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Ontology-based data framework for the digital preservation cultural heritage: A case of *Subak*

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Abstract: Cultural heritage is increasingly fading due to the influence of globalization and social changes that shift traditional values. Digitalization is critical to addressing the degradation of cultural heritage knowledge by enabling more accessible storage and documentation and facilitating preservation and education efforts for future generations. *Subak*, as a unique traditional agricultural system in Bali, Indonesia, has a wealth of valuable knowledge and culture, but it is still scattered and unstructured. An ontology-based Knowledge Management System is designed to capture, organize, and utilize knowledge within a domain using ontologies as a fundamental component. Ontologies explicitly represent knowledge by providing meaning, properties, and relationships with related concepts. This paper proposes data modelling with the Ontology Development framework for the knowledge base. The methodological framework consists of knowledge externalization, including identifying and collecting knowledge based on data modelling through interviews and observations. The second steps are modelling and development of ontology, based on the knowledge that has been previously disclosed, including the hierarchical structure, properties, and relationships that form the knowledge base. The third stage is the Implementation and evaluation, which involves evaluating the quality of ontology using onto metrics and implementing the ontology into the KMS. The result of this study is data modeling for the knowledge base and the Ontology Development framework. The data modelling is a form of data mapping based on a combination of traditional philosophy and modern management principles that underlie Subak activities and artefacts, namely Tri Hita Karana, Desa Kala Patra, and POAC. The proposed framework can be a reference in developing new ontologies from scratch on unstructured cultural heritage data.

Keywords: Cultural heritage, Digital preservation, Knowledge Externalization, Ontology Development, Ontology Evaluation

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Introduction

Digitizing cultural heritage has become a significant concern for researchers and practitioners [1][2][3][4][5][6][7][8]. Cultural heritage is not just about history but about identity, shaping origins, informing current conditions, and guiding the future. This heritage is a source of pride and an irreplaceable basis for human unity. However, as modernization progresses, there is a real fear that these cultural treasures will be lost. Many efforts have been made to digitize cultural information using video content, photos, museums, and digital documents. However, contextual information and tacit cultural practices have not yet been fully accommodated in the process [4]. Tacit knowledge refers to knowledge derived from personal experience, deeply ingrained within an individual, difficult to articulate and convey, and synonymous with practical knowledge [9]. This knowledge is often embedded in social interaction and direct experience, making it difficult to represent it explicitly digitally. A large amount of cultural knowledge is kept secret and shared exclusively within the community. Therefore, a new digitalization approach must incorporate both explicit and tacit aspects of cultural information.

The digitalization of cultural information should increase ease of access and knowledge sharing [10]. Through digitalization, cultural knowledge can be presented in various formats so

that it can be easily accessed. This opens up opportunities to disseminate knowledge among individuals, groups, and communities. Therefore, the digitization of cultural information has great potential to enrich and preserve cultural diversity, encourage intercultural dialogue, and increase understanding and appreciation of valuable cultural heritage for future generations [11]. The digitization of cultural information is essential for managing the risks of losing valuable knowledge [1]. Converting cultural information into digital format makes it durable and easily accessible, minimizing the risk of degradation [12], damage, or loss due to various factors. Digitalized cultural data is valuable for strategic planning, policymaking, and effective cultural heritage management, providing a foundation for sustainable preservation efforts. Knowledge Management System (KMS) [13], a field of science that aims to capture, organize, disseminate, and utilize knowledge, has the potential to be vital in maintaining the sustainability and accessibility of valuable traditions of cultural heritage more effectively [14]. In a KMS, information is collected, stored, and organized using information technology so that users can access and use it efficiently.

Currently, many KMS are developing based on ontology [3], [8], [15], [16], [17], [18]. Ontology-based KMS uses a formal semantic structure to represent knowledge and relationships between entities. Ontologies enable a deeper understanding of the meaning and context of information, thus facilitating more informed decision-making and analysis processes [19]. By leveraging ontologies, KMS can become more competent in providing users with relevant information and deeper insights. Ontology is a formal, evolving knowledge model that defines entities, attributes, relationships, and rules within a domain. It ensures semantic consistency, supports knowledge discovery and reasoning, and facilitates interoperability, thereby serving as the core structure for knowledge creation, storage, retrieval, and application within a KMS [18]. Ontology is the basis for developing intelligent applications and systems that can produce a deeper understanding and consistent interpretation of various aspects of knowledge, one of which is applied in cultural preservation [6]. Based on the literature review, no research has discussed the development of Ontology-based *Subak* KMS, which represents the agriculture Balinese culture and tradition. This project aims to increase the Balinese and the younger generation's understanding of essential aspects of knowledge and culture with the Ontology-based KMS *Subak* in the form of an online digital portal system. Several forms of KMS cultural heritage have been developed in various countries. The South African government has developed the Indigenous Knowledge System [20] to formally protect and promote their traditional practices, knowledge of natural medicines, and oral history. The Korean Cultural Atlas [21] has been created, serving as a digital platform to map and record the nation's various cultures, languages, and traditions.

