Semantic data model for knowledge representation and dissemination of cultural heritage site, Poompuhar

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Among the ancient cities and ports of Tamil Nadu, India, Poompuhar is a historical and coastal port that emerged with the increasing maritime trade of the early Chola kingdom. The ancient trade town and the busy port of Poompuhar symbolize the Tamil culture and civilization up to 200 CE. The city was destroyed and washed away by big shore waves during AD 500. The submerged parts and scattered destruction remains have been identified in onshore and offshore excavations around the coastal lines of the Bay of Bengal in Tamil Nadu. Information on the port city can be found in various sources, such as archaeological evidence, historical references, coastal erosion data and Sangam Tamil literature. Here, a methodology is presented for a semantic representation of Poompuhar port city, integrating heterogeneous data to create a knowledge base by mapping and associating related entities. The knowledge base has been created using CIDOC CRM to represent Poompuhar events digitally. The experimental results of the ontology are verified exploring the submergence of Poompuhar use cases for onshore and offshore excavations through a knowledge graph.

Keywords: Archaeological explorations, cultural heritage, knowledge graph, ontology, semantic data.

AROUND 2000 years ago, the ancient port city of Kaveripoompattinam or Poompuhar, Tamil Nadu, India, was established by the Chola dynasty is the capital city located at the confluence of the Cauvery river and around estuaries. This port city can be found in various sources such as literature evidences in Silpathikaram, Pattinapalai, Manimegalai, geo-archeological coastal line research data sources, data from land excavation and seashore exploration, as well as from scientific research.

The ship sailed from Rome and Arabia for trade. It travelled to various Asian ports from Tamralipati to Palur as mentioned in the literature. When mapping the places with current geolocation, the terminologies were found identical to West Bengal and Odisha. Finally, the ships were anchored at Kaveripoompattinam port. The ancient port city of Poompuhar connected all trading countries and its coastline covered the districts of Nagapattinam, Karaikal, Mayiladurai, Sirkali, Taragambadi, Chennai, Parangipettai and Cuddalore in the present-day Tamil Nadu.

The port known for its mysterious disappearance was found buried due to sea turbulence in AD 500 (ref. 8). The ancient clay sculptures and minarets found in Poompuhar have been identified through excavation and reported in the literature. Its submergence has been researched using various approaches.

The evidence from excavation studies based on satellite images, real-time kinematic surveys and shoreline data of coastal zones revealed that continuous sea level changes led to a shift of the submerged port city. The deltas of the river Cauvery, viz. delta-A, delta-B and delta-C, were formed during the time of the tectonically induced convex coastlines of the region due to continuous changes in the sea level and interconnected land–ocean interactions. Over the period, the submerged Poompuhar port city location moved from coastlines Delta B to Delta C. Doerr et al. reported Poompuhar-1 as Delta A which is depicted as the first submergence of Poompuhar port city at a particular location and moved four times to other locations due to the sea level rise and sea erosions. It has been estimated that the structures found in the Poompuhar-1 harbour may have been constructed around 11,000–15,000 years ago. The patterns and layout of the structures found in other ancient harbours around the world were similar to those of the Poompuhar excavations.

Cultural heritage sites are pride for any country. When represented digitally the ancient Poompuhar port details will transfer on the culture and tradition to future generations. Knowledge of the cultural heritage of Poompuhar needs to be mapped and integrated with disparate data sources.

Semantic technologies are used to integrate heterogeneous data and ontologies are the standard framework used to represent related concepts. In this study, a semantic knowledge base has been created as Poompuhar ontology to integrate information about the ancient port city. The International Committee for Documentation (CIDOC) – Conceptual Reference Model (CRM) is a standardized ontology model for cultural heritage devised with 99 classes and 198 properties to symbolize culture-related tangible and intangible concepts. The proposed ontology was created by mapping the existing CIDOC ontology to relate knowledge of submerged Poompuhar.
Literature review

We focus on the reviews specifically dealing with the construction of the knowledge model related to CIDOC CRM standards to manage data integration problems within the field of cultural heritage. We outline research carried out across various disciplines using existing standards of CIDOC CRM for extending the domain data model to build knowledge sources. The challenges of diverse data representation formats, data standards and ambiguity of context have been addressed using formal ontology for knowledge engineering for data integration.

The global ontologies like CIDOC CRM for representing cultural heritage are mapped with archaeological evidences on a time frame for knowledge management in the domain cultural heritage. To address the data complexity issues in data structure and for optimized data models, CIDOC CRM and FRBRoo are used.

The study on the excavation of submerged Poompuhar locations was done based on the shift of the Cauvery delta and its tectonic movement, to prove the detection of the submerged harbour with GEBCO, MBES data and underwater profile survey. We have used literary works and geo-archaeological evidence, sedimentary evidence from archaeological sites and a chronological view of the submerged ancient port city to identify variation in shoreline and explore the shift of the Cauvery delta with geo-coordinates.

