Documentation and Classification of Heritage Buildings' Styles through Machine Learning: Duhok's City Center as a Case Study

Cebar J. Sadiq†

Department of Architecture, College of Engineering, University of Duhok,
Duhok 42001, Kurdistan Region – F.R. Iraq

***Abstract*—*Duhok,* a city in Kurdistan Region of Iraq, has important historical and cultural evident in its archaeological sites. The city center contains many neglected heritage buildings that necessitate documenting as a crucial preliminary step for their preservation, facilitating a comprehensive understanding of their architectural, historical, and social significance. Consequently, the study aims to document buildings in the study region employing several documentation methods and looking at various aspects, such as architectural, historical, social, and cultural dimensions. The second goal of the study is to build an automated model utilizing advanced machine learning techniques, such as convolutional neural networks, transfer learning, and neural architectural search, to create a robust model for identifying and classifying architectural styles across various regions of the Kurdistan Region. The initials result of the study show the unique attributes of Islamic, vernacular, modern, and postmodern architectural styles within Duhok's legacy. The machine learning categorization of the model is very accurate, highlighting its potential as a reliable analytical tool for identifying and classifying architectural styles in Duhok city and across Kurdistan Region.**

***Index Terms*—Architectural styles, Classification, Documentation, Heritage site, Machine learning.**

I. Introduction

Duhok, located in Iraq's Kurdistan Region is important historically and culturally, featuring many heritage sites in nearby hills and caves that show its long-standing role as a center of civilization in the area (Kurdistan Regional Government, 2020). In the early 20th century, Duhok's population grew a lot and its demographics changed extremely. By the late 1920s, there were about 400 housing units in the city center, including neighborhoods for Muslims, Christians, and Jews (Harori, 2001). These areas contain important heritage buildings that embody the city's cultural and national wealth, underscoring the need for their preservation and adaptive reuse in line with international standards to promote sustainable societal development.

Documentation is an essential component of architectural preservation, required for understanding historic buildings. It survives throughout the conservation process, providing accurate information that enhances the effective management and protection of cultural resources (Muhammad, 2013). Documenting heritage buildings helps us understand their history, such as social and economic context, building techniques, materials, and the broader historical and cultural periods they represent (Khalil, Stravoravdis and Backes, et al, 2020). This study aims to document the buildings of Duhok's city center to identify their architectural features, historical growth, and social context.

The proposed documentation framework analyses architecture within its temporal and cultural context, integrating the historical and esthetic values that characterize each era's conception of beauty. These documented features form the foundation for the identification and classification of buildings into specific architectural styles (Yoshimura, et al., 2018).

Artificial intelligence has demonstrated the ability of machines to learn and differentiate between many style categories with considerable accuracy (Elgammal, et al., 2018). There are several studies that ensure machine learning algorithms can autonomously analyze large datasets, create models, and predict trends by processing and learning from prior data, outperforming human learning capabilities (Sun, Xu and Wei, et al., 2022). For example, (Miao, et al., 2024) proposes an enhanced convolutional neural network (CNN) branches to classify and capture both global structure and local texture of traditional Chinese buildings, achieving 90% accuracy and employing Grad- Class Activation Mapping to validate feature emphasis on roofs, façades, and materials. While (Llamas, et al. 2017**)** creates and releases a dataset of 10,000 images of Architectural Heritage Elements and uses CNNs to automatically classify these elements, they find that CNNs can do high accuracy and faster convergence, which means that heritage elements can be classified automatically on a large scale instead of by hand. (Chen, et al., 2023) study's combines BIM and GIS to digitally document and

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†Corresponding author's e-mail: cebar.sadiq@uod.ac
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protect modern Chinese architectural heritage, building component "family" libraries, and 3D/2D models, which helps with long-term management of the lifecycle. Also, (Han, Hu and Xu, et al., 2025) look at how to use deep learning to find the formal features of vernacular architecture in Jiangsu Province. They are annotating features such as deep eaves, gables, and long windows. Their model analyzes and quantifies regional style differences with high accuracy rates. This shift from qualitative expert judgments to quantitative detection. (Xia, et al., 2020) created a framework based on data to classify and predict the homes' styles in Hangzhou. They identified eight style categories by extracting important morphological features from 372 new real estate projects, validated them through correspondence and discriminant analyses, and then built a neural network to predict style based on five main site variables. Their model achieved a prediction accuracy of 77.2%, illustrating that machine learning can objectively associate design conditions with style outcomes, thereby diminishing subjectivity and assisting planners in making more evidence-based decisions. Furthermore (Cantemir and Kandemir, 2024), study shows a CNN model trained on façade images of Gothic, Modern, and Deconstructivism styles. The model is 84.66% accurate in distinguishing styles and is used as a tool for conservation, restoration, and educational use. This work shows how CNNs can learn the "signature" of each period, which shows how deep learning could help both documents protected buildings and make design choices.

From the above studies, it became clear that deep and machine learning models are transforming the architectural field by enabling fast, accurate, and scalable classification of styles, elements, and design features; also, these models can extract patterns from vast, complex datasets and identify subtle regional or historical differences. This capability accelerates heritage conservation and design planning and supports evidence-based, sustainable decision-making across architecture and urban development.

The main objective of this study is to survey and analysis the heritage center of Duhok through documents and analysis of its history and culture. As part of this process, the study seeks machine learning to find and group different architectural styles in the study rejoin based on their special features of each style. The machine learning method does not have its own goal; instead, it works as a tool that helps and backs up human-led documentation by systematically classifying styles and providing extra verification.

II. Case Study

Dohuk is an important Iraqi city known for its rich historical and geographical characteristics. It has a history that spans from prehistoric times to the Ottoman era, including periods of hunter-gatherer communities transitioning to farming. This evolution led to the formation of large communities, which laid the foundation for modern urban centers (Sołtysiak, Wiercińska and Kozłowski, 2015).

The Dohuk City survey showed that Neolithic period mud brick dwellings constructed in circular form and half-submerged with a Bronze Age internal burial tradition were conspicuously present. Foremost among these, subfloor tomb interments prevailed during early periods across many settlements in which entire villages today lie beneath modern town centers. During later phases in some settlements, extramural cemeteries succeeded housing (Barbaro, 2019).

Dohuk City was under the rule of the Emirate of Bahdinan from 1470 to 1471, and its capital was Amadiyya. After the overthrow of this emirate by Ottoman forces in 1842, Duhok became affiliated under the Mosul Brigade. In 1850, it became one of Nineveh's districts, and later within these 23 years was promoted the center of a district affiliated with Mosul as well. It remained so until May 1969 when it became a governorate with jurisdiction over multiple districts and villages (Mohammed, 2010).

After 1990, due to its multiplicity of geographical locations, its functional and commercial importance increased in particular, and it became an important center for assembling and distributing goods within broad regional frameworks. This trend was strongly reflected in the structure of its commercial composition, and the features of change and complexity became more acute compared to previous periods (Harori, 2001) (Figs. 1 and 2).



Fig. 1. Map of Dohuk city dating back to 1923.

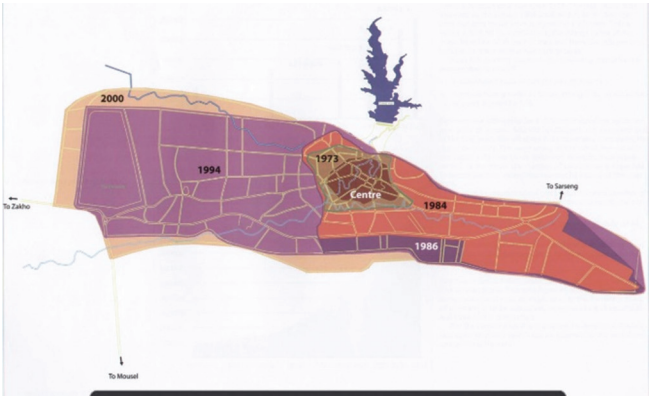


Fig. 2. Urban expansion of Dohuk city according to time periods.

