

# Development of Ancient Khmer Stone Castle Ontology

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## Abstract

*This research delves into the development of ontology, a crucial aspect of knowledge organization system studies. The primary goal is to establish a semantic search system tailored to the Khmer stone castles of the Greater Mekong Subregion (GMS), specifically addressing the challenge of semantic gaps. This paper details a novel approach to developing ontologies for Khmer stone castles in the GMS to enhance our understanding of these countries' rich and ancient cultural heritage. A systematic four-step theoretical framework for ontology development was adopted, utilizing the Hozo Ontology Editor to create the ontologies by used the Wizard for documenting ontologies (WIDOCO) framework for web ontology platform. This methodology plays a key role in differentiating relevant from irrelevant data, thus significantly improving the efficiency of semantic searches. Central to this study is developing a comprehensive ontology encompassing ten primary classes: castle, location, country, Khmer art, art type, castle size, castle type, material, religion, and condition. This ontology is foundational for developing a semantic search system designed explicitly for the Khmer stone castles in the GMS. The insights from this research offer significant implications for advancing semantic search systems in cultural heritage, providing a robust framework for future studies in this field.*

**Keywords:** *Ontology, Semantic technology, Tangible cultural heritage, Khmer stone castle, Greater Mekong Subregion.*

## Introduction

The Angkor civilization has profoundly influenced Mainland Southeast Asia (MSEA) for centuries. Recognized as the successor to the Funan and Chenla Empires, Angkor has endowed the region with numerous architectural marvels that continue to awe scholars and tourists alike. These preceding empires laid the foundational architectural principles Angkor would later refine, drawing from contemporary beliefs and traditions. The systematic approach to building creation, design, and construction during this era involved a collaborative effort among architects, builders, designers, and craftsmen, collectively shaping the architectural landscape with styles and techniques characteristic of their time. The architectural heritage of this civilization includes an array of temples, monasteries, once-thriving cities, and an extensive network of canals, reservoirs, bridges, and roads. Thousands of these heritage sites are scattered across Cambodia, Laos, Thailand, and Vietnam, reflecting the widespread influence of Angkor. Notably, the geographical seclusion of monumental temples like Banteay Chhmar and Preah Khan, along with entire temple cities such as Koh Ker and Sambor Prei Kuk, has protected them from mass tourism. Nestled in jungles and hidden from commercial routes, these structures have often been gradually overtaken by mosses, adding to their mystique. This rich tapestry of historical evidence underscores the grandeur and complexity of the civilization that once thrived in this region (Changmai et al., 2022; Coe, 2020; Higham, 2001; O'Reilly, 2006).

The primary objective of this study is to integrate digital humanities methodologies into constructing an ontology for the shared knowledge of the Khmer civilization in the Greater Mekong Subregion (GMS) countries. This ontology emphasizes the tangible cultural heritage (TCH) of these countries and aims to serve as a vital resource for the aggregation, categorization, and analysis of information, as well as for information retrieval. Consequently, this study outlines the essential aspects of developing ontologies, particularly for stone castles in the GMS countries.

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The Khmer civilization once exerted considerable influence over the Greater Mekong Subregion, with significant evidence found in the form of Khmer stone castles. These structures, distinct from temples, are noteworthy for their historical significance, architectural uniqueness, and cultural impact. Historical Significance: Khmer stone castles, also known as citadels or fortresses, played a crucial role in the defense and governance of ancient Khmer territories. These structures served as military strongholds, administrative centers, and symbols of power and authority for the Khmer Empire, which flourished in Cambodia and neighboring regions during the medieval period. Their construction and strategic placement reflected the geopolitical dynamics and expansionist ambitions of Khmer rulers (Stark, 2023). Architectural Uniqueness: Khmer stone castles are renowned for their impressive architectural features, including massive stone walls, intricate carvings, and sophisticated hydraulic systems. These structures showcase the advanced engineering skills and artistic craftsmanship of the Khmer civilization, demonstrating their ability to harness natural resources and adapt to diverse environmental conditions. The design and layout of Khmer castles exhibit a blend of indigenous Khmer styles with influences from neighboring cultures, resulting in a distinctive architectural heritage that continues to captivate scholars and enthusiasts alike (Miksic & Yian, 2016). Cultural Impact: Beyond their utilitarian functions, Khmer stone castles hold immense cultural significance as symbols of Khmer identity, resilience, and ingenuity. These monumental edifices served as focal points for religious rituals, royal ceremonies, and communal gatherings, reinforcing social cohesion and spiritual beliefs among the Khmer populace. Moreover, the presence of Khmer castles in the GMS countries reflects the broader cultural exchange and diffusion of ideas across regional networks, highlighting the interconnectedness of the GMS countries' civilizations during the medieval period (Buakhao et al., 2023). By integrating digital humanities methodologies, this study not only preserves but also enhances the understanding of Khmer civilization's tangible cultural heritage, contributing significantly to the academic and cultural discourse within the GMS countries.

