An Experimental Approach to AI-Driven Structuring of Semantic Connections in Wajima-nuri for VR Environments

Issei YOSHIDA[1] Soushi MURATANI[1] Kenichi KATO[1]

Abstract: This study demonstrates a data structuring methodology to expand the complex knowledge system of Wajima-nuri—a traditional Japanese craft—into a Virtual Reality (VR) learning space. Traditional craft knowledge is multi-layered, making it difficult to grasp interrelationships through linear text-based learning. While VR offers spatial immersion, effectively utilizing this medium requires restructuring unstructured data into information granularities capable of spatial arrangement. We utilized Generative AI agent to extract "Atomic Facts" from specialized documentation and constructed a Knowledge Graph based on a domain ontology. The results indicate that this structured data serves as a logical foundation for designing information nodes and visual guidance paths within VR, proposing a dynamic knowledge system that enhances information reception efficiency.

1. Introduction

Japanese traditional crafts are globally renowned for their aesthetic beauty and technical precision. Among these, Wajima-nuri (Wajima lacquerware) is particularly acclaimed for its robustness and elegance. The manufacturing process of Wajima-nuri is exceptionally complex and diverse, widely said to encompass more than 100 distinct steps. These steps range from the initial creation of the wood base (Kiji) to the undercoating (Shita-ji), intermediate coating (Naka-nuri), top coating (Uwa-nuri), and final decoration (Kashoku) [1], [2], [3]

Historically, while these advanced skills and tacit know-how have been transmitted through traditional apprenticeship under master craftsmen, for general learners, the techniques have been conveyed primarily through the medium of books. These take the form of technical manuals and specialized texts compiled from decades of artisanal experience. However, a significant challenge lies in the format of this recorded knowledge: it is predominantly composed of text, existing as unstructured data. These texts often contain dense technical terminology and expressions unique to the craftsmen, yet supplementary explanations for the reader are not always provided in situ. While some texts may relegate explanations to separate chapters or footnotes, this dispersion of knowledge necessitates that the learner moves back and forth between multiple pieces of information during the process of understanding.

In response to this difficulty, introductory books and materials aimed at younger audiences have historically employed simplified expressions and reduced the complexity of explanations to promote learner understanding. While this approach reduces the cognitive load of navigating between scattered information, it simultaneously reduces opportunities to expose the learner to critical background information. Consequently, it is difficult to claim that simplified texts are suitable for the systematic succession of deep knowledge. Traditional crafts, including Wajima-nuri, are inextricably tied to their production regions; a bird's-eye grasp of knowledge—including relationships with the local climate, geography, and cultural circumstances—is essential for true comprehension. From this perspective, we concluded that it is necessary to develop a new method to visualize the connections between knowledge in a form that is accessible even to beginners.

A bibliometric analysis of global trends reveals that over the last two decades, research into VR for learning has surged, particularly focusing on complex knowledge acquisition [4]. For these immersive applications to be effective in specialized domains, they must prioritize ease of use, interaction quality, and educational purpose. Consequently, it is necessary to move beyond simple visual immersion by establishing a structured design framework that optimizes the spatial arrangement of information [5], [6]. For a learner to be naturally guided from one piece of information to the next, the "semantic connections" between information must be designed and implemented as "spatial connections."

This study serves as an experimental first step toward constructing a VR space where beginners learning Wajima-nuri can grasp information from a holistic, bird's-eye view. We attempted a method of extracting knowledge from specialized texts regarding Wajima-nuri and structuring and visualizing it as a Knowledge Graph.

2. Research Objectives

The primary objective of this research is to explore the potential of a Knowledge Graph to serve as the foundation for information arrangement in a VR space. To achieve this, we utilize Generative AI to unravel the complex knowledge system surrounding Wajima-nuri and perform automatic tagging, thereby visualizing the connections of each piece of knowledge.

The specific process involves using Generative AI on text extracted from documents to generate "Atomic Memos" knowledge expressed in the minimum necessary description—suitable for Knowledge Graph processing. This atomization is crucial because immersive technologies often impose a high "extraneous cognitive load" on beginners due to the sensory-rich nature of the environment [7], [8]. Subsequently, the content of these Atomic Memos is analyzed by AI, and automatic tagging is

1 Kanazawa Gakuin University

performed based on a domain ontology of processes, materials, tools, and cultural backgrounds. This process structures previously unstructured data into meaningful connections of knowledge. For the visualization of this structured knowledge, we utilize the graph view function of a knowledge management tool to keep the editing and management of each memo at a simple, accessible level. Through this methodology, we aim to build a knowledge system that allows for an easy understanding of the relationships between the various manufacturing processes of Wajima-nuri and the regional background—relationships that were previously understood only through the tacit knowledge cultivated by craftsmen and researchers over decades.