Fig. 1 shows the formal and functional characteristics of the city, as it shows the clear integration and fusion of residential, commercial, service, and other uses of the land in an organic manner. The outskirts of the city are not more than 300 m away from its center. The proximity of the Great Mosque, church, city market, and the pattern of the streets and alleys, which are irregular, crooked and narrow, indicate the characteristics and composition of the Islamic city, While Fig. 2 illustrates the spatial expansion patterns of Duhok City over time, its show in the 1970s, the city experienced minimal changes in its urban form and population due to outward migration driven by political conditions. During the 1980s, it witnessed significant social, cultural, and urban development, leading to expansion in multiple directions, particularly toward the west and north. In the early 1990s, a substantial influx of migrants settled mainly in the western part of the city. After 2000, relative political stability encouraged rural-to-urban migration, resulting in continued expansion, especially toward the west and northwest. (Harori, 2001).

The city center of the Duhok (Research case study), now known as the Brayeti (Brother) neighborhood is a significant location in Duhok city (Fig. 3). This area retains remnants of Duhok's heritage-built fabric but is characterized by widespread decay, ruined buildings, and fragmentation due to commercial expansion. The construction of the Shoresh Bridge demolished parts of the heritage area and divided the remainder into two sections. Despite these challenges, city center still holds strategic value for heritage conservation and cultural tourism development (ARS Progetti Spa, 2014**).**

There is only one study about Duhok City Centre by Italian Cooperation/ARS Progetti Spa master planning project for Duhok City Center completed in 2014, which provided a comprehensive urban planning framework for the conservation, rehabilitation and revitalization of Duhok's heritage district through detailed land use zoning, building typologies based on external building characteristics and targeted intervention strategies. This survey study concluded that the city center is planned as a mixed-use zone with plot-specific allocations for housing, commerce, offices, tourism, cultural centers, and public facilities, while strictly limiting building heights and requiring traditional or compatible forms to protect the historic skyline and maintain continuity with the area's heritage patterns, also Existing buildings were classified as heritage, vernacular, derelict/ruin, modern, or contrast buildings, determining which interventions are allowed (Fig. 4).

Hence, the current study differs from the Italian study in its exploration and in-depth study of multiple aspects of documentation, including historical, cultural, and social aspects, based on historical evidence from scientific sources and interviews with historians, sociologists, and residents of the study rejoin. The current study also focused on the architectural aspect, focusing on documenting all building units in their various details using multiple documentation methodologies, unlike the SR study, which was a study at the urban planning level only. In addition, this study relies on machine learning to classify building styles in the study rejoin, clearly explaining the criteria for classifying these styles. It also presents the results of the machine learning, including accuracy scores, giving the study high reliability, a detail missing from the Italian study.

III. Materials and Methods

This research emphasizes the importance of surveying and documenting heritage Duhok city center to support the preservation of current heritage buildings and assess future development plans. The current study aims to apply a machine learning model to detect and categorize architectural styles in the study rejoin by identifying the formal elements and features that define each style category.

A. Methods used for Documentation

The identification and planning of suitable documentation procedures is a critical preliminary step influenced by various aspects, including:

Scale

Since most buildings in the study region are small, with each building's area not surpassing 200 square meters, the researcher employed traditional documentation methods for their document.

Complexity

The architectural design for the majority of buildings in the study rejoin is characterized by simplicity and minimalism, devoid of intricate embellishments and features. Consequently, conventional documentation approaches were utilized.

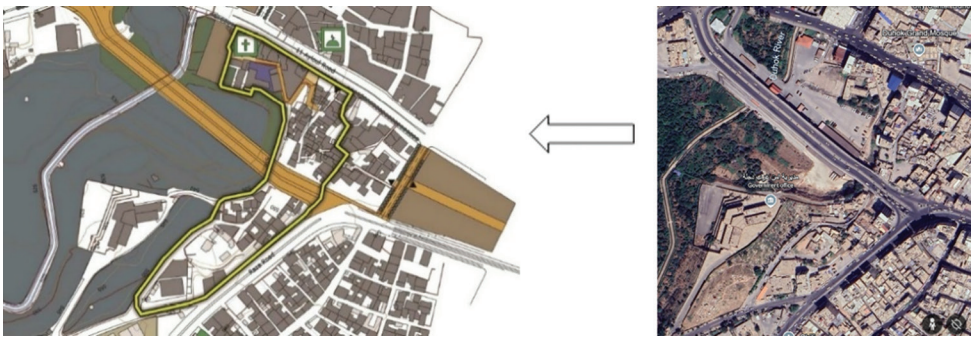


Fig. 3. Spatial boundaries of the study rejoin [researcher].

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Fig. 4. Classification of the buildings in the study rejoin according to the ARS Progetti Spa study [ARS Progetti Spa, 2014].

Accessibility

Unmanned aerial vehicle (UAV) technology was employed to survey the study rejoin, recording 2D and 3D photos, alongside a survey conducted using a total station, due to the site's topography and ruined heritage buildings.

Budget

In a contract with the Dohuk Governorate and Duhok Directorate of Antiquities and Heritage, cost-effective techniques were used to document a 46,000 m^2 site area that content 91 building units with a budget not exceeding $20,000. Consequently, the documentation necessitated the utilization of cost-effective documentation techniques, with emphasis on the accuracy of documentation.

Many investigation tools were used and combined to document and investigate the heritage buildings in the study rejoin which are:

- The heritage site was surveyed using a UAV device for high-precision data with global coordinates and topography (Figs. 5 and 6). The survey was supplemented by Total Station methods, and the collected data were processed and drafted in AutoCAD civil 3D (Fig. 7). The site was divided into seven zones (A-G), based on historical names, streets, alleyways, and neighborhood boundaries, with each zone further partitioned into plots (Fig. 8). Building entrances were marked, and accessibility for vehicles and pedestrians was mapped (Figs. 9 and 10).
- The manual survey technique was used to document each building, employing basic tools and a laser tape measure to record architectural elements (roofs, walls, doors, windows, arches, columns, etc.), civil details (structural system, building condition), and materials. The data was processed utilizing technologies like AutoCAD, 3DMax, Autodesk Sketchbook, and Adobe Photoshop. (Appendix Documentation of Zone A, Units A3 from Figs. A1-A7, and Tables I-III).
- Documentation process also covered social and historical aspects (Appendix Table I).

Archaeological and historical data

The current study brings together a multidisciplinary team of architects, civil engineers, surveyors, archaeologists, historians, and sociologists to produce a comprehensive and reliable documentation of Duhok City Center. This collaboration has allowed the project to go beyond just measurement or mapping: archaeologists show what events took place on the site during its history, cultural growth, and past uses; sociologists explore how residents and communities use with these buildings and public spaces; while architects and civil engineers ensure that



Fig. 5. UAV technique for survey site plan [researcher].

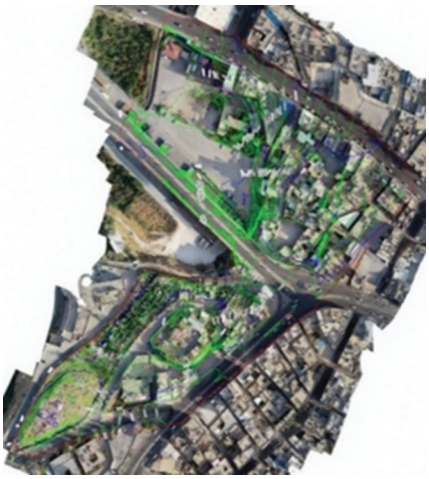


Fig. 6. Topography site plan [researcher].



Fig. 7. Total station site plan [researcher].



Fig. 8. The spatial boundaries of the study rejoin, showing its division into eight main Zones [researcher].



Fig. 9. Plots site plan with buildings entrances site plan [researcher].

material and structural conditions are accurately recorded. This multi-faceted approach not only the study shows physical form of each building, but also examines its historical growth, cultural significance, and social effects. This deeper understanding directly advances the development of accurate survey techniques and lays important strategies for future preservationist planning.

Cultural information

This study gathers data by recording the site's history and sociology, focusing on the building's residence and pertinent social, political, and cultural events.

Past drawings

Past drawings refer to architectural or urban plans, sketches, and measured drawings prepared during earlier documentation or planning campaigns. These provide geometric and spatial data about the original layout, dimensions, and architectural details of buildings before alteration or decay. Numerous 20th-century buildings in the Duhok City Center have been altered due to transitions from residential to commercial use and changing social, cultural, and economic factors. To monitor these changes, the researcher examined previously restricted drawings.



Fig. 10. Movements type's site plan (Streets, Pedestrians, Parking) [researcher].