To effectively organize knowledge for ontology, we first constructed and examined the scope classification, elucidation, concepts, and structural intricacies relevant to the Greater Mekong Subregion (GMS) stone castles. This classification was instrumental in enhancing understanding and facilitating searching for information regarding these historic structures. Our research methodology employed knowledge organization and ontology development, enabling the systematic networking of related information to foster data-sharing efficacy. Additionally, the semantic search capability enables users to access and utilize this data more effectively (Chansanam et al., 2015). Consequently, the developed ontology plays a significant role in enhancing the development of semantic search systems. This advancement is crucial for addressing and bridging semantic gaps in subsequent phases of research on the Khmer stone castles in the GMS countries.

## Methodology

This study aimed to develop an ontology for knowledge relating to the Khmer stone castles across the Greater Mekong Subregion (GMS) countries. The primary objective was to delineate the scope of knowledge and foster an inclusive understanding of the Khmer stone castles in these nations. This ontology serves as an introductory step in enhancing semantic search systems. The Uschold and King methodology for domain ontology development (Uschold & King, 1995) was employed as the directorial framework. This methodology encompasses several key processes:

### *Definition of the Objective and Scope*

The first step involved defining the objectives and scope of the ontology. This was crucial to ensure the ontology development aligned with the research goals. The primary objective was to create a comprehensive and inclusive knowledge representation of Khmer stone castles in the GMS. The scope included the castles' historical, architectural, cultural, and geographical aspects. Detailed discussions with domain experts and a thorough review of existing literature helped delineate the ontology's boundaries and specific areas of focus.

### *Ontology Development*

The ontology development process followed the structured approach proposed by Uschold and King. This step included several sub-processes:

**Conceptualization:** Identify and define key concepts and relationships relevant to Khmer stone castles. This involved creating a conceptual model that represented the domain knowledge. Various sources, including academic articles, historical texts, and expert interviews, were consulted to ensure the accuracy and comprehensiveness of the concepts.

**Formalization:** Converting the conceptual model into a formal representation. This was achieved by defining classes, properties, and constraints using a suitable ontology language such as OWL (Web Ontology Language)—the formal representation aimed to capture the intricacies of the domain knowledge in a machine-readable format.

**Integration:** Ensuring that the ontology could be integrated with existing ontologies and knowledge bases. This step involved aligning the developed ontology with relevant existing ontologies to facilitate interoperability and reuse. Efforts were made to map the concepts and relationships to widely recognized standards and vocabularies.

### *Subsequent Evaluation*

The developed ontology underwent a rigorous evaluation to ensure its validity, reliability, and applicability. This evaluation involved:

**Verification:** Checking the ontology for logical consistency and correctness. Automated reasoning tools were used to verify that the ontology contained no contradictions or logical errors.

**Validation:** Ensuring that the ontology accurately represents the domain knowledge. This involved seeking feedback from domain experts and potential end-users. Their inputs were critical in refining the ontology and addressing gaps or inaccuracies.

**Usability Testing:** Assessing the usability of the ontology in practical applications. Prototype semantic search systems were developed to test the ontology's effectiveness in improving search accuracy and relevance. User testing sessions were conducted to gather insights into the system's performance and user experience.

### *Semantic Search System Development*

Following the evaluation, the ontology was integrated into developing semantic search systems. This step aimed to enhance the retrieval and organization of information related to Khmer stone castles. The key activities included:

**System Design:** Designing the architecture and functionalities of the semantic search system. The design focused on leveraging the ontology to improve search capabilities, such as context-aware searches and advanced filtering options.

**Implementation:** Developing the semantic search system using appropriate technologies and tools. This involved coding the backend logic, integrating the ontology, and developing the user interface.

**Testing and Deployment:** The system was rigorously tested to ensure functionality, performance, and reliability. It was then deployed in a controlled environment, and user feedback was collected for further refinement.

