than a replacement for the clinician. The future of orthodontics will likely depend on the balanced integration of advanced digital technologies and professional clinical judgment.

Keywords: Artificial intelligence, digital orthodontics, orthodontics, clear aligners, treatment planning

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Introduction

Orthodontics has always relied heavily on the careful analysis of diagnostic data. From manual cephalometric tracings to the digital technologies introduced in the early 2000s, the primary objective has remained unchanged: achieving controlled and predictable tooth movement within the craniofacial complex. Modern diagnostic techniques now generate enormous amounts of information, including cone beam computed tomography (CBCT), three-dimensional (3D) intraoral scans, and high-resolution facial photographs. The volume and complexity of these datasets often exceed the capacity of traditional manual analysis.

Artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL), offers powerful tools for processing and integrating complex clinical data. In contemporary orthodontics, artificial intelligence (AI) is increasingly used to support clinicians in diagnosis, treatment planning, and the customized creation of orthodontic appliances (Ye et al., 2025).

The development of digital orthodontics has accelerated significantly in recent years due to improvements in computational technologies, imaging systems, and software algorithms. Orthodontic practice is transitioning from conventional analog methods toward digital workflows that rely on virtual simulations and predictive modeling. Artificial intelligence (AI)- assisted systems are now capable of performing cephalometric analysis, predicting tooth movement, analyzing radiographs, and supporting clear aligner therapy with a degree of speed and precision that was previously unattainable.

Despite these advancements, orthodontic treatment remains fundamentally biological. Tooth movement depends on the response of the periodontal ligament, alveolar bone remodeling, patient cooperation, and individual anatomical variability. Therefore, while artificial intelligence (AI) can improve efficiency and analytical precision, clinical expertise and professional judgment remain essential for successful treatment outcomes.

The purpose of this review paper is to examine the current applications of artificial intelligence in orthodontics, with particular emphasis on diagnostics, treatment planning, clear aligner systems, and patient monitoring. In addition, the paper evaluates the benefits, limitations, and future implications of artificial intelligence (AI) integration in contemporary orthodontic practice.

Cephalometric Analysis

Cephalometric analysis has traditionally been a time-consuming procedure requiring manual identification of anatomical landmarks. Artificial intelligence (AI)-based systems are now capable of automatically identifying skeletal and dental reference points with remarkable speed and accuracy (Cao et al., 2022). Recent studies have demonstrated that artificial intelligence (AI)-assisted landmark detection can achieve accuracy within approximately 2 mm of manually determined positions, which is generally considered clinically acceptable. Advanced deep learning algorithms have shown promising results in both two-dimensional and three-dimensional cephalometric analysis. Song et al. (2024) reported that convolutional neural network (CNN)-based systems significantly improved the reliability of 3D cephalometric landmark identification. Similarly, Lee et al. (2023) demonstrated that automated landmark detection systems could achieve performance comparable to that of experienced orthodontists.

The implementation of artificial intelligence (AI)- assisted cephalometric analysis substantially reduces the time required for diagnosis. Procedures that previously required 15–20 minutes of manual tracing may now be completed within seconds, improving efficiency and reducing interobserver variability.

Detection of Pathology and Bone Assessment

Artificial intelligence (AI) has also demonstrated significant potential in the detection of pathological findings on panoramic and periapical radiographs. Artificial intelligence (AI)- assisted radiographic interpretation contributes to improved diagnostic precision by identifying dental caries, cystic lesions, impacted teeth, and other pathological conditions. Another important application involves skeletal maturity assessment using hand-wrist radiographs and cervical vertebral maturation analysis. Artificial intelligence (AI)- based systems provide more consistent and reproducible evaluations compared with conventional methods (Kavasoglu et al., 2025). Such assessments are particularly important in orthodontic treatment planning because growth prediction influences the timing of orthopedic and functional interventions.

Digital Scanning and Virtual Treatment Planning

The connection between diagnostic algorithms and clinical treatment becomes evident during digital treatment planning. Artificial intelligence (AI) systems transform static diagnostic information into dynamic simulations of tooth movement. Modern orthodontic software automatically segments intraoral scans by identifying individual teeth and separating them from surrounding gingival tissues (Turner, 2025). This process allows the creation of digital setups in which teeth can be moved independently within a virtual three-dimensional environment. In many systems, digital models can be integrated with cone-beam computed tomography (CBCT) data, enabling orthodontists to visualize not only the crowns but also the roots and surrounding alveolar bone structures during treatment planning (Ahn et al., 2024). This integration improves the ability to evaluate root proximity, cortical bone limitations, and potential risks associated with orthodontic tooth movement.