3. Challenges in Knowledge Extraction for Wajima-nuri

The manufacturing process of Wajima-nuri is broadly classified into five stages from wood base creation to completion. Of note is the undercoating process, which forms the foundation of the lacquerware's quality and durability. This stage involves a chain of numerous specialized processes, such as the unique technique of mixing Jinoko (a powder made from diatomaceous earth produced in Wajima) with lacquer and applying it in layers, and Ji-Buchi-Biki (reinforcing edges) to strengthen parts prone to chipping. This chain relationship requires a multi-layered grasp of knowledge simultaneously; thus, conventional simple list-format knowledge management has severe limits regarding its capability to provide a bird's-eye view. For this study, the subject of knowledge extraction was a document data set of approximately 7,000 characters concisely describing the history and painting processes of Wajima-nuri [1]. While this text contains abundant information regarding the order of processes and materials used, it presents several specific challenges for knowledge extraction:

- Unstructured Data: The majority of the source material is described in continuous paragraph format. While the "order" between processes is shown in a bullet-point format, the "causal relationships" between processes and cultural backgrounds are not presented as explicit data structures.
- Granularity and Ambiguity of Knowledge: Because the text explains concepts concisely, multiple materials, processes, and specific artisanal know-how (e.g. "lightly polish the entire surface", "cut to appropriate size") are often mixed within a single process description. This lacks the clear factual separation required to derive computational relationships between phenomena.
- Frequent Use of Technical Terms: The text contains many non-general technical terms (e.g. Kokuso, Nunokise, Soumi-migaki), making it necessary to identify these terms as distinct nodes and define them accurately.

To address these challenges, simply performing keyword extraction to construct a Knowledge Graph is insufficient. Investigations into learner behavior within VR suggest that unstructured spaces lead to unfocused interactions, whereas structured guidance facilitates patterns associated with higher learning performance [9]. To extract accurate relationships that can function as indicators for "information filtering" and "zoning" in VR space, we adopted an approach of decomposing information into "Atomic Facts" (minimal units of fact in triplet format). We believe this is effective in preventing information duplication and clearly defining the edges and nodes of the Knowledge Graph. Additionally, Generative AI is positioned in this study as an agent to realize knowledge structuring through the generation of Atomic Memos and automatic ontology-based tagging.

4. Methodology

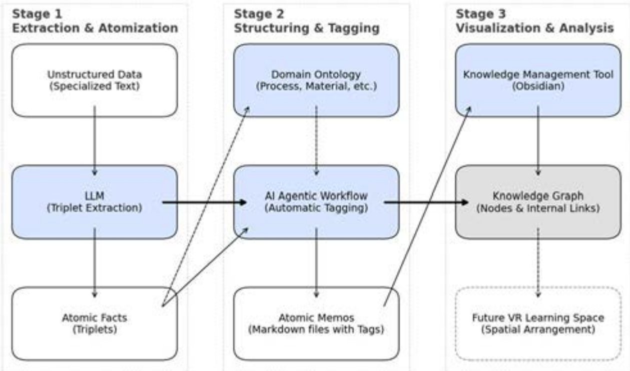

Fig.1. Knowledge Structuring Pipeline

The research methodology followed a structured pipeline of extraction, atomization, tagging, and visualization [Fig.1]. First, we extracted descriptions related to Wajima-nuri from the target document, excluding figure captions, and used paragraph text as the basic unit for the dataset. We instructed the LLM to extract facts in a structured triplet format (Subject-Relation-Object) to ensure machine-readability and eliminate semantic ambiguity. The output was standardized in YAML format to facilitate seamless integration into the knowledge management system. Subsequently, an AI-driven agentic workflow was implemented to automate the generation of Markdown-based 'Atomic Memos,' each containing domain-specific ontology tags for processes, materials, and cultural contexts." Sample tags were selected from three perspectives to allow for multifaceted association:

- Component Tags: Identifying major components (Person, Place, Thing, Concept) such as Technique, Process, Tool, Material, and Geography.
- Contextual Tags: Expressing the background supporting Wajima-nuri (climate, culture, social structure) to deepen the relationship with technology. Tags included Cultural Style, Usage, Economy, Structure, and Raw Material Supply.
- Relational Tags: Expressing connections or actions be-

TABLE I
EVALUATION RUBRIC

Evaluation Dimension	Score 2: Optimal / Accurate (Perfect match with criteria)	Score 1: Minor Issue / Needs Edit (Acceptable but lacks precision)	Score 0: Critical Error / Inaccurate (Fails to meet basic criteria)
1. Factuality & Source Fidelity (Assesses hallucination and information loss)	Perfect consistency with the source text. Contains only facts present in the original source. No fabrications, omissions, or summarizations that alter the original meaning are present.	Semantically correct but ambiguous. The basic facts are correct, but the nuance of the original text is slightly lost, or the phrasing is vague and could lead to misinterpretation.	Contradicts source or contains fabrications. Includes content that contradicts the original text or adds information that does not exist in the source (hallucination).
2. Domain Terminology Accuracy (Assesses proper use of Wajima-nuri terms)	Correct usage of specialized terms, domain-specific terms (e.g. "Jinoko", "Nunokise") are used in the proper context with correct spelling and notation.	Substitution with generic terms. Not incorrect, but generic words are used where specialized terms would be more appropriate (e.g. referring to "Jinoko" simply as "soil").	Misuse of terminology. Specialized terms with different meanings are used incorrectly, or the fundamental definition of the term is mistaken.
3. Structural Integrity & Ontology (Assesses logical triplets and tagging)	Logical triplets and consistent tagging. The "Subject-Predicate-Object" relationship is logically sound, and the assigned tags (e.g. "Process", "Material") completely match the content.	Weak relationships or suboptimal classification. The triplet relationship is slightly unnatural, or the tagging is not optimal but falls within an acceptable range of interpretation.	Broken structure or incorrect categorization. The triplet makes no logical sense, or the tagging is clearly categorized under an incorrect ontology type.

tween nodes, such as "Composed of", "Uses", "Influences", "Is Responsible For" and "Precedes".

The AI was defined to automatically assign up to 10 matching tags to each Atomic Fact. This ensured consistency in node types across all Atomic Memos, serving as the foundation for filtering and structural analysis. We adopted Obsidian as the knowledge management tool, prioritizing its simplicity and suitability for structural analysis within a laboratory setting. Obsidian's graph view functions as a property graph based on nodes (Markdown files) and edges (internal links). To connect these nodes, we had the Generative AI reference the original text and automatically add internal links to each Atomic Memo, taking into account the previously assigned tags and relations. This enabled edge formation based on two elements: node type (tag) and inter-node relation (link).

5. Results and Discussion

Generative AI generated 101 Atomic Memos from the 86 paragraphs extracted from the source documents. To ensure rigorous quality control, we established a specific evaluation rubric covering three dimensions: factuality, terminology, and structure [Table I]. A generated memo was defined as "accurate" only if it achieved a perfect score (Score 2) across all three dimensions according to this rubric. Based on this strict criterion, 100% of the memos were confirmed as accurate. This suggests that with highly specific prompt constraints and a structured source text, LLMs can decompose knowledge into minimal units with high precision, even for documents containing complex technical descriptions.

The decomposition of knowledge into Atomic Facts significantly improved searchability. For instance, relations such as "in which process a specific tool is used" became independent searchable units. This was particularly effective when filtering functions were applied to the Knowledge Graph. A concrete example is the node for "Jinoko" (Wajima clay powder). In conventional books, information about Jinoko is scattered across various pages. However, in our Knowledge Graph, the "Jinoko" node is connected by direct edges to "Geography" (diatomaceous earth unique to Wajima) and "Feature" (micropore structure). This allows a beginner to connect the procedural step of "using Jinoko for undercoating" with the scientific reasoning of "why this technique was established in Wajima". This facilitates the acquisition of "multi-layered knowledge understanding" and "information perspective," which are difficult to obtain through static text learning.