Historic records and photographs

Historical records and photographs provide complementary written and visual evidence that illustrate how architecture of buildings has evolved over time. These sources include official records, property deeds, historical maps, census data, construction documents, and information about ownership and use. Together, they help trace the changes a building has undergone throughout different periods. Meanwhile, archival and modern photographs visually document changes in condition, materials, and stylistic features, revealing physical alterations and offering insight into the building's social and economic context. These sources work together to make a solid framework for looking at both the documentary and physical changes to heritage buildings (Khalil, Stravoravdis, and Backes, 2020). The Duhok Governorate directorate, including Municipality, Antiquities and Heritage, and Real Estate Registry Directorates, collected a lot of information to make it easier to document at different levels.

Oral histories

Oral histories from residents, especially older generations, provide valuable insights into buildings' community roles and socioeconomic transformations. In this study, sociologists and historians collected extensive information through interviews with experts and former residents.

- Structured information form was created for each building, covering details about the building's owner, construction, and the documenter. The documenting engineer completed

it with assistance from a historian, archaeologist, and sociologist (Appendix Table III).

- On finalizing the documentation process, the research endeavored to categories the buildings within the study rejoin based on:

Architectural styles

The study identified four main architectural styles in the rejoin: Modern, postmodern, vernacular, and Islamic, along with a hybrid style combining elements from these categories (Fig. 11).

Land use

The architectural survey of Dohuk's historic city center showed that most buildings are residential, followed by commercial use, with some plots serving dual governmental or religious functions or remaining undeveloped (Fig. 12).

Building's height

The documentation of Dohuk's city center shows that most buildings are two-story residential buildings, followed by single-story units. Three-story buildings, both residential and commercial, are less common, while commercial buildings with four or more stories account for just over 12% (Fig. 13).

Building's condition

The architectural documentation of Dohuk's city center revealed that most buildings are in moderate condition, with a significant portion in bad condition and newly built commercial buildings in good condition (Fig. 14).

Building's entity

The documentation of the ancient Duhok city center showed that most buildings are occupied, while 37.70% of the unoccupied buildings are in poor structural condition (Fig. 15).

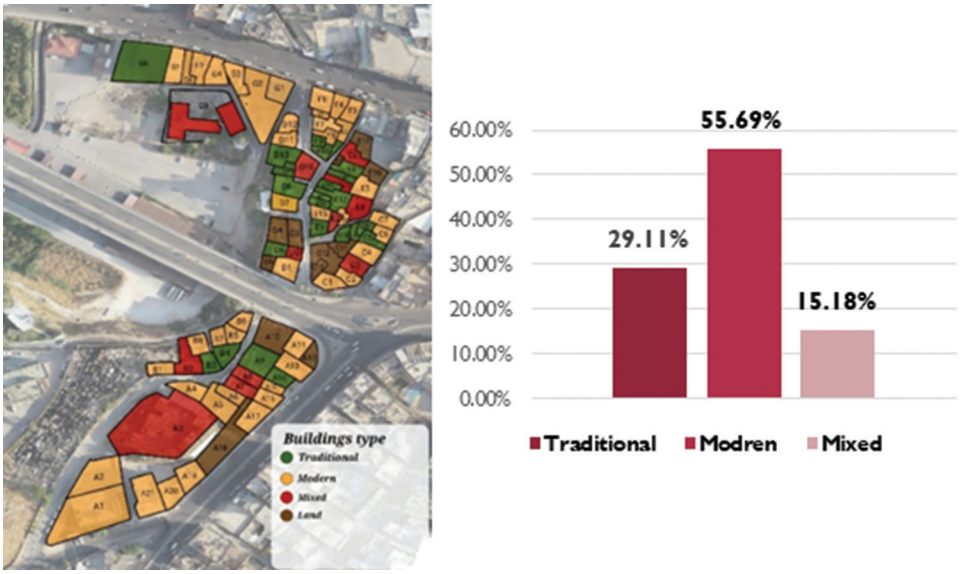


Fig. 11. Buildings styles, classification of building percentage according to architectural style [researcher].

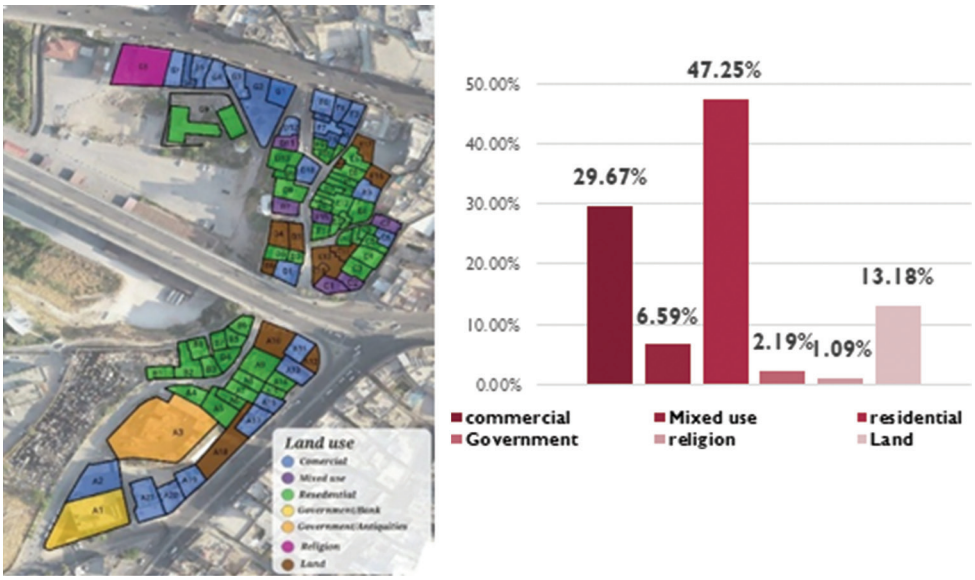


Fig. 12. Land use, Classification of building percentage according to land use [researcher].

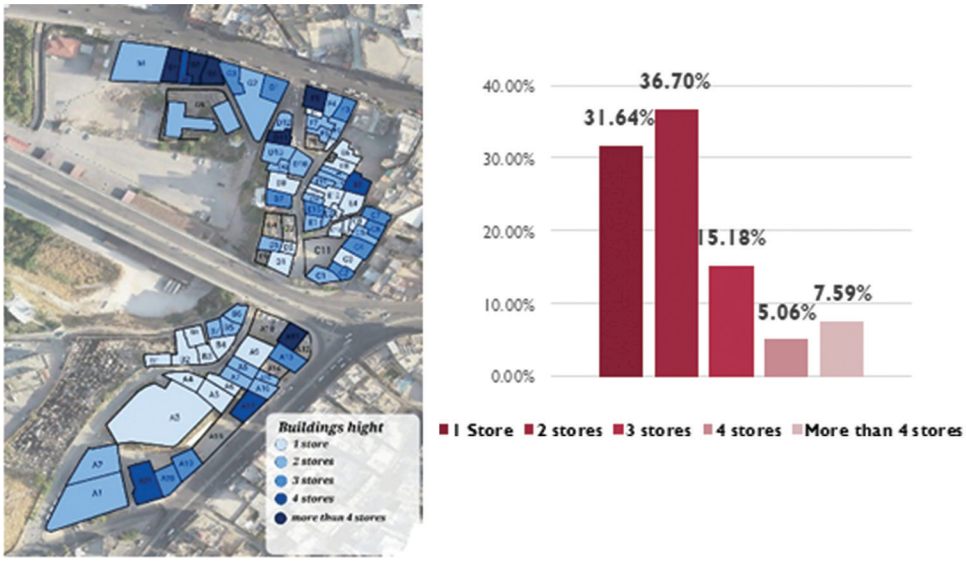


Fig. 13. Building heights, classification of building percentage according to building heights [researcher].

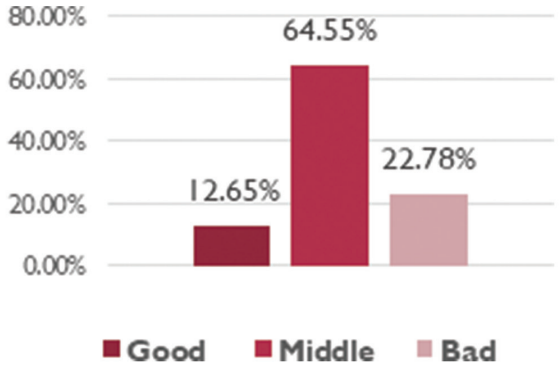


Fig. 14. Classification of building percentage according to buildings' condition [researcher].