Predictive Tooth Movement

Predicting biological responses to orthodontic forces remains one of the greatest challenges in orthodontics. By analyzing large datasets from previously treated patients, artificial intelligence (AI) models are now capable of estimating potential movement patterns and treatment outcomes (Liu et al., 2023; Nordblom et al., 2024). These systems assist clinicians in evaluating root proximity, predicting treatment duration, and optimizing force distribution for movements such as intrusion, extrusion, distalization, and rotation (Alhazmi, 2025). Although artificial intelligence (AI) cannot fully account for individual biological variability, predictive models provide valuable support during treatment planning and risk assessment.

Clear Aligner Systems and AI Personalization

Clear aligner therapy represents one of the most visible clinical applications of artificial intelligence (AI) in orthodontics. Unlike conventional fixed appliances, aligner therapy depends largely on digitally planned treatment sequences.

CAD/CAM Technology

The fabrication of aligners relies on computer-aided design (CAD) and computer-aided manufacturing (CAM). Artificial intelligence (AI)- assisted algorithms optimize the staging of tooth movement by determining the number of aligners and

treatment steps required to achieve the desired outcome (Alhazmi, 2025). Recent technological developments have introduced the possibility of directly 3D-printing aligners, potentially eliminating traditional thermoforming procedures (Khijmatgar et al., 2022). These advancements may improve manufacturing precision and reduce material distortion during production.

Remote Monitoring and Patient Compliance

Artificial intelligence (AI)- supported mobile applications allow patients to perform regular scans of their dentition using smartphone cameras. The acquired images are analyzed by software that evaluates aligner fit and treatment progress (Fawaz et al., 2023). Remote monitoring systems may reduce the frequency of clinical visits while still allowing orthodontists to identify deviations from treatment plans and intervene when necessary. In addition, these technologies improve patient engagement and communication throughout treatment.

Materials and Methods

This review paper was conducted as a comprehensive literature-based study aimed at analyzing the integration of artificial intelligence in modern orthodontics, with particular focus on cephalometric analysis, clear aligner therapy, digital workflows, and predictive treatment planning.

A structured literature search was performed using PubMed, Scopus, Web of Science, and Google Scholar databases. The search included scientific articles published up to 2025. The following keywords and combinations were used: “orthodontics,” “artificial intelligence,” “machine learning,” “deep learning,” “digital orthodontics,” “clear aligners,” “CBCT,” “cephalometric analysis,” and “treatment planning.”

Approximately 100 peer-reviewed articles were initially identified. Studies were selected based on relevance, methodological quality, scientific impact, and clinical applicability. Both original research articles and systematic reviews were included to provide a broad overview of diagnostic, predictive, and therapeutic applications of artificial intelligence (AI) in orthodontics.

The inclusion criteria consisted of:

1. Studies evaluating artificial intelligence (AI) applications in orthodontic diagnosis and treatment planning.

2. Research involving digital orthodontic workflows, cone-beam computed tomography (CBCT) analysis, and aligner therapy.
3. Peer-reviewed articles.
4. Studies demonstrating clinical or practical relevance to orthodontic treatment.

The exclusion criteria included:

1. Studies unrelated to orthodontics.
2. Purely technical computer science studies without clinical applicability.
3. Non-peer-reviewed publications and unpublished data.
4. Duplicate studies and conference abstracts lacking full scientific data.

Data extraction focused on the following areas:

- Artificial intelligence (AI)-assisted cephalometric analysis and radiographic interpretation.
- Digital treatment planning and virtual tooth movement simulation.
- Clear aligner therapy and predictive treatment modeling.
- Remote monitoring systems and patient compliance.
- Clinical outcomes, limitations, and ethical considerations.

The selected literature was analyzed and carefully read to qualitatively identify current trends, reported clinical accuracy, advantages, limitations, and future perspectives regarding the integration of artificial intelligence into orthodontic workflows.

Discussion

The integration of artificial intelligence (AI) into orthodontics represents one of the most significant technological developments in contemporary dental medicine. Nevertheless, despite the impressive capabilities of modern software systems, orthodontic treatment remains fundamentally a biological process. Tooth movement occurs within living tissues, and the response of the periodontal ligament and surrounding bone structures is influenced by numerous patient-specific factors. Consequently, artificial intelligence (AI) should be considered a supportive clinical tool rather than a replacement for professional judgment.

One of the greatest contributions of artificial intelligence (AI) is its ability to process and organize large amounts of diagnostic information. Modern orthodontic workflows frequently combine cone-beam computed tomography (CBCT) imaging, intraoral scans, facial photographs, and digital models. Manual analysis of these datasets may be time-consuming and prone to variability between clinicians. AI-assisted systems can rapidly integrate these data and provide structured diagnostic support, thereby improving efficiency and consistency.

