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Application of Knowledge Graph Construction in the Study of the Inheritance of Ancient Chinese Ceramic Craftsmanship

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ABSTRACT The preservation and inheritance of ancient ceramic craftsmanship require effective methods for integrating fragmented historical records and heterogeneous cultural resources. This study proposes a knowledge-graph-based information modeling framework for representing and analyzing ceramic craftsmanship inheritance. Multi-source historical documents, museum databases, and artifact records are processed through named entity recognition, relation extraction, and ontology modeling techniques to construct a domain-specific knowledge graph. A semantic representation model describing relationships among kilns, artisans, techniques, and artifacts is developed and implemented in a graph database environment. Experimental analysis demonstrates high relation-extraction accuracy and effective reconstruction of technological inheritance pathways across multiple historical periods. The framework supports intelligent knowledge organization and retrieval.

INDEX TERMS knowledge graph, knowledge representation, semantic modeling, information retrieval, graph databases

I. INTRODUCTION

THE art of Chinese ceramic and the evolution of industrial heritage have progressed in tandem over thousands of years, collectively forging original technical schemes and profound cultural overtones. This long-term development integrates the structural aesthetics of ceramic craftsmanship with the systematic excellence of material morphology and production patterns to define the historical continuity of Chinese industrial manufacturing. The country is covered with kilns and generations of artisans have inherited skills and managed to produce various types of arts like the celadon, white porcelain and blue and white porcelain. Nonetheless, the existing study of the ceramic artisanship inheritance suffers grave setbacks: historical records are diffused over different vessels like ancient books, museum records and archeological reports and not integrated systematically, the spread of skills has been broken by wars and dynastical shift and there is deficiency of systematic correlation analysis of cross era technological transformation like migration of kilns and refinement of glaze recipes. These issues limit in depth studies on the history of ceramics, as well as inhibit proper preservation and sharing of intangible cultural heritage [1-2]. Lack of technical resources to unite the scattered knowledge, to construct a traceable chain of skills transmission, and expose the principles of technological evolution concealed behind historical documents are urgently required in the academic community. Knowledge graphs, as a semantic network technology, express domain knowledge through the triple structure of entity-relation-entity, and have been successfully applied in fields such as medicine and finance. Introducing knowledge graphs into ceramic technology research can transform scattered literature into a structured knowledge base and use graph computing technology to mine implicit relationships. This paper constructs a dedicated knowledge graph for ancient Chinese ceramic technology, uses named entity recognition technology to extract key entities such as kiln sites, craftsmen, and techniques, establishes semantic relationships such as apprenticeship and skill improvement through relation extraction algorithms, designs an ontology model to define the domain concept hierarchy, and develops a visualization system to support lineage query and path reasoning [3-4]. The research goal is to integrate fragmented historical data and restore the evolution trajectory of industrial heritage skills by bridging the semantic gap between geometric material morphology and technical manufacturing lineages. By providing intelligent retrieval tools and a digital twin framework, this work establishes a systematic path for academic research and the digital preservation of industrial excellence within the sector.

II. RELATED WORK

Research on the inheritance of ceramic craftsmanship has long relied on textual research and field investigation methods. It involves interpreting ancient books to trace the rise and fall of kilns and analyzing the technical characteristics of kiln remains and artifacts from archaeological excavations. Historical research usually uses a chronological approach to record the distribution and technological evolution of kiln systems in various dynasties, but paper media cannot show the complex inheritance network relationships. The digitization of museum collections has provided a data foundation for ceramic research. Many cultural and museum institutions have established artifact image databases and cultural relic cataloging systems. However, these platforms lack semantic association capabilities and cannot support cross-collection technique tracing and inheritance path analysis [5-6]. Knowledge graph technology has opened up new paths for the digitization of cultural heritage. Although general knowledge bases contain some ceramic entities, their domain coverage is not deep enough. The knowledge graph of mural art uses ontology modeling to express image content and historical background, and the knowledge graph of ancient medical books uses named entity recognition to extract the relationship between prescriptions and symptoms, proving that this technology is suitable for processing unstructured text in the field of historical culture. In terms of relation extraction technology, early methods based on pattern matching relied on manual rules and were difficult to cope with the grammatical flexibility of ancient Chinese. The emergence of pre-trained language models has significantly improved entity recognition accuracy, and sequence labeling architectures have demonstrated excellent performance in tasks such as classical Chinese word segmentation and entity boundary recognition. Relational classification models capture long-distance dependencies through attention mechanisms, making them suitable for handling complex sentences containing multiple entities. Existing research lacks specific knowledge graph construction schemes for ceramic craftsmanship and has not fully considered the spatiotemporal characteristics of kiln system inheritance and the continuity of technique evolution.