*Findings and Insights*

The study highlights the findings and insights gained during the ontology development, as aligned with the research objectives. The developed ontology provided a structured representation of knowledge and demonstrated its potential to enhance semantic search systems. The iterative development and evaluation process contributed to refining the ontology, ensuring its alignment with the domain knowledge and practical usability. The successful integration into a semantic search system showcased the practical applications and benefits of the developed ontology, paving the way for future enhancements and broader implementations..

**Results**

In the realm of ontological classification, the study yielded a comprehensive framework comprising seventy-two (72) distinct classes, hierarchically organized into ten (10) primary categories: Castle, Location, Country, Khmer Art, Art Type, Castle Size, Castle Type, Material, Religion, and Condition. This taxonomic structure provides a nuanced representation of the complex interrelationships within the domain of Khmer stone castles. Notably, the Khmer Stone Castle class emerged as a central node, demonstrating intricate connections with all other classes, as delineated in the Semantic Web Table Specification. This interconnectedness adheres rigorously to the Resource Description Framework (RDF) standards established by the World Wide Web Consortium (W3C) (Manola & Miller, n.d.).

The ontological data were meticulously curated and presented in a descriptive format, exemplified in Table 1 and visually represented in Figure 1. This structured approach not only facilitates a comprehensive and systematic representation of the information but also aligns with best practices in data organization and semantic web standards (Uschold & King, 1995). By adopting this methodological framework, the study contributes to the growing body of knowledge in ontology development and cultural heritage documentation, providing a robust foundation for future research in the field of Khmer architecture and its associated cultural contexts (Chansanam et al., 2015).

This ontological classification system serves as a vital tool for researchers, archaeologists, and cultural heritage specialists, offering a standardized vocabulary and conceptual framework for the study of Khmer stone castles. It not only enhances our understanding of these architectural marvels but also facilitates cross-disciplinary collaboration and knowledge exchange in the broader context of Southeast Asian cultural studies (O'Reilly, 2006; Higham, 2001).

Table 1. List of main classes and definitions

Class/Concept	Definition
Castle	A castle in the context of the Khmer stone castle ontology refers to a fortified structure or complex primarily built during the historical period of the Khmer Empire. These structures, predominantly constructed from stone and characterized by their architectural features, cultural significance and historical value, served various purposes, including religious, administrative, and some residential functions.
Location	This class specifies the geographical coordinates or regional area where the castles are located.
Country	This class indicates the specific country or region within the GMS where the castles are located.
Khmer art	This class covers the diverse range of artistic expressions and creations that originated in or are associated with the Khmer culture, primarily in Cambodia. This art form is known for the unique characteristics which emerged over the

Class/Concept	Definition
	centuries, particularly during the Angkor period.
Art type	This class describes the specific architectural characteristics and influences evident in the castle's design.
Castle size	This refers to the physical dimensions or scale of Khmer stone castles within the Greater Mekong Subregion (GMS) countries. This class covers the quantitative aspect of the castle's characteristics, including area, the amount of space it occupies, or any other relevant measurements that indicate the overall size of the structure.
Castle type	This refers to the categorization of Khmer stone castles based on distinct architectural styles, historical periods, functional purposes and design characteristics unique to the Greater Mekong Subregion (GMS) countries. This classification helps in the identification, comparison, and analysis of various castle structures within the ontology.
Material	The primary materials used for castle construction include various types of material components, such as wood, brick, and stone (e.g. sandstone, laterite).
Religion	The religious significance or usage of the castle, such as Buddhist or Hindu practices.
Condition	The present state of preservation of the structure.