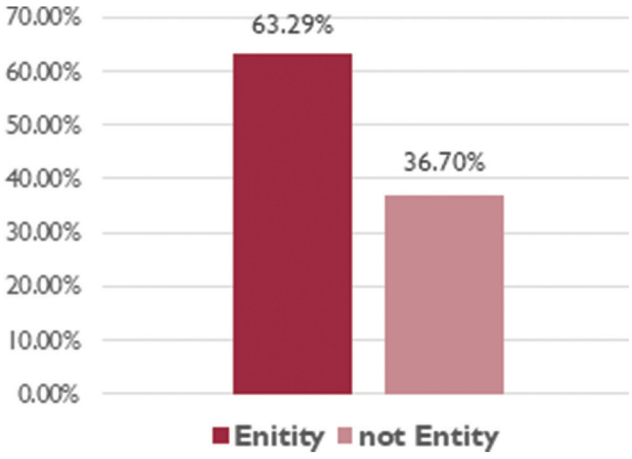


Fig. 15. Classification of building percentage according to buildings' entity [researcher].

Building's owner

Architectural documentation in Dohuk's city center reveals that most residents are renters without property ownership, with a significant percentage of derelict, traditional-style buildings in disrepair (Fig. 16).

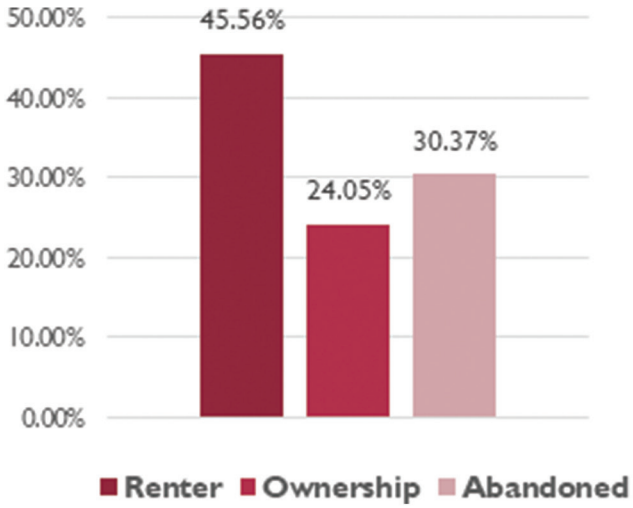


Fig. 16. Classification of building percentage according to buildings' owner [researcher].

- 6) A specialized library was created to catalogue and classify the architectural elements of buildings within the study rejoin, aiming to understand evaluations of the city's architectural heritage. This classification supports future restoration efforts and serves educational purposes.

Roof

The architectural record reveals that modern buildings use reinforced concrete roofs, while heritage buildings feature three types of roofing: (1) Iron Shillman with clay and possibly straw reinforcement, (2) Wooden roofs made of oak-based, palm, or reed mat, and (3) Vaulted and domed roofs of various forms (Appendix Table V).

Doors and windows

The architectural documentation of the Dohuk city center indicates that modern doors and windows are constructed from plastic, aluminum, iron, or wood, whereas the older ones are made of wood or iron and have wooden frames that generally

measure 10 cm in width, while certain variants feature an external stone frame (Appendix Tables VI and VII).

Arches

Arches were employed in heritage buildings, situated above doors, windows, partitions, or walls, and exhibited many kinds. Various types of arches were employed, including round, pointed, segmental, and others (Appendix Table VIII).

Materials

Heritage buildings in the Dohuk city center utilized natural stone, limestone, and mud blocks for walls and roofs, along with iron and wood for doors and windows. Conventional packaging materials such as white soil and (kasl), occasionally augmented with limestone fragments or straw, were employed in facade construction to improve durability.

A. GIS Website

A GIS website was created for the study rejoin, integrating essential documentation details of the heritage site to support the architectural restoration phase (Appendix Fig. A8).

Fig. 17 illustrates the categorizing of the documentation data and methodologies employed in the present study.

B. Methods Used for Classification through Machine Learning

From the literature review, researcher conclude that machine learning and deep learning have emerged as transformative tools in architecture, enabling researchers to automate classification tasks, and integrate predictive analytics into design and conservation workflows. These techniques show how AI reduces subjectivity, enhances precision, and creates scalable methods for architectural research and practice.

Google AutoML vision implementation

The study employs Google Cloud AutoML Vision to develop an image-based architectural classification model that automates search and hyperparameter optimization while improving performance with the Efficient Neural Architecture Search (ENAS) algorithm (Pham, et al., 2018, Zoph and Le, 2016). This study uses reinforcement learning to optimize CNN architectures. The AutoML Vision optimization aimed to enhance binary classification accuracy, utilizing Google's n1-standard-8 virtual machines and an NVIDIA Tesla V100 GPU to expedite the training process (Google. (n.d.), 2025). The dataset was split into training (70%), validation (15%), and testing (15%). The training process took approximately 4.5 node hours. This method is inspired by recent studies emphasizing the efficiency of AutoML in simplifying machine learning tasks (Fritz, 2023).

Transfer learning implementation

A transfer learning has been used in this paper to enhance training efficiency for the classification by using a ResNet-50 CNN pretrained on the ImageNet dataset (He, et al., 2016; Deng, et al., 2009). ResNet-50 is a deep neural network optimization model which decreases the vanishing gradient problem using skipped connections and residual learning (Tan, Zhu, and Chen, et al., 2023). This application is widely used because of its equilibrium between performance and model dimensions. The pre-trained and fine-tuned network was then evaluated against the AutoML model to determine the impact of AutoML relative to transfer learning (Srivastava, et al., 2014). The model's last fully connected layer is replaced with a new fully connected layer, including several units equal to the number of classes (n = 4). The network is subsequently optimized using a cross-entropy loss function and the Adam optimizer, with a batch size of 32 and a learning rate of 0.001 (He, et al., 2015; Nair and Hinton, 2010).

CNN architecture (used as the baseline)

Semiclassical CNN algorithms, like ResNet, VGG, and DenseNet, are usual in image classification (Tan, et al., 2023), which is used as a unique CNN as a benchmark against AutoML. The model employs the Efficient Neural Architecture Search (ENAS) algorithm (Pham, et al., 2018; Zoph and Le, 2016) alongside reinforcement learning to identify optimal CNN architectures. The researcher trains the controller network using the "edge" model configuration, aiming to optimize binary classification accuracy. Furthermore, a Google's n1-standard-8 virtual machines, equipped with 8 CPU cores and an NVIDIA Tesla V100 GPU is used for training. As well, the dataset is divided into training, validation, and testing subsets, requiring around 4.5 node hours (Google, 2024).

Neural architecture search (NAS) within AutoML vision

The application NAS in AutoML Vision is a tool for optimizing hyperparameters in deep learning architectures with accurate model configuration for classification purposes (Pham, et al. 2018; Zoph and Le, 2016). The search algorithm commonly employs versions of the Mobile Net architecture (Tan, et al., 2019). This approach possesses potential benefits in image classification.

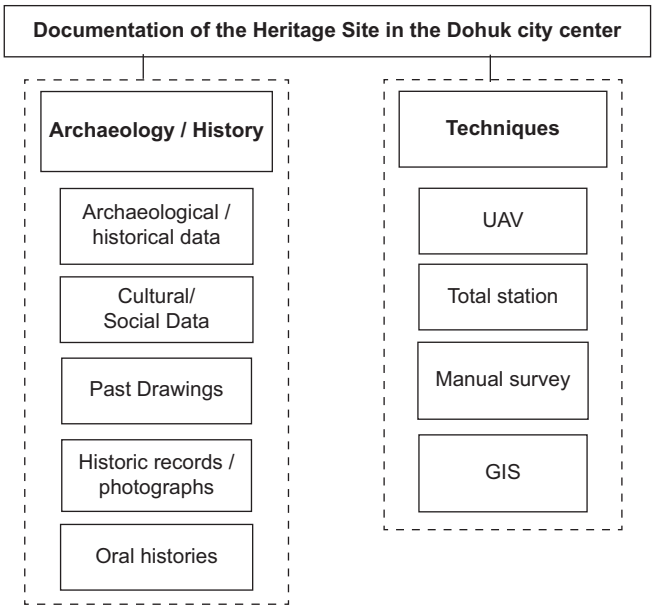


Fig. 17. Proposed categorization of the documentation data and tools that capture for buildings in the Duhok City Center Site [researcher]

Addressing data scarcity

Due to limited training data for the purpose of classification, a ResNet pre-trained model within a CNN framework was initially used; even it produced unsatisfactory results due to limited training data, the AutoML approach demonstrated significant efficacy and yielded positive results.