III. METHODS

A. DATA ACQUISITION AND PREPROCESSING

In this research, the primary sources were selected as the database of digital resources of the National Library of China, the database of ceramic artifacts in the Palace Museum, and the Compendium of Chinese Ceramics History and Treatises. Documents in the documentary capture OCR scans of Ming and Qing dynasty monographs like Tao Shuo and Jingdezhen Tao Lu, 8,247 scholarly journal articles published in 1912-2025. The data of the museum collection has 23,561 entries, which encompass images of the artifacts, rubbing of the inscriptions, and records of excavation.

During the preprocessing phase, to handle the inherent complexity of simplified and traditional characters, variant characters, and the absence of the sentence breaks in old writings, a BERT-trained ancient Chinese word segmentation model was implemented to segment [7-8]. To mitigate Named Entity Recognition (NER) hallucinations caused by polysemous characters in classical Chinese (Wenyanwen), a domain-specific disambiguation layer was integrated, which utilizes semantic co-occurrence constraints from ceramic lexicons to distinguish between technical terms and common vocabulary. A character shape mapping table was used to combine variant characters into standard characters and regular expressions were used to extract patterns of professional terminology e.g. XX kiln and XX glaze. The catalog information of the collections was put onto standardized field mappings which transformed time expressions like Kangxi era and Qing Shengzu period to Gregorian calendar ranges. The copyright notices, page number annotations, and modern commentary texts were filtered out, leaving behind the essence of the text including process descriptions, biographical records and changes to the kiln sites. A specialized dictionary of ceramics was built, containing 312 kiln names, 584 technical terms, and 1,896 historical artisans, which were used as a seed database to later entity recognition. The cleaned structured dataset had 91,204 valid text fragments and an average length of 127 characters, which forms a database on which the knowledge can be extracted.

B. ENTITY RECOGNITION AND RELATION EXTRACTION

Entity recognition adopts a BiLSTM-CRF architecture fused with the BERT-wwm Chinese pre-trained model, and labels six types of entities, namely kiln, craftsman, technique, vessel shape, glaze, and decoration, as BIO sequence labels. The training set consists of 5,120 manually labeled sentences from ceramic literature, with labeled examples such as "Jingdezhen kiln_B Jingdezhen kiln_I firing_O blue and white porcelain_B blue and white porcelain_I". The model input layer receives 512-dimensional character vectors, and the bidirectional LSTM hidden layer is set with 256 neurons to capture contextual dependencies. The CRF layer constrains the label transition probability to ensure that "craftsman_B" does not lead to illegal sequences such as "technique_I". For the problem of recognizing the abbreviations of the five famous kilns "Guan, Ge, Ru, Ding, Jun", a dictionary matching post-processing rule is introduced to complete "Guan kiln" and "Ge kiln" into complete entities [9-10]. The RoBERTa-wwm model of sentence-level classification is used to extract the relations, and 9,384 training samples were constructed manually which included 12 categories of relations that include: apprenticeship transmission, technique improvement, kiln site migration, and glaze recipe inheritance. All pair of samples are formatted in the format of <head entity, relation type, tail entity, context sentence. The model learns entity pairs and the respective sentences as 768-dimensional vectors that are mapped to a 12-dimensional relation probability distribution using a fully connected layer. The problem of the imbalance in the classes is resolved by using focal loss, in which

the category of the technique improvement only covers 3.7% of the samples. A validation on temporal inference is carried out on the extracted triples to eliminate temporal inconsistencies like Ming Dynasty techniques being passed on by the Yuan Dynasty craftsmen. However, to distinguish between direct lineage and historical imitation, the system incorporates a 'revival' attribute for technical nodes; this allows for the logical representation of cases where later dynasties (e.g., Qing) intentionally mimicked earlier styles (e.g., Song) without falsely implying a continuous master-disciple lineage.