The reviewed literature demonstrates that artificial intelligence (AI)-assisted cephalometric analysis significantly reduces the time required for landmark identification while maintaining clinically acceptable accuracy. This improvement not only enhances efficiency but also minimizes human error and interobserver variability. Similar findings have been reported regarding artificial intelligence (AI)-assisted radiographic interpretation and skeletal maturity assessment.

At the same time, it is essential to recognize the limitations of algorithm-based predictions. Artificial intelligence systems (AI) rely on previously collected datasets and statistical models. Although such systems can identify patterns across large populations, they may not accurately predict the biological response of every individual patient. Variations in bone density, periodontal health, age, genetics, and patient compliance can influence treatment outcomes in ways that algorithms cannot fully anticipate.

Another important aspect involves digital treatment planning systems used in clear aligner therapy. Artificial intelligence (AI)- assisted software allows clinicians to visualize predicted tooth movements and treatment outcomes before therapy begins. However, clinical experience indicates that in vivo tooth movement does not always correspond precisely to virtual simulations. Movements such as extrusion, rotation of rounded teeth, and bodily translation may occur more slowly or less predictably than expected. Consequently, orthodontists often incorporate overcorrections and refinement stages into aligner therapy.

The expansion of digital orthodontics has also created new possibilities for remote patient monitoring. Smartphone-based applications and artificial intelligence (AI)-supported monitoring systems allow patients to submit photographs and scans that can be evaluated remotely. Although these technologies improve convenience and communication, they should not replace direct clinical examination entirely. Evaluation of occlusion, periodontal health, temporomandibular joint function, and patient comfort still requires professional clinical assessment.

Ethical considerations represent another important dimension of artificial intelligence (AI) integration in healthcare. The use of artificial intelligence (AI) requires careful attention to patient privacy, data security, algorithm transparency, and professional responsibility. Clinicians must ensure that artificial intelligence (AI)-generated outputs are interpreted responsibly and that patient care remains individualized and biologically safe. Furthermore, the legal responsibility for treatment decisions still rests entirely with the clinician, as artificial intelligence (AI) tools function only as supportive systems and not autonomous decision-makers.

The role of the orthodontist is gradually evolving within this highly digital environment. Traditionally, orthodontics relied heavily on manual procedures such as model analysis, wire bending, and cephalometric tracing. With increasing digitalization, the clinician's role is shifting toward interpretation, treatment strategy, and supervision of technologically assisted workflows. In this context, the orthodontist becomes not merely a technician but a clinical strategist responsible for integrating digital information with biological understanding and patient-centered care.

Despite rapid technological advancement, the human aspect of orthodontic treatment remains irreplaceable. Successful treatment depends not only on technical precision but also on communication, trust, motivation, and empathy between clinician and patient. Artificial intelligence (AI) can support treatment monitoring and predictive analysis, but it cannot replace the clinical intuition and ethical responsibility of the orthodontist.

Ultimately, the future of orthodontics will likely depend on a balanced integration of advanced technology and clinical expertise. Artificial intelligence (AI) offers powerful analytical capabilities that improve precision and efficiency; however, its greatest value lies in complementing—not replacing—the knowledge, experience, and judgment of the clinician.

Conclusion

The integration of artificial intelligence (AI) into orthodontics represents a transformative advancement in contemporary dental medicine. Evidence from recent scientific literature demonstrates that artificial intelligence (AI) -assisted systems improve diagnostic precision, optimize treatment planning, and enhance efficiency in orthodontic workflows. Applications such as automated cephalometric analysis, cone-beam computed tomography (CBCT) interpretation, predictive tooth

movement modeling, and clear aligner staging have significantly reduced the time required for routine clinical procedures while maintaining high levels of accuracy. In addition, remote monitoring technologies and smartphone-based applications contribute to improved patient communication, compliance, and treatment supervision. Despite these advancements, orthodontic treatment remains fundamentally dependent on biological principles and individualized patient responses. Artificial intelligence (AI) cannot fully predict the complexity of tissue adaptation, patient cooperation, and anatomical variability. Therefore, clinical expertise and professional judgment remain essential in interpreting artificial intelligence (AI)-generated data and ensuring biologically safe treatment outcomes.

The reviewed literature suggests that the future of orthodontics will involve a synergistic relationship between artificial intelligence (AI) and clinician expertise. Artificial intelligence (AI) should be regarded as a powerful adjunctive tool that enhances efficiency, precision, and personalization rather than as a replacement for the orthodontist.