This research is the initial stage of a digital project that aims to uncover and present complex knowledge through a digital platform in order to benefit many individuals who have a deep interest in Balinese culture and traditions. This paper presents a framework for structuring and categorizing knowledge to facilitate preserving, archiving and disseminating distinctive cultures by leveraging people's expertise and understanding of their cultural heritage. The challenge in digitizing cultural heritage is preserving non-material information, such as historical narratives and cultural practices. UNESCO has recognized that such information is fragile and prone to being forgotten, making the digitization of cultural knowledge essential for preservation [22]. Bali, renowned as a global tourist destination, owes its appeal to its distinctive culture, encompassing activities and practices, traditional music, dance, painting, and stunning natural landscapes. The complexity of Balinese cultural knowledge [23] necessitates significant effort to model it, even for cultural experts and local communities. Much of this knowledge is embedded in tacit forms and integrated into the everyday practices and traditions of Balinese life.

One interesting cultural practice in Bali is *Subak*, an irrigation and farming activity rooted in Balinese culture. Moreover, in the lack of detailed documentation on Balinese culture, especially the Balinese *Subak*, this study becomes even more challenging and meaningful. Furthermore, the diverse and non-standard complexities of *Subak* practices emphasize the importance of accurately understanding and capturing this information and integrating it into a suitable system.

Methodology

Ontology Modelling

Ontologies have been developed based on various research methodologies in various cultural preservation domains. Most of the ontology of cultural preservation was formed from

scratch [24]. This causes the research methodology to be more adapted to the characteristics of data collection challenges and the scope of the knowledge domain. The challenges of data collection in cultural preservation often include data sources that are scattered across multiple media, languages, and formats. In addition, a deep understanding of the cultural domain is required to recognize that cultural data is deeply rooted in local traditions and interpretations, which require careful handling to maintain accuracy and authenticity in representing aspects of intangible heritage. Previous research conducted a literature study to formulate a research methodology for developing the *Subak* ontology as a stage of this research [25]. The system in this study is designed and developed using the Ontology Development Methodology (ON-ODM), which has been adapted to the *Subak* knowledge domain.

Ontology modeling is needed to represent knowledge. Ontology modeling is a framework for analyzing relationships between classes and their properties. CIDOC-CRM is an ontology modeling developed to harmonize the domains of libraries, museums, archives, and cultural data sets. It has now defined 99 classes and 198 properties [26]. In this research, CIDOC-CRM is only used as a modelling reference; many adjustments have been made considering that the complexity and characteristics of the specific *Subak* domain are very different from the framework offered.

Ontology evaluation involves external validation and internal consistency. External validation begins with selecting CQs to become Golden CQs, which are then implemented using SPARQL queries and modelling guidelines as references to validate ontology modelling. Experts will confirm the validity of fulfilling sufficient knowledge that SPARQL can find. If it is deemed insufficient, enriching the ontology is necessary. Internal consistency checks the ontology's syntactic correctness and internal consistency using the reasoning program (reasoned) included in Protégé. Ontology Metrics OntoQA [27] are used to measure ontology consistency. Considering that knowledge continues to develop, knowledge adequacy is addressed by continuous and structured knowledge enrichment.

Proposed Model

The proposed model Figure 1 based on previous study [25], involves three activities: 1) Knowledge externalization, 2) Modelling and Development and 3) Implementation and Evaluation. Knowledge will continue to be completed in the enrichment stage to ensure sufficient knowledge. Knowledge externalization ensures that implicit and explicit knowledge in the cultural domain can be identified and systematically structured. Furthermore, Modelling and Development enable the knowledge to be translated into an organized ontology structure, while Implementation and Evaluation ensure that the ontology functions well in real applications and is relevant to the purpose of cultural preservation.