The domains of archaeology, architecture, cultural heritage, history, library, archival sciences, museology and preservation science have extended their ontology model with CIDOC conceptual reference. The semantic applications for publishing and visualizing linked data for museums have been discussed using CIDOC CRM as the domain knowledge representation.

CIDOC CRM ontology

CIDOC CRM defines the formal structure of cultural objects and their implicit and explicit relationships for museums. It was developed by the International Council of Museums and the International Council of Documentation to build one common metadata standard and formal ontology for solving information management problems for museum data. CIDOC CRM was recognized as an ISO standard in 2006. The model has temporal entities involving historical information and events related to spatio-temporal information. CIDOC CRM contains formal ontology with a global schema to integrate domain-specific entities relating to global standards. The present CIDOC CRM ontology contains 99 classes and 198 properties. It can be extended with formal ontologies like FRBRoo to represent bibliographic information and PreSSoo to document and relate bibliographic information with serials. The ontology can be extended as specified: CRMinf is the global schema for integrating metadata of different domains with cultural heritage. CRMsci is used to map scientific observations and measurements. CRMdig is used to represent 3D modelling data. CRMarchaeo is used to document on excavation objects. CRMgeo is used in the domain of geophysics for representing geolocations with base-compatible standards.

Architecture and methodology

Figure 1 describes the construction of data architecture to develop a knowledge model to digitize Poompuhar. The conceptualization of Poompuhar requires mapping information related to the culture, civilization and landscape of the ancient city. The data sources to represent Poompuhar have been extracted from the Sangam Tamil literature and other archaeological sources, such as artefacts, inscriptions in temple pillars and copper coins to conceptualize cultural knowledge base. Information on the submergence of Poompuhar denoted as ‘sea-submerged Poompuhar’ due to repeated floods, neo-tectonic activities, tsunamis, sea incursions, changes in ecology, invasions, natural calamities, changes in climate deforestation, water flow structure change in rivers, and other reasons like declining of Indus civilization by external invasions and epidemics are gathered from a literature study on the geological landscape to integrate into the knowledge base. The gathered domain knowledge was mapped to the global standard CIDOC CRM to describe the knowledge base to extract information on the ancient port city.

Knowledge graph: creation

Step 1: Data acquisition – acquisition of cultural heritage data from heterogeneous data sources (*.txt, *.docx, *.html, *.shp; Figures 1 and 2).

Step 2: Data cleaning and data standardization phase was carried out to preprocess data to remove inconsistencies, transform and retrieve domain entities. (i) Identifying individual entities using named entity recognition (NER) as a port, ruler or king. (ii) Taxonomy: Domain conceptualization of Poompuhar entities in a hierarchical structure.

Step 3: Creation of knowledge model: (i) Construction of ontology by representing concepts as classes, properties of both data and object as relations, instance data as attributes and individuals (Figure 3) and (ii) Representation of concepts, properties and instances to relate and associate the ontology terminologies with cultural heritage domain knowledge.

Step 4: Exporting knowledge representation in machine readable form as .RDF.

Step 5: Visualize knowledge as a knowledge graph.

The methodology for exploring Poompuhar was carried out in two phases. In the first phase, entities conceptualized from archaeological and literature sources (Figure 1) were mapped with CIDOC CRM entities directly and indirectly. In phase 2, CIDOC CRM properties, types and axioms of
**Figure 1.** Architecture of knowledge mapping: cultural heritage Poompuhar, Tamil Nadu, India (KM: CHP).

**Figure 2.** Data acquisition – cultural heritage.

**Figure 3.** Ontology mapping – cultural heritage.
Poompuhar entities were related to the events of culture, and submergence of city-specific to timeline.

**Phase 1: Direct and indirect entity mapping of Poompuhar with CIDOC CRM:** The archaeological and geological evidence of the submergence of Poompuhar3 associated with landscape, culture and artificial objects were mapped with temporal events, timelines, evidence from inscriptions directly using CIDOC CRM19 classes and properties (Table 1).

**Mapping of entity evidence with CIDOC subclass for inscriptions**

**Domain knowledge:** The ‘inscriptions’ related to the port city of Poompuhar found in the ancient literature were mapped with CIDOC CRM (Table 2 and Figure 4).

**Indirect mapping by the creation of new classes**

CIDOC CRM does not have relevant classes to be mapped with the identified evidence in the archaeological excavation carried out at off-shore locations of Poompuhar and below sea level3. New CIDOC CRM entities were created as new classes to represent the port city with prefix as DPE (digital Poompuhar entities) and corresponding properties with the prefix DPpro (digital Poompuharproperty). The created classes and properties were used to map the domain knowledge of research experts for conceptualizing the submergence of Poompuhar based on geological studies indirectly with CIDOC CRM (Table 3)3.