In conclusion, the successful integration of artificial intelligence (AI) into orthodontics requires a balanced approach that combines advanced digital technologies with evidence-based clinical practice, ethical responsibility, and patient-centered care. Orthodontists who effectively integrate artificial intelligence (AI) into their workflows will likely define the future standards of modern orthodontic treatment.

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Development and Performance Study of an Atomized Kerosene Oven for domestic use in Nigeria

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Abstract

This study was conducted to design, develop, and evaluate the performance of an atomized kerosene oven. The oven was developed to address the high operating costs, low thermal efficiency, and incomplete combustion associated with conventional kerosene ovens. It premixes atomized kerosene with steam in a 1:3 ratio to enhance atomization and improve air-fuel mixing, thereby promoting more complete combustion. Experimental evaluation methods for atomized kerosene stoves focus on determining their thermal efficiency, emission characteristics, and combustion quality, often comparing them with traditional wick stoves. The method includes the water boiling test (WBT), emission monitoring using flue gas analyzers, and pressure-controlled combustion testing. The oven comprises four main components: the oven chamber, kerosene tank, pressurized tank, and burner, with volumes of 338611 cm3, 59582 cm3, 884122 cm3, and 2061 cm3, respectively. The oven is medium-sized and intended for domestic use. The oven can bake 30 loaves of bread, each with an area of 120 cm2, within 35 minutes. The production cost was N117,441.00 (approximately $87.316). The operating temperature ranges from 180°C to 322°C. Based on the general energy equation, the oven generated 875.237 kJ of energy comparing it with traditional oven which has 675kj of energy and the operating temperature ranges from 150 °C to 250 °C respectively. Performance testing confirmed that the oven functions efficiently. It produces a stable blue flame with minimal soot, reduces fuel consumption, enhances heat transfer, and offers a cost-effective and cleaner baking solution, particularly in low-resource settings.

Keywords: Atomized kerosene oven, combustion efficiency, thermal performance, domestic baking technology, energy-efficient cooking systems

Introduction

Food has a close relation to people's daily life, with significant health implications and as such food processing is a key point in the food industry. Baking is a major food processing method that has been practiced for ages and continues to be relevant (Gujba et al., 2015). Baking is an energy consuming process of cooking using dry heat to prepare food from raw staple agricultural products. In the baking process in the oven, the raw food is converted into edible food and concurrently, microorganisms that cause food spoilage are destroyed preserving it for a long time (Layeni, 2016; Lefebvre, 1980) Normally, baking is carried out in an oven or by using of a stove, but it could also be done in hot ashes or on hot stones. An oven is an enclosed thermally insulated space or cavity used for baking, drying or heating food (Lefebvre, 1980; Manhiça et al., 2012). Fellows (Muneer & Mohamed, 2003) indicated that the heat energy transfer across an enclosed oven is defined by a coefficient dependent on the changes in temperature of surfaces. The moisture present in the food substance instantaneously diffuses near the surfaces where it is transferred by means of convection. Moisture content is removed from food material via continual motion of the oven ambient air (Onakoya et al., 2023). Therefore, this study on baking ovens is vital in developing an efficient baking process leading to an improved quality of the product with good energy efficiency.

Over the years, it has been observed that food stuff gets wasted because of lack of good storage facilities or a device that can preserve it for a long period of time. The locally made oven was implemented to solve this problem, but was not good enough. The local oven, which uses wood as a source of fuel, has led to ecological problem such as deforestation, environmental problem such as air pollution, ecosystem disruption and negative impact on climate change (Romieu et al., 2019 & Sambo, 2019) over dependence on wood fuel as a domestic energy supply source has worsened the deforestation rate, leading to desert encroachment, leaching of soil as a result of wind and water erosion, reduction in the mineral contents of the soil and also led to the absence of wind breakers in some parts of Nigeria (Zhang & Datta, 2006). According to the International Energy Agency (Makonese et al., 2012), the household (domestic) cooking sector is a major user of energy in Nigeria, with about 80% of its population relying on fuel wood and charcoal for domestic cooking and other household energy use. As reported by the Food and Agriculture Organisation (Ogundahunsi et al., 2024), the yearly deforestation rate is projected at around 3% yearly, equal to the depletion of 410,000 hectares of wooded land per annum. Also, a gas oven was produced with the aim of solving this