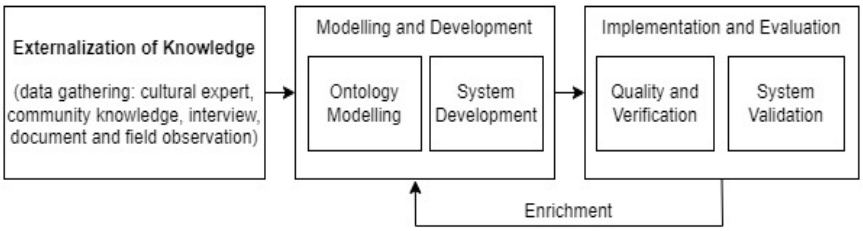

Figure 1. Proposed ontology development methodology

Results and Discussions

The knowledge domain must be determined before developing ontology-based knowledge; this is to provide limits to the extent to which the scope of knowledge will be accommodated and focused. This step is followed by determining the objectives of ontology formulation and the stages of developing the ontology.

To build an inclusive and comprehensive Balinese Subak ontology, a structured and collaborative approach needs to be applied so that all aspects of Subak culture and knowledge

are represented. The first step is to conduct an in-depth identification of the concepts and relationships in the Subak system, such as the principles of Tri Hita Karana, irrigation practices, and agricultural land management, which can be broken down into more detailed sub-categories. Next, involve various stakeholders, such as Subak farmers, community leaders, cultural experts, and academics, to collect tacit and explicit knowledge that may not be formally documented but plays a vital role in Subak's sustainability. Participatory mapping and focus group discussions with stakeholders can ensure that the practical knowledge and social values underlying Subak are documented in the ontology.

Subak knowledge is not only documented but also hierarchically structured and connected in certain relationships. This procedure allows aspects of tradition, environmental values, and Subak ritual practices to be integrated into a digital system. The resulting ontology supports the interoperability of cultural knowledge, so that cultural data such as Subak can be shared, analyzed, and utilized by various parties at the international level for research, education, and culture-based tourism. The Subak ontology can be a model for other cultures to overcome the challenges of digitalization and preservation, while maintaining the authenticity and richness of local values within the global ecosystem.

Knowledge Domain

Bali is an island that is part of Indonesia's country and is known as one of the provinces with the smallest area. Balinese cultural heritage is preserved by carrying out daily activities and religious rituals to maintain the continuity of tradition. The next generation learns and accepts this heritage through experience at every stage of local Balinese cultural activities. The foundation of Balinese culture is found in the structure of traditional Balinese society, including *Desa Adat* (also known as *Desa Pekraman*), *Banjar*, and *Sekaa*. Although the trend of modernization has emerged, religious ceremonies, which are an integral part of the thoughts and views of the Balinese people, are still upheld at the same level of relevance and importance from the past to the present. The traditional agricultural system exclusive to the island of Bali, namely the *Subak* System, plays a central role in the structure of Balinese society and acts as an irrigation method that is still carried out from generation to generation.

Subak is a traditional irrigated farming system unique to the island of Bali, Indonesia, and forms the core of Balinese life. The *Subak* system is based on the principle of Tri Hita Karana, a philosophical concept about the three causes of human happiness that can be achieved by maintaining harmony between the elements of *Parhayangan* (God), *Pawongan* (humans), and *Palemahan* (environment) [23]. In *Subak*, farmers respect and perform various religious ceremonies, ensure the sustainability and fertility of nature through fair and sustainable water management, and promote mutual welfare by dividing the harvest fairly among *Subak* members. In addition, *Subak* is also related to the concept of Desa Kala Patra, namely the view that the village is a reflection of the wider cosmos. *Subak* has an essential role in reflecting and implementing the principles of Desa Kala Patra by setting the time and planting season based on the layout of the Hindu calendar and astronomical order. Farmers consider the right moment to carry out agricultural processes and religious ceremonies based on natural cycles, creating a balance between human activities and the universe. Those activities show that *Subak* has implemented modern management principles in planning, organizing, actuating, and controlling (POAC) activities. UNESCO recognized *Subak* as a World Cultural Heritage in 2012 for its role in preserving cultural values, sustainable agricultural practices, and social harmony on the island of Bali [28]. Even though faced with the challenges of modernization and urbanization, *Subak* continues to survive and adapt to changing times so that it remains a valuable cultural heritage and becomes an essential part of the identity and life of the Balinese people.