C. ONTOLOGY MODEL DESIGN

The ontology model uses the OWL2 language to define the conceptual hierarchy and semantic constraints of the ceramic craft domain. The top-level class design includes four root nodes: Material Culture (kilns, artifacts, raw materials), Technology (processes, firing methods), Personnel (craftsmen, supervisors), and Spatiotemporal (dynasties, geographical locations). The Kiln class is further subdivided into three subclasses: Official Kilns, Folk Kilns, and Export Kilns. Each instance carries the attributes "Establishment Year," "Abandonment Year," "Geographical Coordinates," and "Product Type." The Craftsman class includes functional attributes such as "Specialized Skills," "Kiln Position," and "Apprenticeship Source," connecting the apprenticeship relationship chain through the object attribute 'apprenticeOf'.

The definition of relationships is based on domain-range semantic constraints. As an example, the field of the relationship of skill transmission is confined to the class of craftsman and the range of values is confined to the skill technique class. There is a transitivity axiom that is added to support the reasoning of intergenerational inheritance. The relationship between kiln sites migration and a timestamp attribute is bound to the kiln migration year and the successor attribute linked to the kiln migration successor is associated with the new kiln site. The evolution relationship between glaze formula components associates the entities of the chemical components using the hasIngredient attribute and the relationship between formula improvement inherits the relationship between derivedFrom attribute to reflect the technological relationship. Mutually exclusive constraints are created to avoid situation Jian kiln and Jingdezhen kiln being alone labeled as the same source of artifacts. The cardinality is employed to state that each artifact type should be allowed to have up to 5 mainstream firing techniques.

D. KNOWLEDGE GRAPH STORAGE AND VISUALIZATION

The graph database is installed in a 64GB server of the Neo4j database where the model is that of a labeled attribute graph in which the entity nodes and relationship edges are stored. Kiln nodes have the KILN tag and have 12 attributes, such as latitude and longitude positions and duration. Craftsman nodes have the tag CRAFTSMAN, which contains information about birth and death year, place of origin, and representative works. Directed edges are used to represent the relationship edges; an example is the TEACHES relationship edges between the master node and the apprentice node with other attribute values being the years of instruction and the contents of the technique. A composite index is constructed to hasten fast search as querying all craftsmen of a given kiln in given dynasty. The APOC plugin is configured to execute graph algorithms to calculate the shortest path for the transmission of skills.

The visualization system is based on D3.js force-directed layout which is in turn used to render the node network. Kiln nodes are located as the red circles, whose sizes are scaled to correspond to production scale, and the artisan nodes are represented by blue squares with the information about the dynasty. Furthermore, morphology data and patterns are visually mapped as hexagonal green nodes; the edge thickness between these and ceramic technique nodes represents the degree of cross-domain structural similarity in the digital twin framework. The lineage of the techniques of Ding Kiln can be obtained by Cypher query MATCH path=(k:KILN)-[:INHERITANCE1..5]->(successor) WHERE k.name=Ding Kiln. The system rewinds relationship paths that have a depth of not more than 5 levels and identifies them. Timeline slider control also allows dynamic presentation of distribution variation of the kilns between the Tang and Qing dynasties. When a vessel type node is clicked on, a corresponding query is generated and then the evolution tree of the firing techniques of that vessel type is shown. A built-in geographic information system module superimposes the coordinates of kiln sites onto a historical map and on top of a trade route layer to examine the network of distribution of export porcelain.

IV. RESULTS AND DISCUSSION

A. KNOWLEDGE GRAPH CONSTRUCTION RESULTS

Once the knowledge graph is built, statistical analysis is done on the different entity nodes and relation edges. The system itself works through the number of labels of all nodes within the Neo4j database and counts up the number of entities with six types: kiln, craftsman, technique, vessel shape, glaze and decoration. Aggregate queries are used to compute relation type statistics to find out the number of edges and average completeness of attributes of 12 different types of relations such as apprenticeship, technique improvement, and kiln site migration. Evaluation of performance is carried out on manually labeled test set. The precision, recall and F1 score of each type of relation are calculated using confusion matrix and macro-averaging of the results of each type of relation would give the overall classification accuracy.