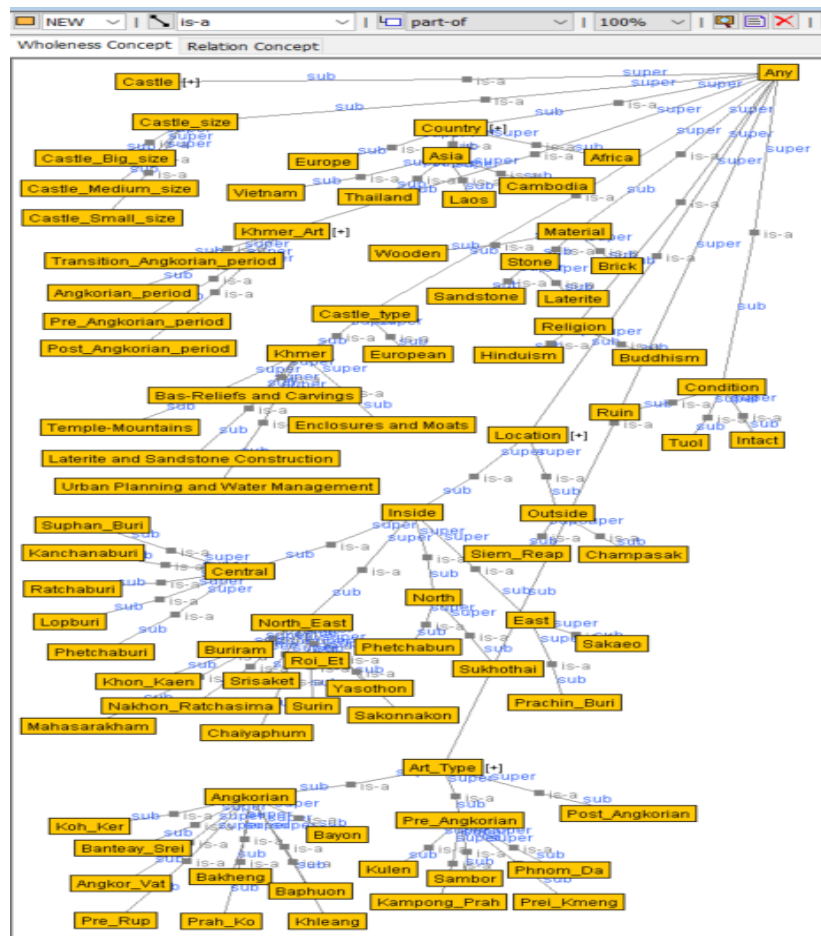


Figure 1. The Khmer Stone Castle ontology

This ontology is designed to represent and organize knowledge about Khmer stone castles, their characteristics, and related concepts. Let's break it down further:

### *KhmerStoneCastle (Main Class)*

This is the central concept of the ontology. It represents the physical structures built during the Khmer Empire period. These castles were multi-functional, serving religious, administrative, and sometimes residential purposes. The properties of this class link to other classes, providing a comprehensive description of each castle. The Khmer stone castles were predominantly constructed as temples and sanctuaries dedicated to Hindu and Buddhist deities, reflecting the spiritual and religious ethos of the Khmer Empire. These structures also played a pivotal role in the empire's administrative framework, functioning as centers of governance and administrative control. Additionally, in certain contexts, they served residential purposes, housing monks, priests, and occasionally royal family members or administrative officials.

### *Location and Country*

The classes "Location" and "Country" play a critical role in accurately pinpointing the geographical placement of each Khmer stone castle within the Greater Mekong Subregion (GMS). Location refers to the specific geographical coordinates or detailed descriptions of the exact sites where the castles are situated. This class encompasses precise data such as latitude and longitude coordinates, altitude, and other pertinent geographical markers. This granular level of detail facilitates precise mapping and analysis, which is essential for historical documentation, archaeological studies, and heritage conservation efforts. By providing exact locations, researchers can conduct spatial analysis, assess environmental and geographical factors influencing the castles, and compare these factors across different sites. Country, conversely, situates each castle within the broader national context within the GMS. This class includes information on the nation-state boundaries and administrative regions encompassing the castle sites. Understanding the national context is indispensable for several reasons. Firstly, it aids in the comparative analysis of cultural, political, and historical influences on the construction and preservation of castles across different countries. Secondly, it provides insights into each country's legal and regulatory frameworks governing heritage conservation, which can vary significantly. Lastly, it facilitates cross-border studies and collaborations aimed at preserving the shared cultural heritage of the Khmer civilization. These classes provide a comprehensive geographical framework supporting micro-level (specific site) and macro-level (national context) analyses. This dual-level geographical information is crucial for many scholarly pursuits, including historical and geographical studies, cultural heritage preservation, and regional planning. By integrating detailed location data with broader country-level information, researchers can achieve a nuanced understanding of the distribution, context, and significance of the Khmer stone castles within the GMS.

### *KhmerArt and ArtType*

Khmer art is a significant aspect of the cultural and historical identity of the Khmer stone castles, reflecting the rich heritage and artistic achievements of the Khmer civilization. To accurately represent this facet, the ontology incorporates two specific classes: KhmerArt and ArtType.