Cultural heritage is a cultural heritage from the past in the form of physical artefacts (cultural assets) and intangible attributes that are still used for the lives of today's society and then passed on to future generations in a sustainable manner. To move into the digital era, cultural heritage institutions such as galleries, libraries, archives, and museums have begun to identify the need to digitize their collections and make them available online [29]. The most important goal of cultural heritage KMS is to make cultural heritage knowledge accessible, further developed, and passed on to future generations. In addition, cultural information has an important role as a facilitator of collaboration because it involves various interrelated disciplines,

allowing students, researchers, teachers, and the community to explore and study cultural heritage [3]. Cultural heritage KMS includes sites, objects, and intangible objects with cultural, historical, aesthetic, archaeological, and scientific value for groups and individuals. KMS is not just about preserving information but also about optimizing the use of organizational knowledge. It involves the systematic management of the knowledge held by an organization to ensure that the knowledge is not only well stored but also well organized and easily accessible to members of the organization.

Externalization of Knowledge

The initial phase in converting knowledge from tacit to explicit within the construction of the *Subak* ontology is called externalization. Currently, individuals possess tacit knowledge, such as farmers, community leaders, or *Subak* experts. This information is being transformed into explicit knowledge, organized and standardized based on ontology. The primary objective of this initial phase is to externalize knowledge and construct a fundamental ontology model that a computer-based system can utilize to enhance the process of searching and retrieving information about *Subak*. This phase can be conducted through direct interaction, interviews, observation, and also active engagement in *Subak* activities.

This tacit knowledge includes traditional practices, cultural values, ways of thinking, and understandings that are only sometimes easily expressed verbally. *Subak* knowledge is primarily tacit and transmitted through socialization processes (tacit-to-tacit) within the Balinese social system across generations. Therefore, representing this knowledge often involves using imagery, activities and other non-verbal methods that do not rely on formal language. However, the externalization of tacit knowledge remains one of the most challenging stages in the knowledge conversion process. An extensive literature review was conducted to develop the interview framework and identify critical issues related to *Subak*. The snowball sampling strategy was employed to facilitate the externalization of community-based tacit knowledge. In this method, participants are asked to recommend others relevant to the study, making it particularly suitable for research involving unfamiliar topics or complex phenomena. Each snowballing process, initiated independently by experts in specific groups, generates distinct networks of participants. The snowballing continues until data saturation is achieved, meaning no new information emerges, and participants begin to provide redundant responses.

A semi-structured interview was employed to collect data, enabling the researcher to address specific questions and topics. It also allows participants to offer additional insights and elaborate on any aspects of their experiences they consider relevant to the study [30]. The interview questions were organized into three primary categories: (a) the history of *Subak*, (b) the artefacts of *Subak*, and (c) the practices of *Subak*.

The stage of knowledge externalization is through three approaches: metaphors, analogies, and models [13]. The metaphor-based externalization method uses comparisons or metaphors to express tacit knowledge. Knowledge of water flow in nature can be used as a reference for understanding the concepts and functions of the *Subak* irrigation system, thereby assisting in designing an appropriate and more structured ontology structure. Furthermore, analogies can be used to describe how the *Subak* irrigation system functions by likening it to more familiar examples. For example, the *Subak* irrigation system is analogous to a modern water canal system. This analogy helps us understand the functions and mechanisms of the *Subak* irrigation system more quickly and clearly, thereby facilitating the representation process in ontology. The third approach is modeling, where a physical or digital model can show how the *Subak* irrigation system works, how the cropping pattern is carried out, and how other aspects of *Subak* interact. This model helps in visualizing knowledge about *Subak* in a more concrete and in-depth manner.

Modelling and Development

Based on the interview result, we propose the *Subak* ontology-based data Framework as depicted in Figure 2. The framework is used for ontology modeling to explore, classify, and organize *Subak* knowledge. The ontology is designed using Balinese language representation, considering that many *Subak* terms are terms Balinese people use in their traditional lives. With this framework, the mapping of *Subak* knowledge is carried out by outlining the main principles of Balinese culture, namely Tri Hita Karana and Desa Kala Patra, as well as the application of

modern management, namely the POAC principle. Tri Hita Karana, a philosophical concept about the three causes of human happiness [23] which consists of (1) Universal (*Parahyangan*), namely the relationship with the creator of the universe, (2) the environment (*Palemahan*), namely the relationship with nature, and (3) humans (*Pawongan*) namely harmony between people. These three concepts are applied in *Subak* activities, where each stage of rice field management will begin with a religious ceremony (*Parahyangan* activities), starting from seeding, tillage, planting, and maintenance until harvest time arrives to preserve nature (*Palemahan* activities). Activities will be carried out together in mutual cooperation (*Pawongan* activities).