The experimental model was developed through data augmentation, storage, and configuration, uploading augmented images to a Google Cloud Storage bucket. Training data according to AutoML Vision's default were divided into (70% for training), (15% for validation), and (15% for testing) with customized configurations for performance enhancements (Fig. 18).

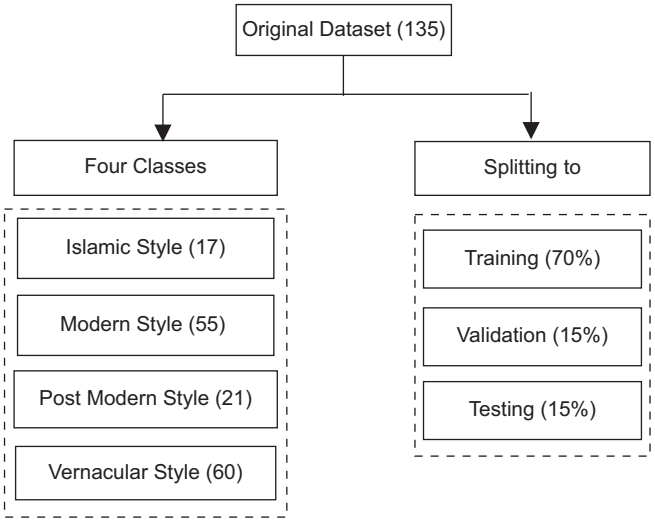


Fig. 18. Splitting the dataset for building and testing an AutoML model [researcher].

The thorough documentation of Duhok's city center, encompassing its architectural, cultural, and historical aspects, serves as the basis for the subsequent phase of analysis. Based on these findings, the study employs machine learning techniques not as an isolated practice, but as a supplementary tool that enhances and corroborates the outcomes of human documentation and classification. By doing this, the research links traditional heritage analysis with new technology, ensuring a continuous and integrated methodological flow from documentation to classification.

IV. Results and Discussion

A. Results Related to the Documentation

The classification of architectural styles in Duhok's heritage city center combines comprehensive field surveys, historical records, and previous studies. The researcher recorded each building's age, form, materials, and social context, and then cross-checked these findings with archival maps and oral histories. By integrating these datasets, the researcher could clearly define the characteristics of each style (Islamic, vernacular, postmodern, and modern) based on measurable criteria such as age of the building, typology, construction techniques, roof and wall types, and façade articulation.

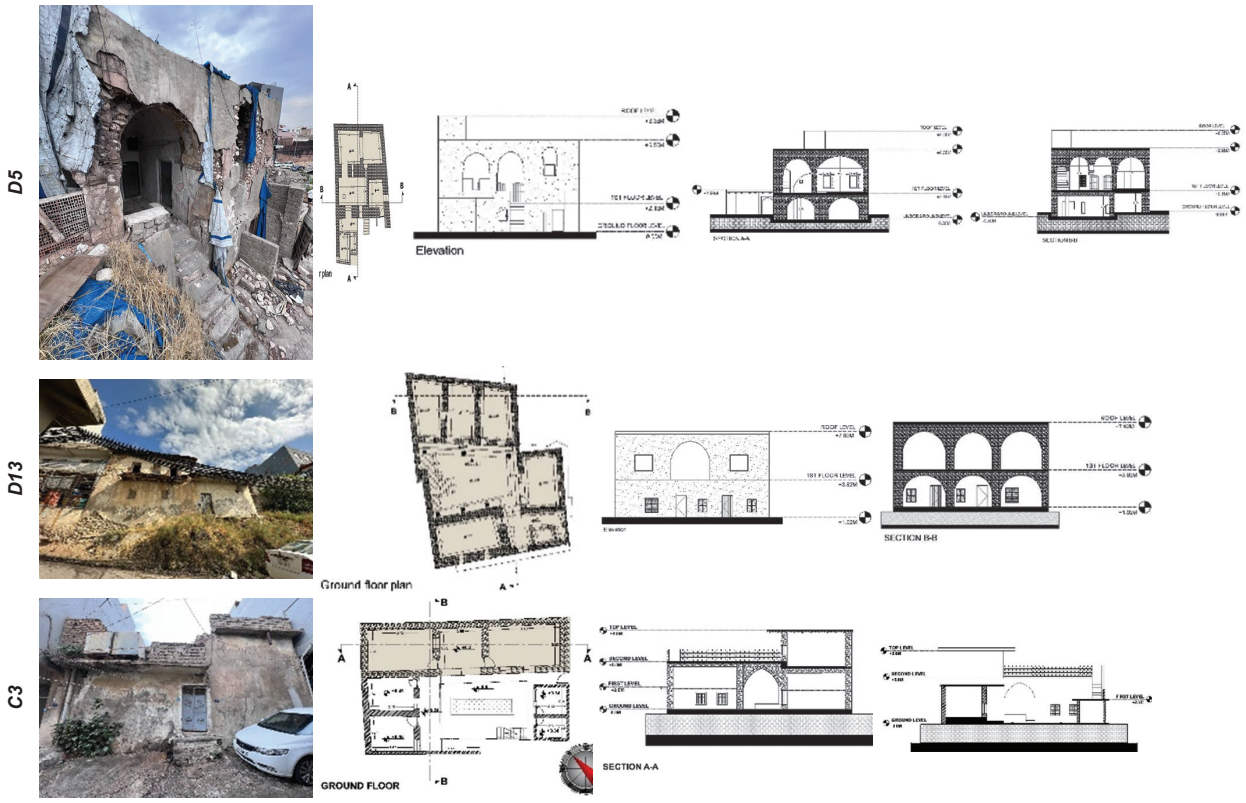


Fig. 19. Some Examples about Islamic architectural style in the study rejoin [researcher].

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Islamic architecture style

Islamic buildings in the study rejoin, dating back over a century, reflect the social status of their owners, with larger homes indicating wealth these buildings are outwardly orientated, devoid of internal courtyards, and exhibit facades with several openings. In general, two floors high, occasionally featuring a basement. Roofs are frequently vaulted or domed, constructed from stone and lime, while strong stone walls – exceeding one meter in width – offer thermal insulation and privacy (Fig. 19).

Vernacular architectural style

This category includes buildings over sixty years old, reflects the construction traditions rooted in the rejoin as well as the rural way of life at that time, rather than any formal or Ottoman stylistic influence. These dwellings emerged through spontaneous craftsmanship, locally available materials such