TABLE 1. Statistical Results of Entities and Relationships in Knowledge Graph

Category	Entity/Relationship Type	Quantity	Average number of attributes	Accuracy/Completeness
Entity Node	kiln	4,127	8.3	92.4%
Entity Node	artisan	6,891	6.7	87.6%
Entity Node	Techniques	2,348	5.2	91.8%
Entity Node	vessel shape	3,219	7.1	90.2%
Entity Node	Glaze	1,249	9.4	88.5%
Relationship edge	Master-disciple transmission	12,347	3.6	91.7%
Relationship edge	Technological Improvement	8,562	4.2	85.3%
Relationship edge	Kiln site relocation	1,834	5.8	93.1%
Relationship edge	Glaze inheritance	6,219	4.7	87.9%
Relationship edge	Product manufacturing	13,194	3.1	90.6%
total	All types	17,834 nodes / 42,156 relationships	6.2	89.3%

Table 1 indicates that kiln sites and artisan nodes take up more than 60% of the main network that is the backbone of the network. Despite the 18.7% missing rate in folk artisan attributes, the 93.1% accuracy in kiln site migration is primarily derived from cross-referencing official gazetteers and archaeological stratum evidence, rather than relying solely on fragmented artisan movement records. The suitability of technique improvement relations is not that high (85.3%), as there is some ambiguity and subjectiveness on the descriptions of the technological innovations in the ancient writings. The mean glaze entity attributes are 9.4 with the attributes being specific parameters like chemical composition and firing temperature. The relationship

of the apprenticeships is the most numerous, it is 12,347, which successfully creates a web of artistic lineages throughout five dynasties: Tang, Song, Yuan, Ming and Qing. Statistical analysis of attribute completeness demonstrates that the data on kiln sites and techniques are fairly exhaustive, whereas the rate of the missing attribute of some folk artisans is up to 18.7% as a result of inaccessibility of the historical resources. Local gazetteers and genealogical data should be complemented by future research in order to achieve better coverage.

B. ANALYSIS OF GENEALOGICAL RECONSTRUCTION

Inheritance path mining was done based on the lineage transmission, technique improvement, and migration of kilns sites relationships in the kiln map. The depth-first search algorithm was used, where the source kilns like Yue kiln, Ding kiln and Longquan kiln were the starting point, following the chain of evolution of the technique branches and kiln systems, and time span limitations were applied to make the sequence of inheritance follow historical logic. The development of the formula of the celadon glazes was analyzed, leading to extraction of all glaze nodes with the "celadon" attribute. The chemical composition attribute clustering was applied as a method to detect the generational differences in formula, compute the strength of the glaze formula inheritance relationships among the neighboring nodes and marked important innovative nodes which result in the significant change of the color effect.

TABLE 2. Statistics on the inheritance network of major kiln systems and the evolution nodes of celadon glaze

Kiln system name	Origin Era	Number of inheritance branches	Maximum depth of inheritance	Key technology nodes
Yue kiln system	Tang Dynasty (618-907)	11	4th generation	The recipe for secret-color porcelain (Late Tang/Five Dynasties)
Ding Kiln System	Tang (618-907)	12	7th generation	Overlay firing technique (Northern Song Dynasty)
Longquan kiln system	Northern Song Dynasty (960-1127)	twenty four	8th generation	Formula for celadon glaze (Southern Song Dynasty)
Jingdezhen kiln system	Song (960-1279)	31	10th generation	Blue and white porcelain technique (Yuan Dynasty)
Jian Kiln System	Song (960-1279)	8	6th generation	Rabbit fur teacup firing (Song Dynasty)
Celadon glaze node 1	Eastern Han Dynasty	Iron content 1.8%	Reducing flame	Proto-celadon
Celadon glaze node 2	Tang Dynasty	Iron content 2.3%	Lime-alkali glaze	Yue ware secret color porcelain
Celadon glaze node 3	Northern Song Dynasty	Add wood ash	Thick glaze	Ru ware sky blue glaze
Celadon glaze node 4	Southern Song Dynasty	Multiple glazing	1280 $^{\circ}$C	Longquan celadon glaze
Celadon glaze node 5	Yuan Dynasty	Cobalt material introduction	Blue and white porcelain technique	Jingdezhen blue and white porcelain

Table 2 presents the Jingdezhen kiln system of 31 inherited branches with the maximum number of generations of issuance, and proves its technological radiation capacity of the porcelain capital. The 24 branches of Longquan kiln system are mostly concentrated in the coastal parts of Zhejiang and Fujian showing the influence of maritime trade that was encouraging in the expansion of the kiln system. The Southern Song Dynasty Longquan powder blue glaze was one of the seven important nodes in the evolution of celadon glazes, and the formula used a multi-application glazing to make the glaze layer thicker (1.2 mm) and regulated the amount of iron oxide in the formula (2.1%), to produce the effects of powdery and lustrous. The addition of cobalt material to the blue and white porcelain technique of the Yuan Dynasty was a breakthrough of the underglaze color system; and this node was the source of technology of the polychrome porcelain of Ming and Qing Dynasties.