problem but its disadvantages include causing devastating fire outbreaks resulting from gas leakages and being too expensive to maintain in both rural and urban communities. The electric oven was made and imported but the interruption of power supply in the middle of operations makes its usage ineffective. This affects the quality of the baked or heated product and also, an electric oven consumes more energy (Ibrahim et al., 2024), described that 26% of the Nigerian populace use kerosene as cooking fuel comprising 48% urban and 9% rural owing to its accessibility and safety. An atomized kerosene oven can be more effective, with a good percent of energy used for heating the food. Atomization can be defined as a process where a volume of liquid is transformed into a multiplicity of small drops (Garipov et al., 2025), the kerosene is naturally burned as a suspension of droplets produced by the atomization process. In this process, the surface area of the liquid is increased via vaporization making it have a bigger affinity with atmospheric oxygen for suitable and efficient combustion. The overall kerosene stove thermal efficiency is generally cited between 20 – 40% for wick kerosene oven but with this oven it has well maintained pressurized stove achieving over 50%. It has flame quality (combustion quality and emission) which produces a blue flame indicating near-complete combustion. The pressurized stove indicates high CO2 emissions (e.g. 2739PPm) and low carbon monoxide CO (e.g. 73PPm) under optimal high pressure, blue flame conditions. The serpentine burner design and the use of heat radiation shields significantly increased the efficiency by reducing thermal losses. The kerosene stove remains popular for its economical, portability and high performance in both urban and rural areas in Nigeria. The performance factors, increasing cylinder pressure in pressurized stove (up to 2 bar) significantly improves thermal efficiency and combustion quality. The limitations of the wick stove in the market has the safety hazards of explosion from the pressure build-up, maintenance nozzle can become clogged by carbon build-up (soot) if the fuel is inpume or the combustion is not optimized. Thus, this work is aimed at designing and constructing a medium but efficient atomized kerosene oven that has higher thermal efficiency with optimal performance around 2 bar (max), leading to increase flame temperature and reduced fuel consumption. The fuel temperature at the nozzle is critical for proper vaporization such as high efficiency and heat, less pollution and affordability has made this oven very important over the existing oven that has about 1 bar with lower pressures (0.2 – 0.4 bar) leading to reduced flame temperature and increased fuel consumption. This kerosene burner has great advantages over the existing oven in the market which could be used for domestic purposes.

Materials and Methods

The selection of materials that best suit the work was duly considered considering the desired engineering properties of the materials and their impact on the environment and the human health. The atomized kerosene oven is capable of converting the chemical energy of the volatile substance (kerosene) into heating energy for baking foodstuffs such as bread and cake. Various design factors were considered, including the area of the kerosene oven (3136 cm2), the volume of the kerosene tank (59582 cm3) and the pressurized water tank (88412 cm3).

Design Considerations

The Design of Kerosene Tank

Kerosene tank is designed using equation (Gujba et al., 2015).

V=LBW =59582 〖cm〗^3 (Gujba et al., 2015).

Where L, B, and W are the length (62 cm), breadth (31 cm), and height (31 cm) of the tank, respectively.

The Heat Supply for Combustion of Kerosene

Heat interaction occurs across the oven via a heat source, prompting the temperature of the food to rise. It is assumed that the heat given is uniform. The quantity of heat supply is given by equation (Layeni, 2016).

Q=MCθ =1.8432 kJ (Layeni, 2016).

where M,C,and θ are the quantity of heat supply by kerosene,(KJ) while the mass of Kerosene (kg), heat capacity of the kerosene (KJ/KgK), and temperature difference between the final and initial temperature (T1 – T2) (K).

Hence; Q = 0.1152 x 0.5(355-323); Q = 1.8432 KJ

Temperature of The Oven

The temperature within the oven will vary greatly depending on the amount of heat supplied from the source. The temperature of the oven is high enough to ensure that less time is needed to bake the food. The oven temperature can be obtained in equation (Lefebvre, 1980).

T=T_∞+(T_0-T_∞)l^(-at) (Lefebvre, 1980).

where T is the temperature of the oven; T0 is the temperature of the oven; T∞ is the ambient temperature; ℓ is the index of the atmospheric temperature; - at is the exothermic reaction; T is the baking temperature. Hence; T = 50 + (82 – 50) ℓ0.1296 x 30; T = 355K

Design of The Oven

In the design analysis of the oven, it will be noted that the oven is rectangular in shape. Thus, the volume of the oven is given by equation (Manhiça et al., 2012).

V = l x b x w (Manhiça et al., 2012).

Where: l = 91 cm is the length of the oven; w = 61 cm is the breadth of the oven, and w = 61 cm is the height of the oven.

Hence, V = 91 x 61 x 61= 338611 cm3

The area of the oven is large enough to ensure that about 30 loaves of bread, each with an area of 120 cm2, can be baked. The volume of the oven chamber is 338611 cm3, which is the same as the volume of the oven. The area of the oven is calculated in the analysis using equation (Muneer & Mohamed, 2003).

A = L x B (Muneer & Mohamed, 2003).