The KhmerArt class is designed to encapsulate the artistic elements and artifacts associated with the Khmer stone castles. This class includes various art forms, such as sculptures, relief carvings, and decorative motifs. The elements within this class are characterized by their stylistic features, cultural significance, and historical context. By structuring the artistic elements into a dedicated class, the ontology can provide a detailed and organized representation of Khmer art, facilitating a deeper understanding and appreciation of its unique characteristics.

Key attributes and properties within the KhmerArt class may include:

SculptureStyle: Descriptions of different sculpture styles found within the castles, including their defining features and historical origins.

**ReliefCarvings:** Information about the relief carvings, including thematic content, artistic techniques, and cultural narratives depicted.

**Decorative motifs:** This section details the various decorative motifs used in the castles, exploring their symbolic meanings and artistic influences.

The **ArtType** class focuses on specifying the architectural characteristics and influences that define the artistic expression within Khmer stone castles. This class categorizes and details the different architectural styles, materials, and construction techniques employed in the creation of these structures. By distinguishing the architectural elements, the ontology can provide insights into the evolution of Khmer architecture and its interaction with other cultural and artistic traditions.

Key attributes and properties within the **ArtType** class may include:

**ArchitecturalStyles:** Classification of architectural styles observed in the castles, detailing their defining features and historical periods.

**Construction Materials:** Information about the materials used in the construction of the castles, including their sourcing, preparation, and application.

**Influences:** Exploration of external influences on Khmer architecture, such as interactions with neighboring cultures and adopting new techniques and styles.

By integrating the **KhmerArt** and **ArtType** classes, the ontology aims to offer a comprehensive and nuanced representation of the artistic and architectural elements of the Khmer stone castles. This structured approach not only enhances the ontology's semantic richness but also supports advanced search and retrieval functionalities, enabling users to explore and analyze the artistic heritage of the Khmer civilization in a systematic and meaningful way.

### *CastleSize*

The **CastleSize** class is designed to represent the physical scale and dimensions of the Khmer stone castles. This class can encapsulate various measurements that describe the castles' size and structural attributes. These measurements might include, but are not limited to, the total area covered by the castle grounds, the height of the walls or towers, and the overall volume of stone utilized in the construction. By documenting and analyzing these metrics, researchers can gain valuable insights into the magnitude and architectural prowess involved in the construction of these historical structures. Understanding the physical scale of the castles not only helps in appreciating their architectural significance but also aids in comparative analyses with other similar structures across different regions.

### *CastleType*

The classification of castles under the category "**CastleType**" is pivotal in understanding and categorizing these historical structures based on several critical factors. This classification framework considers various dimensions, including architectural style, historical period, and primary function, to categorize comprehensively. **Architectural Style:** Castles are grouped according to their architectural characteristics, which can reveal significant information about the technological advancements, cultural influences, and aesthetic preferences of the period during which they were constructed. This classification can help trace the evolution of architectural styles and identify regional variations. **Historical Period:** This factor involves categorizing castles based on the period in which they were built. By classifying castles according to historical epochs, researchers can better understand the socio-political context, technological advancements, and historical events that influenced their construction and use. This temporal categorization also aids in chronological mapping and comparative analysis across different eras. **Primary Function:** Castles often served various purposes, from religious to administrative. Some were primarily built as temples, reflecting their role in spiritual and religious activities. Others might have functioned as

administrative centers, indicating their importance in governance and management. Classifying castles based on their primary function helps us understand their role in historical society and their contribution to the community. By employing the "CastleType" classification, researchers and historians can gain a nuanced understanding of the diversity and complexity of castles, aiding in more detailed and organized studies of these historic structures.

### *Material*

The "Material" class within the ontology is designed to specify the types of stone used in the construction of Khmer stone castles. This class acknowledges the possibility that different types of stone were utilized for various structural elements of the castles or during distinct historical periods. By incorporating this class, the ontology aims to capture the diversity and specificity of materials, which can provide insights into the construction techniques and historical context of the stone castles. This detailed classification not only enhances the understanding of the architectural and cultural significance of the castles but also aids in the accurate documentation and analysis of the material properties associated with different time periods and structural components.