**Property mapping with domain entity for representing coastal erosions**

**Domain knowledge:** The archaeological evidence and literary works that describe the repeated occurrence of natural calamities in the Poompuhar (coastline town) region were mapped (Table 4). The relevant classes and properties to describe the domain knowledge, as shown in Figure 5, were not available in CIDOC CRM. Hence a new class ‘coastline town’ and property were mapped with the ontology.

**Phase 2: Property types and axioms related to entities**

The description of Poompuhar requires functional mapping of multiple related entities through property relations, property
Table 2. Poompuhar entity mapping with CIDOC CRM subclasses

<table>
<thead>
<tr>
<th>Entity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E31 document</td>
<td>Port city evidence: inscription described in the literature</td>
</tr>
<tr>
<td>E32 authority document</td>
<td>Evidence identified through archaeological excavation</td>
</tr>
<tr>
<td>E55 type</td>
<td>Objects identified through AR excavation mapped as man-made and natural</td>
</tr>
<tr>
<td>E16, E54, E60</td>
<td>Objects identified for their measurements (the structure of the onshore explorations), dimension (the width and depth of the object findings of the Poompuhar), scale and value</td>
</tr>
</tbody>
</table>

Table 3. Indirect data mapping of domain entities (Poompuhar)

<table>
<thead>
<tr>
<th>Created entity</th>
<th>Object properties</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPE2: Evidence</td>
<td>DP_{np,1} – has suggested (created)</td>
<td>To map, the archaeological evidence and literary work to state natural calamities that occurred at the Poompuhar region</td>
</tr>
<tr>
<td>DPE3: Coastline town</td>
<td>DP_{np,2} – border of</td>
<td>To map the current location of Nagapattinam district and other districts of submerged Poompuhar</td>
</tr>
<tr>
<td>DPE4: Place (E53) name</td>
<td>DP_{np,3} – submerged due to (created)</td>
<td>To map Poompuhar (DPE4) submergence due to (DP_{np,3}) coastal erosion and other related sea events indirectly using (E53 – name)</td>
</tr>
<tr>
<td>DPE4: Place (E53) name</td>
<td>DP_{np,4} – had yielded</td>
<td>To map the offshore exploration of current geological studies of Poompuhar location Kilaiyur (E53) indirectly (DPE4) using has yielded (DP_{np,4}) to archaeological evidence (DPE2)</td>
</tr>
</tbody>
</table>

Figure 4. Direct entity mapping: digital Poompuhar ontology. (CIDOC CRM concept: conceptual object).

restrictions and axioms to infer knowledge. Table 5 lists the relations identified in CIDOC CRM to map the Poompuhar ontology entities.

Figure 6 shows the knowledge model of the port city developed as the Poompuhar ontology mapped with CIDOC CRM. The ontology is related to the literature and archaeological evidence associating multiple entities and natural events to infer knowledge on evidence of the port city, the richness of cultural heritage mapped with spatio-temporal events, trade links, submergence of Poompuhar and objects identified at various timelines. The developed ontology consists of 147 classes, 13 object properties, five data properties and 34 individuals. The use cases for results and discussions have been inferred from the Poompuhar ontology.

Results and discussion

Here we discuss the use case to extract the related knowledge of the port city events caused in offshore and onshore sites using the Poompuhar ontology.

Offshore excavations – archaeological evidences

Digital Poompuhar evidence has been categorized under three variant sources: archaeological, geological and literary parts. The offshore excavation data of Poompuhar were extracted from archaeological evidence on ancient artefacts like pottery, jewellery made of beads and terracotta, copper objects like vessels, rings, bangles, wires and rattle, stone objects like...
Table 4. Poompuhar property mapping with domain entities

<table>
<thead>
<tr>
<th>Created entity</th>
<th>Object properties</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linguistic object (E33)</td>
<td>Represents (P138)</td>
<td>Explored evidence found in the epics (Pattinapalai) is mapped with physical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>man-made things (E24) identified during archaeological excavation such as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>excavated burnt bricks</td>
</tr>
<tr>
<td>CIDOC CRM entity</td>
<td>Properties</td>
<td>Created classes property mapping</td>
</tr>
<tr>
<td>E33: Linguist object</td>
<td>P72: has language</td>
<td>Evident inscriptions</td>
</tr>
<tr>
<td>E90: Symbolic object</td>
<td>Has inscriptions</td>
<td>Depicts civilization</td>
</tr>
<tr>
<td>E24: Physical man-made thing</td>
<td>P45: consists</td>
<td>To excavate burnt bricks</td>
</tr>
</tbody>
</table>

Figure 5. Indirect entity mapping (CIDOC CRM concept – digital Poompuhar ontology).

pestles for grinding grain, iron knives, nails, brick figures and copper coins. The objects identified through archaeological excavation described in the epics were integrated and related with geological locations mapped to districts in the Poompuhar ontology as the knowledge base.