A = 60 x 60 = 3600 cm2

Heat of Combustion from the Burner to the Oven

The heat transfer by convection from the design analysis is given in equation (Onakoya et al., 2023).

∂/∂x (K (∂T)/∂x)+∂/(∂y) (K (∂T)/∂y)+∂/(∂Z) (K (∂T)/∂z)+qv= p_cp ∂T/∂x (Onakoya et al., 2023).

Where K = material conductivity (Wm-1K-1); q_v = the rate of energy generation per unit volume of the medium (W.m-3); p_(cp =)the density (kgm3); c_(p =)the specific heat capacity (Jkgk-1).

Q = hA(Ts – Tw) (Romieu et al., 2019).

Where h is the thermal conductivity of the material (W/moK); A is the area of the section through which heat flows by conduction (m2); Ts is the initial temperature of the oven (K); Tw is the final temperature of the oven during baking (K).

Therefore, Q = 47.57 W x 0.1296 m2 x 32 k/m2K = 197.28

Heat of Radiation from the Oven Wall to the Foodstuff

From the design analysis the heat transfer through radiation is given in equation (Sambo, 2019).

Eb = σAT4 (Sambo, 2019).

Where: Eb is the radiant energy for heat transmission (KJ/hr); σ is the dimensional constant (Stefan-Boltzmann constant) (KJ/hr.m2T4); A is the area of the oven exposed to radiant energy (m2); T is the temperature of the body (K).

Hence; Eb = 5.67 x 10-4 x 0.1296 (3554 – 3234) = 36.72 W.

The Heat Content of Combustion Products

The heat content of the combustion products was determined using equation (Zhang & Datta, 2006).

Hp = Cn/V (Zhang & Datta, 2006).

Where Hp is the quantity of heat supplied with respect to the mass volume of the kerosene (KJ/Kgm3); Cn is the calorific value of the kerosene (KJ/Kg); V is the volume of the kerosene (m3)

Therefore, Hp = 42250 KJ/Kg /5.9582m3 = 7091.067KJ/kgm3

Unsteady Conduction of Heat from the Heating Chamber of Mild Steel of the Oven

The unsteady conduction into the oven through the mild steel is given in equation (Makonese et al., 2012).

Q = "-KA (T - Ts)" /"dt" (Makonese et al., 2012).

Where K is thermal conductivity in W/mK; A is the area of the section through which heat flow by conduction (m2); T is the inner temperature of the oven (K); Ts is the atmospheric temperature of the oven (K).

Hence, Q = -88 W x 0.1296 m2 x 32 k/mK x 0.0015 m^2 = -243.30 KJ

The Heat of Conduction from Mild Steel Sheet to the Oven

The heat of conduction from mild steel sheet is given in equation (Ogundahunsi et al., 2024).

q = k(t1-t2)/x (Ogundahunsi et al., 2024).

Where K = the thermal conductivity of mild steel (W/mok); t1 = the final temperature of mild steel (K); t2 = the initial temperature of mild steel (K); x= the thickness of the mild steel (m).

Therefore, q = 88 W/mk x 0.1296 m2 x 32 K /0.0015m = 243.30 KJ.

The Design of the Burner

The design of the burner is given in equation (Ibrahim et al., 2024). where the volume of the burner is:

V = πr2h (Ibrahim et al., 2024).

Where V = the volume of the burner (cm3); r = the radius of the burner (cm); and h = the vertical height of the burner (cm)

Therefore; V = 3.142 x 42 x 41= 2061 cm^3

Additionally, the surface area from the analysis is given in equation (Garipov et al., 2025).

S = 2 πr (h + r) (Garipov et al., 2025).

S = 2 x 3.142 x 4 (41 + 4) = 1131.12 cm2.

Design of Pressurized Water Tank

The design of the pressurized water tank is described by equation (Ogundahunsi et al., 2024). The volume is calculated as follows:

V = H x B x W (Ogundahunsi et al., 2024).

Where H = 92 cm (length of the pressurized water tank)

B = 31 cm (breadth of the pressurized water tank)

W = 31 cm (width of the pressurized water tank)

Therefore, V = 92 x 31 x 31= 88412 cm3

The volume of the pressurized water tank is sufficient to prevent the need for frequent refilling during the baking process.

Design of Pressurized Water Tank

From the design analysis, the area of the glass fibre selected is given in equation (Moh, 2010).

Area = L x B (Moh, 2010).

Where: A is the area of the glass fibre (cm2); L is the length of the glass fibre (cm); and B is the breadth of the glass fibre (cm).

Therefore, A = 91 x 61= 5551 cm2

Also, the volume of the glass fibre selected is given in equation (Pande et al., 2024).