### *Religion*

The religious significance of Khmer stone castles is a critical aspect of their historical and cultural relevance. Many of these structures were not merely architectural marvels but also centers of religious practices and beliefs. The classification of these castles into categories based on their association with Buddhist or Hindu practices, or a combination of both, is essential. This classification reflects the complex religious history and transitions that occurred within the Khmer Empire. Understanding the religious affiliations of these castles provides insights into the spiritual life of the period, including how religious practices influenced architectural design and how these sites served as focal points for religious activities. Moreover, the transitions between Hinduism and Buddhism within the empire can be traced through the analysis of these castles, offering a deeper understanding of the syncretism and religious dynamics of the Khmer civilization.

### *Condition*

The "Condition" class is a critical component in the ontology, representing the current state of preservation of each Khmer stone castle. This class captures a range of preservation statuses, from well-preserved structures to those in various stages of deterioration or ruin. Accurately documenting the condition of each castle is essential for archaeological research and conservation efforts, as it provides valuable insights into the historical and current state of these heritage sites. By categorizing the preservation status, this class aids in prioritizing conservation actions and understanding the factors contributing to the preservation or degradation of these cultural monuments.

The relationships between these classes create a web of information. For example, a specific KhmerStoneCastle instance might be linked to:

A specific Location and Country

Particular types of KhmerArt and ArtType

A CastleSize that indicates its grandeur

A CastleType that reflects its primary purpose

The Material it's made from

The Religion it's associated with

Its current Condition



This ontology structure allows for detailed representation of individual castles while also enabling broader analyses. For instance, one could use this ontology to:

Compare the sizes of castles in different regions

Analyze the distribution of different castle types across the GMS

Study the correlation between castle size and religious significance

Track the preservation conditions of castles built with different materials

By organizing information in this structured way, the ontology facilitates research, preservation efforts, and cultural understanding of these important historical structures.

The development of the Khmer Stone Castle ontology was grounded in Hjørland's knowledge organization framework (Broughton et al., 2005). This approach prioritized the identification and categorization of knowledge elements by delineating concepts, establishing semantic relationships, and mapping connections between relevant conceptual entities. The methodological approach involved a systematic presentation of findings, organizing primary concepts into a hierarchical structure based on related content groups through classification schemes. This initial data structure was subsequently refined into a comprehensive ontology.

The ontology development process adhered to the conceptual framework proposed by Uschold and King (1995), which encompasses three distinct phases: defining purpose and scope, ontology development, and ontology evaluation. For the ontology development phase, the study employed Noy and McGuinness's (2001) seven-step methodology, utilizing the Hozo Ontology Editor. Hozo, a sophisticated graphical ontology editor developed in Japan, was designed for constructing complex ontologies. This tool was the result of a collaborative effort between the Department of Knowledge Systems (Mizoguchi Laboratory) and ISIR-Osaka University, in partnership with Enegate Co. Ltd. (Osaka University, 2011).

Throughout the development and evaluation processes, the ontology underwent rigorous scrutiny by domain experts and was subjected to application-based evaluation methods. This approach ensured the ontology's accuracy, relevance, and practical applicability within the domain of Khmer Stone Castle knowledge representation.

The methodology encompassed a rigorous process of knowledge categorization initiated by identifying key concepts and their interrelationships. These conceptual relationships were subsequently mapped, facilitating the development of comprehensive classification schemes. The resulting data hierarchy visually represented the interconnected concepts, establishing a foundation for subsequent ontology development (Broughton et al., 2005; Uschold & King, 1995). The research implemented Uschold and King's (1995) conceptual model to ensure a systematic ontology development process. This model delineates a structured approach, commencing with defining purpose and scope, progressing through the construction phase, and culminating in a thorough evaluation. The widely recognized seven-step protocol proposed by Noy and McGuinness (2001) was a guiding framework throughout the developmental phase, offering a systematic approach to ontology construction. The Hozo Ontology Editor, developed by Osaka University (2011), was employed as the primary tool for ontology construction. This choice was predicated on its user-friendly graphical interface and robust capabilities in handling the complexities of constructing comprehensive ontologies. The utilization of Hozo facilitated the intricate process of translating conceptual relationships into a formalized ontological structure, thereby enhancing the overall quality and coherence of the resulting ontology.

The ontology documentation process employed WIDOCO (Garijo, 2017), a widely recognized tool for generating comprehensive and standardized ontology documentation. This methodological approach encompassed several critical steps:

Selection of an appropriate Ontology Web Language (OWL) file template, ensuring compatibility and adherence to semantic web standards.

Meticulous metadata input, enhancing the ontology's discoverability and interoperability within the broader semantic web ecosystem.