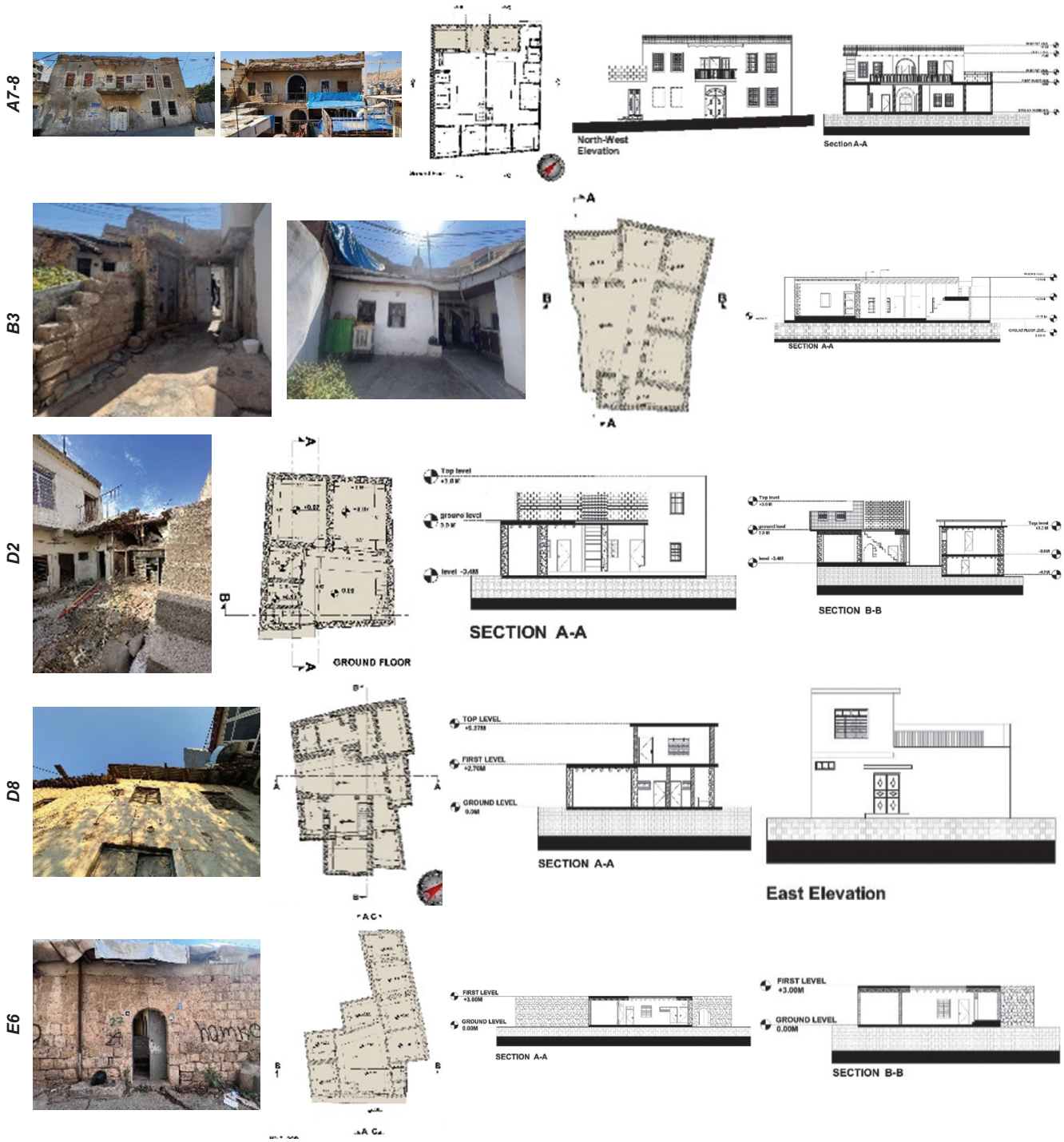


Fig. 20. Some examples of vernacular architectural style in the study rejoin [researcher].

as stone, mudbrick, and lime were used to respond directly to climatic, social, and economic needs. Furthermore, this style is distinguished by the presence of internal courtyards surrounded by multifunctional spaces. The façades are modest, with few external and small windows, while multiple openings face the courtyard to regulate light and airflow. Their thick walls and limited height (typically one to two stories) provided thermal comfort and structural stability (Fig. 20).

Postmodern architectural style

This style appears in some buildings in the study rejoin from the 1970s to the early 1990s, making a shift from simply functional modernism to designs that integrate diverse, heritage, and symbolic elements, often in response to Duhok's regional social, political, and cultural context. This style was represented in residential, commercial, and government buildings, blending traditional esthetics with modern designs. These buildings often feature reinforced concrete, ceramic tiles, and metal panels, with the flat roof type, walls thickness ranging from 20 to 30 cm for structural stability and thermal insulation. Postmodernism buildings are known for outward orientation, having many openings on the facade, and using geometric patterns and designs inspired by local shape and materials to express cultural meaning (Fig. 21).

Modern architectural style

The modern Duhok architectural style was born in the 1970s, when urban development began to expand following western design principles. This period started a new phase of architectural style, characterized by simple forms, functional layouts, and the employment of modern construction materials like reinforced concrete. Most modern buildings in the study rejoin serve a residential purpose, with adding new functions such as bathrooms, kitchens, and sanitary facilities to reflect the changes in social life at that time. The facades are usually oriented outwards and feature simple geometric forms, including rectangular openings; they are rarely decorated. Flat reinforced concrete roofs became standard, replacing traditional vaulted or domed forms, and walls ranging from 15 to 20 cm in thickness were commonly built with concrete blocks for structural efficiency (Fig. 22).

Firthermore, Fig. 23 shows distinguishing characteristics of each architectural style.

B. Results Related to the Classification by Machine Learning

The model evaluation shows great results in the precision-recall curve and threshold analysis, with an average precision score of 0.998, which means it is very accurate at various



Fig. 21. Some examples about postmodern Architectural Style in the study rejoin [researcher].



Fig. 22. Some examples about modern architectural style in the study rejoin [researcher].

Characteristics	Architectural Style			
	Islamic	Vernacular	Post Modern	Modern
Construction period	More than 100 years	More than 60 years	1970–1990	1970s-present
Typology	Outward orientation Inward orientation	Inward orientation	Outward orientation	Outward orientation
No. of floors	2–3 Floors	1–2 Floors	More than 4 Floors	2–10 Floors
Roof type	Vaults, Domes	Wooden, Arches	Reinforced concrete slabs	Reinforced concrete slabs
Roof materials	Natural stone or Mud brick+Lime	Wood (Karita+Mat) Arches (I-beam iron+Mudbrick+Gypsum)	Concrete	Concrete
Wall width	1m or exceed it	0.70 M	0.20–0.40 M	0.15–0.20 M
Wall materials	Natural Stone, Mud Brick	Natural Stone, Mud Brick	Block	Block

Fig. 23. Characteristics of Architectural Styles [researcher].

recall levels. The model has a low false positive rate and a remarkable balance between precision and recall at 95.7%, meaning the researcher can trust its predictions a lot (Fig. 24). The allocation of images across training, validation, and test sets indicates a systematic evaluation system, with 70% of the data designated for training and validation and the test sets reserved for impartial assessment (Fig. 25).

The confusion matrix demonstrates exceptional classification capability for vernacular style, modern style, and post-modern architectural styles. While the classification

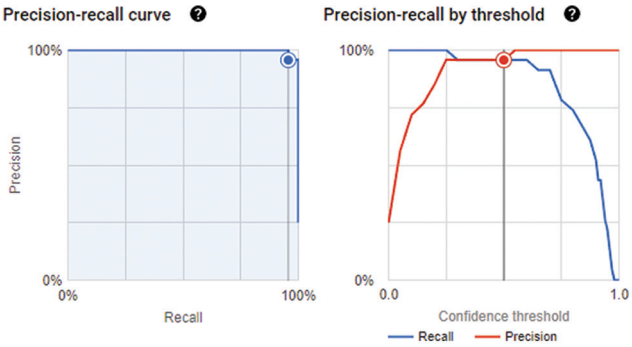


Fig. 24. AutoML model evaluation [researcher].

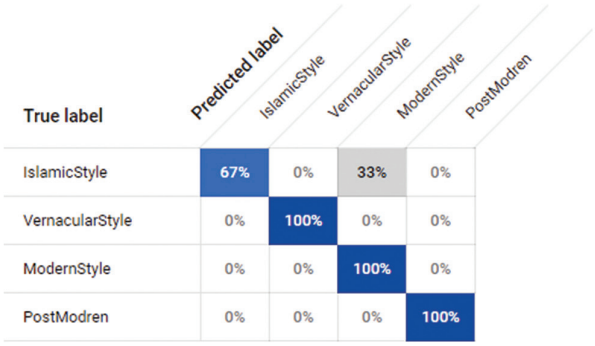


Fig. 25. AutoML confusion matrix [researcher].

capability was 67% for the Islamic style, highlighting the need for further investigation into the circumstances that led to this misclassification. This misclassification is because of the existence of modern elements within the Islamic style, which could be attributed to inadequate restoration and preservation.