V = L x W x B (Pande et al., 2024).

Where W is the width of the glass fibre (cm), and B = 0.5cm. Hence; V = 2775.5 cm3

Material Selection for Insulation (Plywood)

The area of the plywood selected is calculated using equation (Smith et al., 2023).

A = L x W (17)

A = L x W (Smith et al., 2023).

Where L is the length of the plywood (cm); and W is the width of the plywood (cm)

Hence, A = 91 x 61= 5551 cm2

Also, the volume of the plywood selected is calculated using equation (Johnson et al., 2021).

V = L x W x B (Johnson et al., 2021).

Where W is width of the plywood (cm); B is the breadth (cm); and L is the length (cm)

Hence, V = 91 x 61 x 1= 5551 cm3

Galvanized Pipe Connecting Kerosene Tank to Burner

The volume of the galvanized pipe linking the kerosene tank to the burner is given in equation (Gyan et al., 2025).

$V = \pi d^2 L/4$ (Gyan et al., 2025).

Where d is the diameter of the galvanized pipe (cm); L is the length of the galvanized pipe (cm). Therefore; V = 3.142 x 22 x 117/4= 367.614 cm3

The Selection of Pneumatic Pump

The pneumatic pump selected is the wheel barrow-sized pump with a capacity is 30 kgf/cm^2.

The Selection of Pneumatic Pump

The energy balance equation is given in equation (Sharma et al., 2025)

$Q = K_m A_m + hA (T_s - T_w) + Ka_1 Aa_1 + K_f A_f + \sigma AT^4$ (Sharma et al., 2025)

$Q = 631670 + 197.28 + 243300 + 36.72 + 33.28 = 875.237$ KJ

Materials Selected for Construction of Atomized Kerosene Oven

The design and construction of the atomized kerosene oven consist of three main parts:(a) the chamber (b) the insulator, and (c) the casing. Key design factors were considered in the selection of materials for these three main parts to enhance the oven's effectiveness, reliability, stability, workability, and sustainability. Some other components that are the atomized kerosene oven are standard parts readily available in the market. It was realized that buying them is cheaper than producing them in-house. These components include; valve, pipes, pneumatic pump, oven lock, hinge, galvanized steel pipe, hoist, nipple, and door handle. Table 1 presents a summary of the materials selected for the construction of the three main sections of the atomized kerosene oven.

Table 1

Materials selection for atomized kerosene oven components

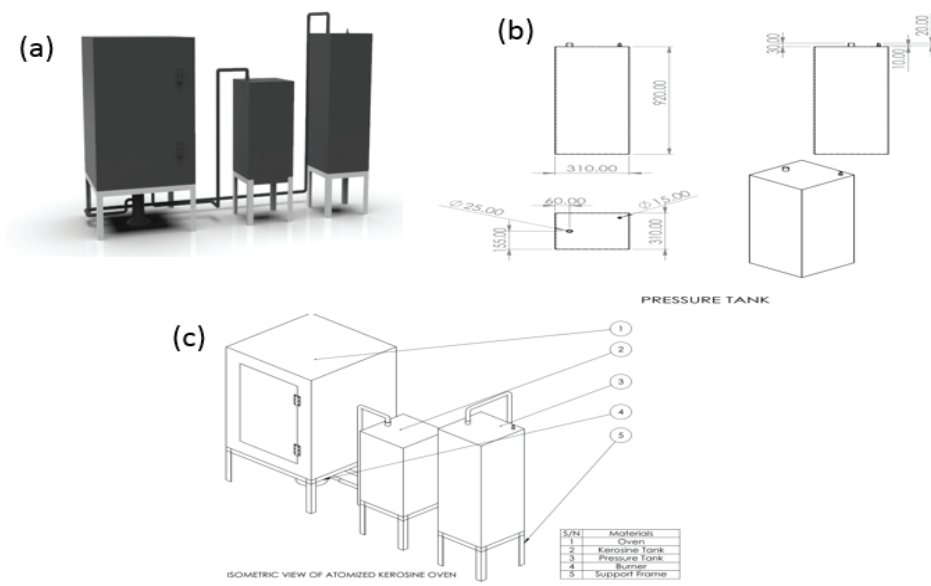
S/N	Components	Materials selected	Reason
1	The chamber	Mild Steel	High thermal conductivity, Minimum heat loss, toughness, low cost, availability
2	Insulators	Asbestos	Low thermal conductivity, low cost, suitability
		Polystyrene	Low thermal conductivity, low cost, suitability
		Glass fibre	Low thermal conductivity, low cost, suitability
3	Casing	Mild Steel	High Toughness, low cost, good tensile strength.