Systematic uploading of textual data, including concept definitions, relationships, and axioms, to populate the ontology structure.

Following these preparatory stages, all files about the Khmer Stone Castle ontology were uploaded and made publicly accessible via a dedicated web portal (<https://ischool.kku.ac.th/owl/index-en.html>).

Figure 2 visually represents the WIDOCO-generated documentation interface, illustrating the organized presentation of the ontology's structure, classes, properties, and associated metadata.

This rigorous documentation process not only ensures the ontology's accessibility but also facilitates its understanding and potential reuse by other researchers in cultural heritage informatics and Khmer architectural studies.

The screenshot displays the WIDOCO-generated documentation interface for the Khmer Stone Castle ontology. The page title is "The Khmer Stone Castle ontology" and it shows release information (31-01-2024), latest version URL ([https://ischool.kku.ac.th/owl/stone\\_castle\\_2023.owl](https://ischool.kku.ac.th/owl/stone_castle_2023.owl)), authors (Wirapong Chansanam), contributors (Wirapong Chansanam, Khon Kaen University), publisher (KKU iSchool), and download serialization options (JSON-LD, RDF/XML, N-Triples, TTL). It also includes a license field and a visualization option (WebVowl). An abstract section is visible below.

**Abstract**

This study centers on developing a semantic search system for Khmer stone castles in the Greater Mekong Subregion (GMS), aligning with UNESCO's cultural heritage preservation guidelines. The study proposes a comprehensive knowledge base by compiling tangible cultural heritage data, encouraging research, and building a specialized database. The semantic search system showcased high effectiveness, serving as a potential benchmark for cultural information retrieval. The research lays the groundwork for similar systems across diverse studies, contributing valuable insights to ontology development for cultural heritage preservation. Its far-reaching implications offer methodologies to conserve and make our diverse cultural heritage accessible.

**Figure 2.** The Khmer Stone Castle ontology by WIDOCO

Developing an ontology to encapsulate knowledge of Khmer stone castles in Greater Mekong Subregion (GMS) countries represents a significant advancement in cultural heritage informatics. This research aimed to create a comprehensive framework for defining and elucidating the concepts and relationships within tangible cultural heritage, specifically focusing on Khmer stone castles in Thailand, Laos, Vietnam, and Cambodia. The study's innovative approach bridges the gap between architectural characteristics and historical contexts, contributing to a more nuanced understanding of regional cultural heritage (Changmai et al., 2022; O'Reilly, 2006; Higham, 2001). The ontology development process adhered to established methodologies in knowledge organization and semantic web technologies (Uschold & King, 1995; Manola & Miller, n.d.). The resulting framework catalogs architectural elements and interweaves historical narratives, providing a multidimensional perspective on these ancient structures (Coe, 2020). This approach aligns with contemporary trends in digital humanities, emphasizing the interconnectedness of cultural artifacts within their broader historical and geographical contexts (Chansanam et al., 2015). A semantic search application was implemented to demonstrate the ontology's practical utility. This application showcases the ontology's capacity to facilitate complex queries, leveraging the intricate relationships among ontological classes. The evaluation process, conducted by ontology specialists, focused on assessing the

framework's efficacy, particularly emphasizing its hierarchical structure. This hierarchical organization proved crucial in ensuring the ontology's accuracy and usefulness within its designated domain of expertise (Buranarach et al., 2016).

The validation process employed a comprehensive evaluation methodology to assess the ontology's structural integrity and descriptive precision. Three specialists in ontology development conducted an in-depth analysis, scrutinizing aspects such as hierarchy, relationships, and terminology consistency. This rigorous evaluation process aligns with best practices in ontology development and validation (Noy & McGuinness, 2001; Garijo, 2017). A series of scenario-based evaluations were designed to assess the ontology's real-world applicability further. These scenarios were carefully crafted to simulate potential real-life applications, testing the ontology's functionality in facilitating information retrieval and integration within dynamic environments. This approach ensures that the ontology meets theoretical standards and demonstrates practical utility in diverse contexts (Belew, 2000). The structural evaluation and practical application test results were systematically compiled and analyzed. The findings indicate that the ontology successfully captures the complexity of Khmer stone castles while maintaining clarity and consistency in its knowledge representation. Moreover, the semantic search application demonstrated the ontology's capability to handle complex queries with high accuracy, retrieving precise information from the intricate network of relationships defined within the ontological structure.