C. TYPICAL CASE VERIFICATION

The database retrieved all nodes labeled "Jian Kiln" or "Jian ware" from the atlas, extracting records of artisan activities, kiln firing conditions, and points of discontinuity in technique transmission from the Song, Yuan, Ming, and Qing dynasties. By comparing these records with original texts from documents such as Song Huiyao Jigao and Tiangong Kaiwu, the accuracy of the extracted timelines for the loss and revival of Jian ware was verified. A panel of experts manually annotated 312 Jian ware-related ternary sets, calculating precision, recall, and time-location error, and statistically analyzing the logical correctness of the technique dating inference.

TABLE 3. Verification Results of the Spatiotemporal Trajectory of the Loss and Revival of Jianzhan Craftsmanship

Time Node	Event Type	Image recognition results	Literature verification results	Accuracy
1127-1279	Prosperity	87 craftsmen, 12 kiln sites	91 craftsmen, 13 kiln sites	93.8%
1368-1644	Lost period	0 artisans recorded; kiln site abandoned.	No records found in Ming Dynasty documents	100%
1279-1368	recession	The number of artisans was reduced to six, and production plummeted.	Only sporadic firings were produced during the Yuan Dynasty.	91.7%
1981-1986	Early Reconstruction	Laboratory re-firing successful 3 times	The literature records four experiments.	88.9%
2009-2017	Scale Revival	There are 42 inheritors, with an annual output of 150,000 pieces.	Official statistics show 47 individuals and 162,000 items.	95.3%

Table 3 was successful in determining the fall of the Jianzhan (Jian ware) pottery in the Yuan Dynasty since the number of craftsmen significantly declined with the Southern Song Dynasty to Yuan Dynasty with the figures standing at 87 in the Southern Song Dynasty to 6 in the Yuan Dynasty respectively confirming the decrease in demand with the fading of the tea-tasting culture in the Mongol rule. The level of accuracy in identification of the Ming Dynasty period of loss was at 100%. The periodization of the technique was determined by the atlas, using interrupted craftsman records and abandoned kiln site markers, which were just what literature records indicated, that Ming Dynasty tea bowls transitioned to Jingdezhen white porcelain. During the initial years of the revival in 1981, the atlas had found 3 successful laboratory re-firing experiments, and the real literature 4. The mistake was as a result of a description of an experiment that was unsuccessful in the journal Fujian Ceramics which was not properly classified. The statistical deviation in large-scale revival phase after 2009 was 5.3%, owing to the fact that some folk inheritors were not registered in the official database.

V. CONCLUSION

This paper discusses the fragmented historical records and inadequate technological background of ancient Chinese ceramic artisanship by developing a dedicated knowledge graph that integrates the structural semantics of industrial heritage. By mapping the evolution of technical lineages across both ceramic and material manufacturing systems, the proposed scheme bridges the data gap and provides a systematic material framework for the digital preservation of industrial excellence. Multi-source heterogeneous data makes use of named entity recognition and relation extraction techniques in extracting structural knowledge. Semantic relationships in the ceramic domain are defined as an ontology model, and stored and efficiently retrieved through the Neo4j graph database. The query system of visualization facilitates dynamism and path reasoning of lineages of inheritance. The verification experiments prove that the graph is able to accurately re-construct the evolutionary path of the kiln systems and the lost and rediscovered techniques. The present study can serve as a method of knowledge retrieval to ceramic historians, as it allows filling the gap of cross-period technological links. The knowledge graph method can be extended to industrial heritage, providing a technological paradigm for the digital preservation of traditional material morphology and historical manufacturing lineages. This systemic integration bridges the semantic gap between geometric physical data and the cultural expression of weaving excellence, ensuring the structural consistency of industrial craft data.

AUTHOR CONTRIBUTIONS

Xinlong Zhu designed, collected and analyzed the data, and drafted the manuscript. Xinlong Zhu conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Xinlong Zhu participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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