Construction Process

Fabrication of the automated kerosene oven was done at the Engineering Workshop of the Faculty of Engineering, Federal University of Technology, Yola, Nigeria. The processes involved in the manufacture of the components include marking out, cutting, shearing, bending, drilling, welding, and grinding. Some of the tools and equipment used include; welding machine, try square, hammer, center punch, anvil, vice, drilling machine, mallet, shearing machine, steel rule, and hack saw. The exploded view of the atomized oven is shown in Figure 1a, the top view of the designed atomized oven is shown in Figure 1b, and the isometric view of the atomized oven is shown in Figure 1c. Based on the design specifications, pressurized water tank stand, oven stand, and kerosene tank stand were fabricated using an angle iron device that was cut into suitable sizes and joined together by welding serve as support for pressurized water tank, oven, and kerosene tank.

Figure 1

Exploded view of the atomized oven (AV): (a) Top view of the AV, (b). Isometric view of the AT, and (c) Side view of the AT



Construction Process

In the design of the atomized kerosene oven, three forms of cost were involved, namely; material/components cost, direct labour cost, and overhead cost. The cost of material purchased for the fabrication of the atomized kerosene oven including bought – out component is shown in Table 2. It gives the outline of all the cost expended during the design and construction of the atomized kerosene oven. Overview of all the actual cost in producing the machine.

Table 2

Cost analysis of materials and bought – out component of the atomized kerosene oven.

S/N	Materials	Specifications	Qty.	Unit cost (₦)	Total cost (₦)
1	Mild steel sheet		3	5000	15000
2	Burner		1	5000	5000
3	Asbestos		4	1500	6000
4	Plywood		1	3000	3000
5	Angle bar		1	2500	2500
6	Square pipe		1	3000	3000
7	Packet of electrode	0.5 mm	1	4000	4000
8	Elbow union connection		2	1000	2000
9	Hinges		2	600	1200
10	Oven door lock		1	500	500
11	Valve		3	1200	3600
12	Pneumatic pump	Medium size (30 kgf/cm2)	1	1800	1800
13	Paint (Ash)	Dulux	1 Liter	5000	5000
14	Round pipe (galvanize)		2	1000	2000
15	Nipple		3	1500	4500
	Total				59100
16	Direct Labour cost				20700
17	Overhead cost				10200
18	Transportation				12000
19	Miscellaneous				15000
	Total				#117,000.00

Results

Performance Tests

After the design and construction of the atomized kerosene oven, performance evaluation was carried out to determine its functionality, as shown in Table 3. The kerosene burner underneath the oven was wheeled out so that its burner could be seen from the top. The stove was then lit up and positioned at the center of the burner. As the wicks began to burn, a bluish color was noticed, signifying complete combustion. The water in the burner changed to steam, allowing the flow of kerosene through the pipe for atomization, resulting in a brighter burning flame in the oven. The oven door was opened, and the first test was ready to be conducted. The first test involved the atomized kerosene oven with cake flour of weights: 36.05 g, 32.13 g, and 30.82 g. The weights were determined using a manual weighing scale. The cake flour was loaded into the oven chamber, and after some time with initial and final temperatures recorded, a baked cake was obtained. For the second test, groundnuts of weights: 30.12 g and 32.16 g were determined using a manual weighing scale. The groundnuts were loaded into the oven chamber, the burner was lit up, and after some time with initial and final temperatures recorded, fried groundnuts were obtained. Lastly, a bread measuring 120 cm2 in a mold was loaded into the oven chamber, the burner was lit up, and after some time with initial and final temperatures recorded, a baked bread was obtained.

Table 3

Results obtained in the performance test.

Test	Food Stuff Baked	Weight (g)	Time (Mins)	Initial Temp.°C	Final Temp. °C	Result
1	Cake	36.05	35	180	322	Baked cake was obtained
		32.13	30	180	322	
		30.82	28	180	322	
2	Groundnut	30.24	11	180	227	Fried groundnut was obtained
		32.11	13	180	227	
3	Bread	36.05	35	180	322	Baked bread was obtained
		34.15	33	180	322	
		32.45	30	180	322	

Conclusion

The constructed atomized kerosene oven represents a serious effort to satisfy the need for an inexpensive oven in rural areas where electricity is limited. The parts were carefully designed to achieve the objective of an atomized kerosene oven as stated in the introduction. In the end, it was possible to relate an efficient and operating atomized oven. Considering the high cost of purchasing of kerosene, atomized kerosene is very economical because one liter of kerosene will be atomized with about three liters of steam for fast and smokeless fuel combustion. Finally, with the use of smokeless fuel, it saves time and energy, making it more hygienic to bake food commodities using atomized kerosene oven.

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