Analysis of the graph revealed that the node with the highest centrality was "Wajima-nuri", followed by tags such as "Technique", "Process", "Usage" and "Cultural Style" [Fig.2]. The identification of these "hub nodes" provides a logical blueprint for spatial anchoring within the VR environment. These nodes function as "Information Waypoints" where learners can orient themselves within the complex knowledge network, thereby fostering "learning engagement"— a key moderating factor for the successful transfer of skills from virtual environments to real-world artisanal tasks [10]. While the

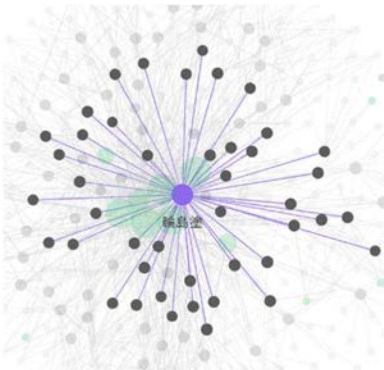

Fig.2. Graph View (detail)

generated graph effectively visualized key clusters, a structural challenge emerged: high-degree nodes led to visual "entanglement" in the Graph View. This suggests that for VR implementation, a simple conversion of graph edges to spatial proximity may induce cognitive overload. Future work must investigate spatial zoning algorithms based on node centrality to ensure intuitive navigation.

6. Conclusion and Future Work

This study verified a preliminary method for converting the complex, unstructured specialized knowledge of Wajima-nuri into a structured Knowledge Graph using Generative AI. By successfully atomizing technical descriptions into discrete units, we have established a dataset with the granularity required for effective use in VR learning spaces. Moving forward, we aim to expand this methodology by applying it to other technical manuals and specialized texts with significantly higher word counts to analyze the scalability of the system. Additionally, we will challenge the model with highly detailed and complex texts focused on specific, intricate Wajima-nuri manufacturing processes to test the limits of its precision. While the current experimental graph has successfully identified key hub nodes, it also revealed challenges regarding the spatial density and entanglement of certain nodes within the network, indicating clear room for improvement in spatial organization. By refining the spatial distances and positioning of these information nodes, we aim to minimize cognitive interference and evaluate the actual learning efficiency of users in the finalized environment. Our long-term goal is to realize a comprehensive, dynamic knowledge system for traditional techniques, where the semantic logic of artisanal expertise is seamlessly integrated into an immersive learning environment.

Acknowledgements

This research was supported by JSPS KAKENHI Grant Number 24K06316.

References

[1] K. Shimaguchi, "Characteristics of Wajima-nuri and Lacquer Art Techniques (Wajima-nuri no Tokuchou to Shikko Gijutsu", *Journal of Painting Technology (Tosou Kogaku)*, vol. 28, no. 2, pp. 73–80, 1993.

[2] Y. Komatsu, “Wajima-nuri: The Beauty and Technique of Lacquerware (Wajima-nuri: Shikki no Bi to Gijutsu)”, *Dentou to Bunka*, no. 14, pp. 2-13, Oct. 1990.

[3] Ishikawa Prefectural Museum of History, Ed., *Lacquer: A Cultural History of Vessels (Urushi: Utsuwa no Bunkashi)*, Kanazawa, Ishikawa: Ishikawa Prefectural Museum of History, Oct. 1988.

[4] A. D. Samala, et al., "Global Publication Trends in Augmented Reality and Virtual Reality for Learning: The Last Twenty-One Years", *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 2, pp. 109–128, 2023.

[5] G. Al Farsi, et al., "A Review of Virtual Reality Applications in an Educational Domain", *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 15, no. 22, pp. 99–110, 2021.

[6] B. Yang, "Virtual Reality and Augmented Reality for Immersive Learning: A Framework of Education Environment Design", *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 20, pp. 23–36, 2023.

[7] M. Poupard, F. Larrue, H. Sauzéon, and ricot, "A systematic review of immersive technologies for education: Learning performance, cognitive load and intrinsic motivation", *British Journal of Educational Technology*, 2024.

[8] Y. Jia and R. Qi, "Influence of an Immersive Virtual Environment on Learning Effect and Learning Experience", *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 6, pp. 83–95, 2023.

[9] A. Prakash, D. S. Shaikh, and R. Rajendran, "Investigating interaction behaviors of learners in vr learning environment", *Proc. 2023 IEEE Conf. Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 931–932, 2023.

[10] P. Yang and Z. Liu, "The Influence of Immersive Virtual Reality (IVR) on Skill Transfer of Learners: The Moderating Effects of Learning Engagement", *International Journal of Emerging Technologies in Learning (iJET)*, vol. 17, no. 10, pp. 62–73, 2022.