V. Conclusion

A. Conclusion Related to the Architectural Styles

- The Islamic architectural style in the study region emphasizes functionality and harmony with the local environment and culture by utilize local materials, combined with traditional construction techniques, to fulfill practical and environmental requirements. The minimalist design, medium heights, and little ornamentation embody standards of modesty and cultural norms, while robust walls, vaulted and domed roofs, and strategically positioned windows reflect climatic conditions. Islamic architectural style integrates esthetic and functional components, preserving the architectural character of the region.
- The architectural formations of the vernacular style were defined by simplicity and appropriateness to local conditions, community's adaptation to local resources, environment, and cultural values, utilizing local materials and traditional construction methods, thereby ensuring that the elements maintained their structural, functional, climatic roles, facilitated privacy, ventilation, and family interaction. Furthermore, this style is defined by the principles of reduction and brevity in facade features, including ornamentation and other elements.
- The influence of the international style on the postmodern buildings' is apparent through its effect on the elements, principles, and rules of form, marked by a shift in scale with the rise of multi-story buildings during this period, as well as new construction systems, finishes, and modern materials. Concurrently, there was a superficial manifestation of heritage through the use of terminology that conveyed formal regional references, particularly in the outer shell represented by the facades. The approach to this vocabulary varied, encompassing modification, simplification, abstraction, and other treatments, resulting in contemporary forms and shapes.
- The modern style in Duhok emerged in the 1970s. Urban growth and western influence are dual causes for this style, which has been defined by its functional simplicity and lack of ornamentation. It prioritizes functionality, showcasing the building's purpose through a machine esthetic. Over time, the traditional pitched roof was replaced by a flat concrete slab, and the walls were rebuilt, local materials began to run out due to a shortage of skilled craftsmen, or perhaps an assessment that western models represented modernization and progress.

B. Conclusion Related to the Classification by Machine Learning

The machine learning model developed provides a method for categorizing buildings within the study rejoin as well as a framework applicable across the city. The study offers a practical tool for the systematic identification of architectural styles. This way up not only can deepen people's understanding of Duhok cultural and historical built heritage to promote it, but it also stresses that urgent action is needed to prevent any deterioration. In future conservation strategies, both scientific analysis and cultural guardianship must be taken into account.

C. General Conclusion

In this study, the integration and improvement of traditional documentation with advanced machine learning techniques is achieved to better analyze and classify Duhok's architectural styles. This research brings human expertise and technological innovation together by combining historical records, archives of culture, and documentation building styles into an automatic style recognition system. While this combination of the two has been successful in realizing heritage styles differentiation methods that are both complete (in the sense of covering all necessary factors) and obtainable for others to use.

VI. Acknowledgments

The author would like to thank Duhok Governorate and Duhok Directorate of Antiquities and Heritage for funding the site documentation process.

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Author Queries???
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Appendix

Documentation of Zone A

Zone A, previously called an Islamic neighborhood, is now contains residential and commercial units. It is bordered by (Brother Street) to the east and (Zimar Alleyway) to the west. The sector comprises 21 units, each have varying architectural styles (Heritage, Modern, and Hybrid) and unbuilt land. Figure A1 illustrates the numbered area based on access, from A1, to A21.



Fig. A1. Dividing the Zone A into 21 Units, [researcher].



Fig. A2. Old photo of the Cumberland Palace.



Fig. A3. Roger Craig Cumberland.

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Fig. A4. Recent pictures of the interior and exterior facades of building A3, [researcher].

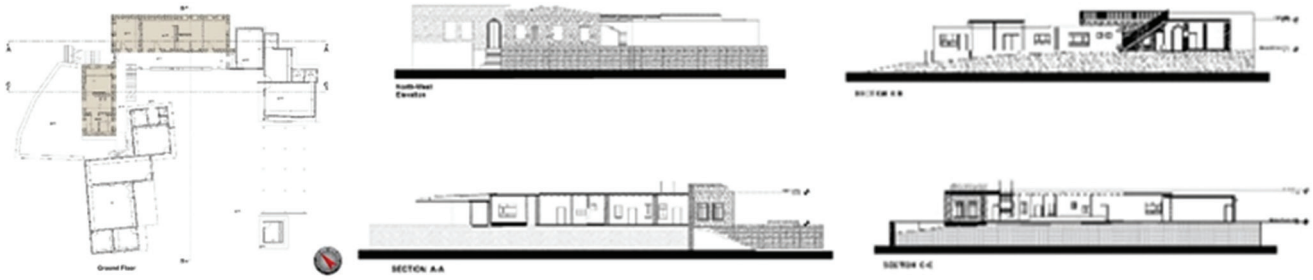


Fig. A5. Plan, sections, elevation of unit A3, [researcher].

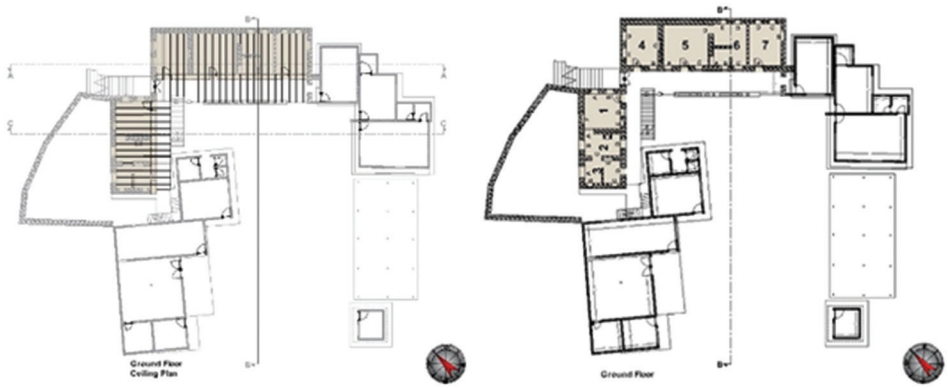


Fig. A6. Roof plan, details plan of unit A3, [researcher].

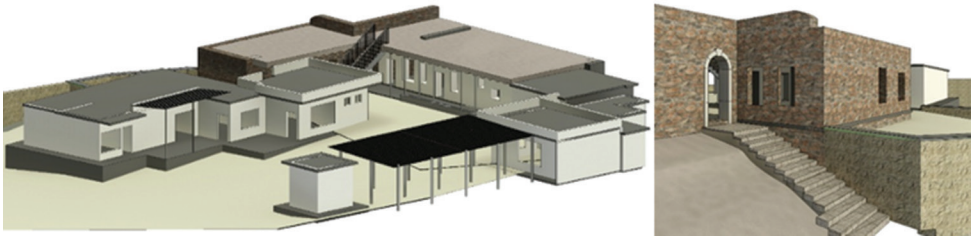


Fig. A7. Perspective of unit A3 [researcher].

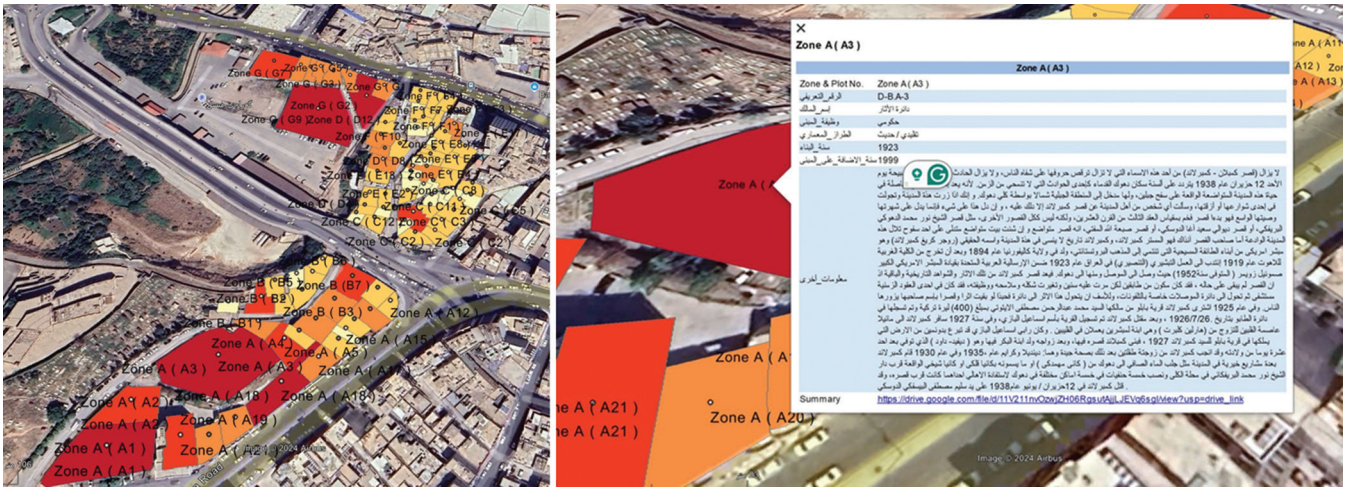


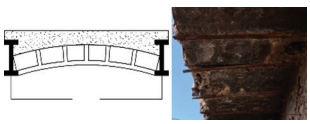
Fig. A8. GIS survey for the study rejoin [researcher].