Table 2. List of main classes and definitions

Aspects	Mean	Meaning (Degree)		
Scope determining	4.65	High		
Classes /Concepts defining	4.60	High		
Properties defining	4.50	High		
Instances creation	4.50	High		
Future development and application	4.85	High		
Total	4.62	High		

Thenceforth, results from these practical evaluations were both qualitative and quantitative and contributed insight into the ontology's performance under different conditions and contexts, as shown in Table 2. These dual approaches featured evaluation—combining specialists' evaluation and practical application—to ensure that the ontology accurately reflected theoretical concepts in the real world, facilitating practical and effective implementation of semantic search systems.

The implementation of semantic search technology has significantly enhanced contextual search capabilities by intelligently interpreting the relationships between ontological schemas and contextual meanings (Buranarach et al., 2016). Unlike conventional search systems that primarily rely on character comparison methods for data or document retrieval, semantic search employs a more sophisticated approach to comprehend user queries' underlying concepts and intentions (Belew, 2000; Manola & Miller, 2011). This advanced search methodology transcends the limitations of basic keyword matching, which often fails to represent user intentions accurately. Consequently, semantic search reduces the retrieval of cognate yet irrelevant results, facilitating a more precise and contextually relevant search experience (Uschold & King, 1995). These improvements address the challenges posed by the semantic gap between computer interpretation and human understanding, a persistent issue in information retrieval systems (Buranarach et al., 2016). They were developing the system as a web-based application, considering multiple factors to deliver meaningful search results and enhance accessibility. These factors included search contexts, word variation arrangements (corpus), and comprehensive synonym lists (Chansanam et al., 2015). The semantic search system accommodates both generalized and specialized queries, catering to diverse informational

needs, including those of domain experts, through advanced concept-matching techniques (Noy & McGuinness, 2001). Concept matching is crucial for professionals and researchers who require precise and relevant search results within specific knowledge domains. These users often work with complex concepts that may not be explicitly mentioned in the texts or documents they are searching through. Therefore, they rely on the search system's ability to understand context and conceptual relationships to identify pertinent information (Broughton et al., 2005; Garijo, 2017). By addressing these challenges and incorporating advanced semantic technologies, the search system provides a more intelligent and user-centric approach to information retrieval, significantly improving the accuracy and relevance of search results in academic and professional contexts.

This research contributes significantly to cultural heritage informatics by providing a robust ontological framework for Khmer stone castles in the GMS region. The study's methodology, combining rigorous ontology development with practical application testing, offers a model for future research in digital cultural heritage. By bridging the gap between theoretical knowledge organization and practical information retrieval, this ontology paves the way for enhanced understanding and preservation of Southeast Asian architectural heritage.

## Conclusion

In conclusion, this study has significantly developed an ontology for a semantic search system for Khmer stone castles in the Greater Mekong Subregion (GMS), aligning with UNESCO's cultural heritage preservation policies. The research emphasized the importance of compiling tangible cultural heritage inventories, fostering scholarly inquiry, and accumulating relevant documentation to support effective safeguarding measures and educational initiatives. To this end, we proposed and implemented a specialist-verified database of Khmer stone castles, ensuring high data quality and reliability. The systematic organization of this database facilitated the establishment of a comprehensive knowledge base structured to maximize accessibility and utility for educators, researchers, and other stakeholders in the field. We enhanced the knowledge base's value and applicability by adhering to rigorous standards and requirements. At the same time, regular updates and data interlinking strategies were employed to optimize knowledge dissemination—a crucial aspect of tangible cultural heritage management. The study's outcomes demonstrate the ontology's efficacy and potential in accessing information about Khmer stone castles in the GMS countries. This ontology serves as a potential benchmark for cultural information retrieval. It paves the way for developing similar search systems across various domains, potentially revolutionizing knowledge storage and retrieval methodologies. Moreover, this research lays the groundwork for further exploration of ontology-based approaches in cultural heritage preservation, particularly in developing sustainable, web-based information search systems utilizing semantic networks. The implications of this study extend beyond its immediate scope, offering valuable insights and methodologies that contribute to the ongoing efforts to conserve and democratize access to our rich cultural heritage.

Future research directions may include expanding the system to encompass a broader range of cultural artifacts, integrating machine learning techniques for improved search accuracy, and exploring cross-cultural applications of the developed semantic framework. Additionally, investigating the potential of this system in supporting virtual tourism and enhancing global cultural understanding could yield fruitful avenues for further study.

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