The second concept, known as space (*desa*), time (*kala*), and circumstance (*patra*), suggests that individuals are active agents who continuously adapt to the environmental conditions influencing their lives. This Desa Kala Patra framework provides a lens through which to understand the variations in *Subak* irrigation management rules applied in different Balinese communities' locations. The third mapping concept is that modern management functions have been implemented in every *Subak* activity, from planning, organizing, actuating, and controlling [23]. So, in the end, it will map *Subak*'s knowledge in the category of artifacts and practices. According to the UNESCO Convention in 2021, intangible cultural heritage encompasses a wide range of practices, representations, expressions, knowledge, skills, instruments, objects, and artefacts that exist across diverse cultural contexts [22].

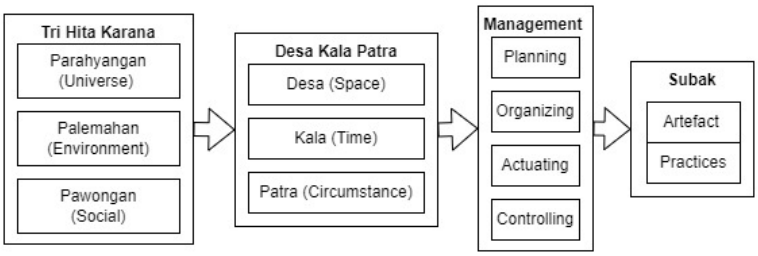

Figure 2. *Subak* ontology-based data Framework

Information representation operates on two distinct levels: syntax, which emphasizes the volume or structure of the information, and semantics, which focuses on the meaning of the information and its relationships with other concepts [31]. Ontology is an alternative to represent the knowledge domain, where this method helps in modelling semantic concepts and logical language.

Ontology modelling framework refers to CIDOC-CRM that allows information integration, mediation, and exchange of heterogeneous cultural heritage data and its correlation with digital libraries [32], [33], [34]. Knowledge will be modelled in the ontology concept. The concept of knowledge ontology has several main components, namely: Classes: explain concepts, general things from knowledge in a domain. A class has subclasses that are intended to express more specific concepts than the superclass. Properties are two-way relationships that connect classes with other classes to form knowledge/concept links. There are two types of ontology properties, namely object properties which connect objects with other objects, and data properties which connect objects with data type values (text, string or number). Object properties define the relationship between classes, where Subclass is an inheritance relationship. Data Properties is properties of data that represent attribute of the class. Instances/particular things/objects are individuals/members, which are actual objects of a class containing facts/information from a concept/knowledge. Constrains are rules for these things. Relationship is the concept of relationships between these things. Functions are processes that involve these things. Protégé is used to help visual depiction of knowledge concepts. This stage produces class hierarchy and an ontology graph.

Ontology development can be classified into two categories: (i) creation from scratch [35] and (ii) reuse and integration with existing ontologies based on the specific knowledge representation needs [36]. In this study, the ontology was developed from scratch to provide flexibility for knowledge expansion, as the process of collecting *Subak* knowledge is conducted incrementally.

Implementation

The KMS *Subak* ontology-based knowledge base publication technology will be based on the semantic web, translating ontology into OWL, XML, RDF, and SPARQL as a query language. RDF (Resource Description Framework) is a standard framework for representing data through web-based graphics. RDF describes resources and the relationships between those resources in the form of subjects, predicates, and objects, known as triples. OWL(Web Ontology Language) creates ontologies on the semantic web. OWL used to define concepts, properties, and relationships between these concepts in more detail and formally. SPARQL Query Language is utilized to access and manage data structured in RDF (Resource Description Framework) format. SPARQL allows users to extract specific information from RDF datasets using syntax similar to SQL.

Evaluation

Ontology evaluation involves external validation consisting of Competency Questions and Expert confirmation. Meanwhile, internal consistency using Ontology Metrics, which is accompanied by a graph ontology application, in this case, Protégé. Considering knowledge continues to develop, knowledge adequacy is addressed by enriching knowledge in a sustainable and structured manner. Ontology Metrics OntoQA [27][37] used in measuring ontology consistency include Schema Metrics (1)(2)(3), Knowledge base Metrics (4)(5), and Graph Metrics (6)(7)(8)(9)(10)(11). Each metric is calculated based on Equation 1-11.

Schema Metrics [27]

1. Attribute Richness (AR)

$$\mathrm{AR} = \frac{|\mathrm{att}|}{|\mathrm{C}|} \tag{1}$$

Where: |att| is the total number of attributes, and |C| is the total number of classes and subclass in the ontology.