TABLE I
HISTORICAL, SOCIAL INFORMATION RELATED TO UNIT A3 [RESEARCHER]

Antiquities Directory	Owner's name	D-B, A-3	ID
Traditional/Modern	Architectural style	Governmental	Building function
1999	Year of addition to the building	1927	Construction year

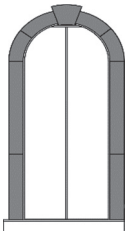
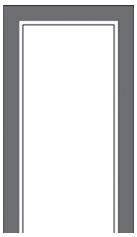
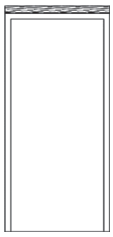
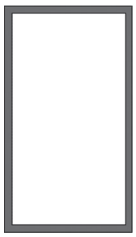
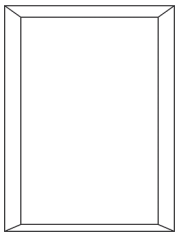
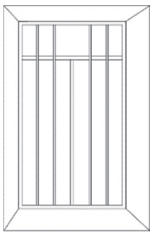
(Cumberland Palace), located in Dohuk, is a significant event in the city's history. The palace, initially a sumptuous 1910s palace. The owner at the time was a Presbyterian missionary from the United States named (Roger Craig Cumberland). he was born in California in 1894, completed his studies at the Western College of Theology in 1919, and worked for the United Arab Mission under (Samuel Zwemer). He visited Mosul and Dohuk, where he left a lasting impression. The palace clears a reminder of both the significance of historical sites and the city's rich past. In 1927, Cumberland married (Harleen Gilbert in Manila, Philippines, and subsequently constructed his palace in Dohuk, and he initiated humanitarian endeavors in 1930, including the provision of clean water in Dohuk via (Kani Mahmudki) and the installation of five taps for the residents. (Salim Mustafa Al-Duski) fatally shot (Cumberland) in 1938. The Cumberland Palace, a heritage monument, has experienced considerable transformations over time, functioning as both a hospital and a telephone directory, and currently Antiquities Directory

TABLE II
BUILDING MATERIALS RELATED TO UNIT A3 [RESEARCHER]

Elements	Type name	Description	Photo
Walls	Bearing wall	Materials: • Natural stone, mudbrick, clay • Limestone • Mudbrick (0.10×0.20×0.40) M	
Roof	Arched (Alakada)	Materials: • I beam iron • Mudbrick • Gypsum	

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TABLE III
BUILDING DETAILS RELATED TO UNIT A3 [RESEARCHER]

Type name	Type shape	No	Dimensions	Description	Photo
			Doors		
Traditional segmental arch entrance door		1	2.20×1.18 M	• Limestone outside frame • Limestone casing • Iron door	
Traditional wood door		6	2.10×0.97 M	• Wood casing • Wood door	
Traditional flat wood door		4	1.79×0.71 M 2.07×1.05 M	• Wood casing • Wood door	
			Windows		
Traditional flat window		3	1.52×0.86 M 1.67×1.12 M 1.27×1.22 M	• Limestone outside frame • Wood casing	
Traditional flat window		5	0.98×0.73 M 0.90×0.78 M 0.85×0.75 M	• Iron casing • Iron frame	
Traditional flat window		3	2.0×1.29 M	• Iron casing • Iron frame	

(*Contd...*)

TABLE III
(*Continued*)

Type name	Type shape	No	Dimensions	Description	Photo
			Doors		
			Wall cavities		
Traditional flat cavity		4	1.67×0.90 M 1.61×0.63 M 1.43×0.65 M 1.87×1.20 M 1.65×1.05 M 1.62×1.13 M	• Material: Stone and clay	
			Details		
Traditional fire place		1	1.21×0.88 M TH=0.52 M		

TABLE IV
Information Form (Ownership Data) related to Unit A3 [Researcher].

Antiquities authority					Neighborhood		ID		
	Haven't	●	Have		Zimar Alleyway		D-B-A-3		
Bond number		Coordinates UTM			Building number		Building name		Building information
464/14		321,327.52E, 4,081,161.08N Zone 38N			246/1/12		Cumberland Palace		
Building condition					Current building function		Original building function		
●	Bad	Middle		Good	Government		Residential		
Importance of the building					Accessibility				
	No	Little	●	Big		Impossible	●	Possible	
Construction date									
	Renewal	1999	Rebuilding	2007	Maintenance	2023	Construction		
Owner's name					Building entity				
●	Governmental		Civilian			Uninhabited	●	Inhabited	Owner information
Possibility of ownership					Accommodation owner				
	Impossible	●	Possible		●	Ownership		Renter	
Dimensions					Number of floors		Structural system		
Area (m)	Height (m)	Width (m)	Length (m)		One floor		Bearing Walls		Architectural and structural information
470	7.25	36.25	36.6						
Construction materials									
Clay/Cement			Floors		Natural Stone, Limestone/Block			Walls	
Concrete/Tile			Finishing		I beam+Stone and Clay+Soil/Concrete			Roofs	
Important details									
	Columns	●	Vaults	●	Arches			Balconies	
Fire Place			Others		Floral ornaments			Geometric ornaments	
Report date			Documentation date		Person responsible for documentation				Documenter information
September 20, 2023			September 20, 2023		Cebar jamel				
General notes									
Heritage style+Modern style									

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TABLE V
TYPES OF ROOFS FOR HERITAGE BUILDINGS IN THE STUDY REJOIN

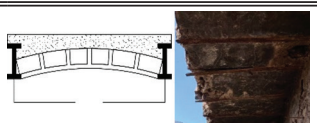
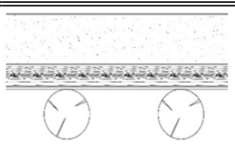
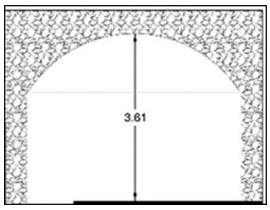
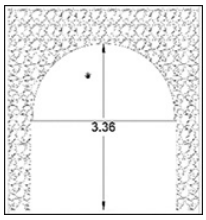
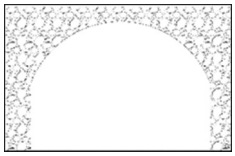
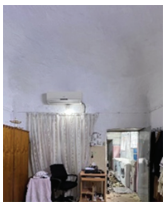
			
Arched (Alakada)		Wooden roof	
			
Hemispherical dome		Segmental dome	
			
Semicircular vault		Pointed vault	
			
		Segmental vault	

TABLE VI
TYPES OF DOORS FOR HERITAGE BUILDINGS IN THE STUDY REJOIN [RESEARCHER]



(*Contd...*)

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TABLE VI
(*Continued*)

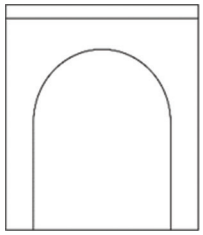
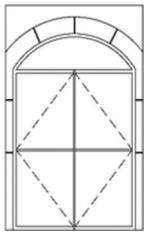
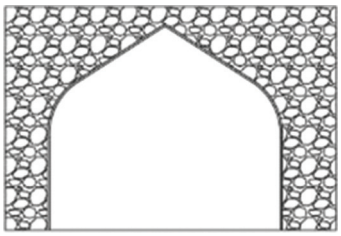
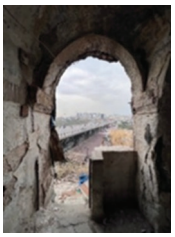
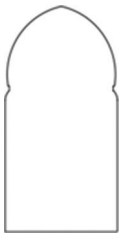
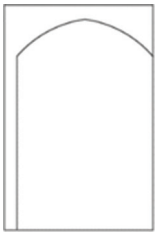
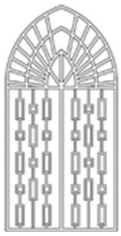


TABLE VII
TYPES OF WINDOWS FOR HERITAGE BUILDINGS IN THE STUDY REJOIN [RESEARCHER]



 http://dx.doi.org/10.14500/aro.12227

TABLE VIII
TYPES OF ARCHES FOR HERITAGE BUILDINGS IN THE STUDY REJOIN, [RESEARCHER]

			
Segmental arch		Round arch	
			
Pointed arch		Ogee three centered arch	
			
Traditional foil arch		Pointed segmental arch	
			
Three-pointed arch		Triangular arch	
			
		Half round arch	