2. Inheritance Richness (IR)

$$\mathrm{IR} = \frac{|\mathrm{H}|}{|\mathrm{C}|} \tag{2}$$

where |H| is the number of subclass relations, and |C| is the total number of classes in the ontology.

3. Relationship Richness (RR)

$$\mathrm{RR} = \frac{|\mathrm{P}|}{|\mathrm{H}| + |\mathrm{P}|} \tag{3}$$

where |P| is the total number of non-inheritance relations (object properties), and |H| is the total number of inheritance relations(subclasses).

Knowledge base Metrics [37]

1. Average Population (AP)

$$\mathrm{AP} = \frac{|\mathrm{I}|}{|\mathrm{C}|} \tag{4}$$

where |I| is the total number of instances of the knowledge base, and |C| is the total number of classes

2. Class Richness (CR)

$$\mathrm{CR} = \frac{|\mathrm{C}'|}{|\mathrm{C}|} \tag{5}$$

where |C'| is the number of classes in the knowledge base, and |C| is the total number of classes

Graph Metrics [37]

1. Absolute Root Cardinality (ARC)

$$ARC = n_{ROO \subseteq g} \quad (6)$$

where $n_{ROO \subseteq g}$ represents the number of elements in the set of root nodes ROO in the directed graph g.

2. Absolute Leaf Cardinality (AC)

$$AC = n_{LEA \subseteq g} \quad (7)$$

where $n_{LEA \subseteq g}$ represents the number of elements in the set of leaf nodes LEA in the directed graph g.

3. Average Depth (AD)

$$AD = \frac{1}{n_{p \subseteq g}} \sum_{j}^{P} N_{j \in P} \quad (8)$$

where $N_{j \in P}$ represents the number of elements on the path j that belong to the set of paths p in the directed graph g.

4. Maximum Depth (MD)

$$MD = N_{j \in P} \forall i \exists j (N_{j \in P} \geq N_{i \in P}) \quad (9)$$

Where $N_{j \in P}$ is the number of elements on the path j, and $N_{i \in P}$ is the number of elements on the path i, which belong to the set of paths P in the directed graph g.

5. Average Breadth (AB)

$$AB = \frac{1}{n_{L \subseteq g}} \sum_{j}^{L} N_{j \in L} \quad (10)$$

where L represents the set of levels in the directed graph g; $n_{L \subseteq g}$ is the number of elements in L, and $N_{j \in L}$is the number of elements on the level j.

6. Maximum Breadth (MB)

$$MB = N_{j \in L} \forall i \exists j (N_{j \in L} \geq N_{i \in L}) \quad (11)$$

where $N_{j \in L}$ and $N_{i \in L}$ are the number of elements on the level j and i respectively that belong to the set of levels L in the directed graph g.

Conclusion

We have discussed the specifics of our research into one area of cultural preservation, the traditional Subak irrigation system in Bali. Our contributions include creating an ontology to capture *Subak*'s largely implicit and fragmented knowledge and externalizing it, which has not been discussed in previous research. This research provides innovation in the documentation and digitization of Subak irrigation and cultural systems through an ontology-based approach. The framework produced in this study integrates the Balinese philosophical basis of Tri Hita Karana, Desa Kala Patra, and POAC management modern, which are founded on Balinese cultural principles, are used to collect, classify, and organize cultural artifacts and apply knowledge. The methodology includes the Externalization of Knowledge, Modeling and Development, Implementation and evaluation stages. Model verification and validation are carried out through consultation with local experts, domain experts, the Subak community, and academics. This approach ensures that the ontology developed is valid, comprehensive, and relevant. This iterative and participatory process allows the ontology model to be adjusted to suit user needs and research developments. The resulting ontology will be used in order to facilitate knowledge sharing and the development of a prototype online digital portal for *Subak* Bali. We are now developing an ontology within the suggested framework and integrating it into the online digital portal system. For implementation, community-based crowdsourcing will be required to provide more detail in order to improve and update the knowledge provided. The *Subak* ontology will be expanded using user input, and the functionality of the digital portal will be improved. This ontology model provides an extensible basis for documenting other cultures, making it a long-term reference for research into local Indonesian culture and the application of technology for sustainable cultural preservation. The ontology development and modeling framework can be a

reference in developing new ontologies from scratch on other unstructured cultural heritage data, especially in the domain of agriculture and social organizations which are often found in agricultural countries.

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