Use case 1: Integrated information: archaeological evidence on Poompuhar excavation objects

Knowledge mapping: terracotta ring wells: The evidence of terracotta ring wells, square copper coins, shaped brick structures, wharves, brick buildings, boat jetties and water reservoirs of excavated objects related with the information cited in the epics like Ahananuru, Purananuru, Pattinapalai, Silappadikaram and Manimekalai were integrated and mapped with offshore locations Kilaiyur, Vanagiri and Sampathi Amman Temple. The Poompuhar ontology was also integrated with information extracted from the literature review of geological studies related to offshore excavation locations.

Knowledge mapping: Buddha statue: In 1927, near Melaiyur some offshore evidences of Poompuhar like gold-plated statues of Buddha or Bothi Sathuva Mytheya, Wharve structures were identified. These evidences are mapped with timeline, period and spatio-temporal location concepts.

Use case 2: Integration of Sangam literature of Poompuhar evidence

The Sangam literature and epics elaborate the whole town-planning system of ancient Poompuhar. The glory of Poompuhar and the life and achievements of King Thirumavalavan, also known as Karikala Cholan, are also mentioned.

Mapping of history of rulers described in poetry: The Chola king Musunkunda Chakravarthi ruled from the city of Karur (present). His rule ended with the conquer of the fortress by the mythological Chola king Sembian.

Knowledge mapping on the exploration of the ancient town of Poompuhar with the epic Silapathigaram: The ancient town of Poompuhar was surrounded by five mandrams, four gardens, and nearly 16 temples as mentioned in the epic Silapathigaram listed with town layout containing avenues, streets, mansions, residences of foreign merchants, gardens, market places, traders, workshops, well-designed streets occupied by Yavana sailors, overseas traders, weavers, silk
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Table 5. Poompuhar ontology property mapping

<table>
<thead>
<tr>
<th>Properties</th>
<th>Type</th>
<th>Axioms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property relations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP: found_yields</td>
<td>Transitive property</td>
<td>Yields (evidence) found in more than one place.</td>
</tr>
<tr>
<td>DP: Cauvery delta</td>
<td>Functional property</td>
<td>Yields (evidence) found in more than one place.</td>
</tr>
<tr>
<td>Inverse property of DP: ContainsExplanations</td>
<td></td>
<td>River cauvery delta movement along with the changes of sea level contains explorations of submerged puhanar.</td>
</tr>
<tr>
<td>DP: Cauvery delta</td>
<td></td>
<td>Yields (evidence) found in more than one place.</td>
</tr>
<tr>
<td>DP: nearby cities</td>
<td></td>
<td>Connects a city to the neighbouring countries to establish trade links and culture-sharing.</td>
</tr>
<tr>
<td>DP: Country</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP: State and DP: City</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class axioms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP: Archaeological_Sources</td>
<td>Complement</td>
<td>Two complement subclass of DP: Archaeological_Sources: one for artefacts and another one for inscriptions, such that no member of one class can be a member of the other.</td>
</tr>
<tr>
<td>DP: Evidence</td>
<td>Union of</td>
<td></td>
</tr>
<tr>
<td>Property value restriction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP: City</td>
<td>Has value</td>
<td>The ancient port city located in Kaveripoompattinam, property value restriction depicts as</td>
</tr>
<tr>
<td>DP: Country</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP: State and DP: City</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| traders, grain merchants, jewellers and gem makers. Figure 7 shows the domain mapping of Poompuhar temples, gardens and mandrams inferred from the literature as a knowledge graph.

Onshore explorations – geological evidences

The onshore exploration of Poompuhar below sea level based on scientific studies in the literature was integrated into the Poompuhar ontology.

Use case 3: Geological evidence for Poompuhar region through explored structures under the ocean

Mapping Poompuhar submergence onshore evidence with the literature: Poompuhar has submerged due to natural calamities like tsunami, floods, coastal erosions or sea incursions. In epics and literatures, information about the submergence of city can be found. Using past shoreline data from general bathymetric chart of the oceans (GEBCO), traces about the existence of submerged Poompuhar with geographical evidences have been reported. The geographical onshore explorations revealed coast cairn circles, urn burials (Suryakundam, Somakundam, U-shaped structure) at a water depth of 8–25 m in the Bay of Bengal near the shoreline, sand sediments and the movement of shoreline data. Presently, the Poompuhar location exists with six villages, namely Sayavanam/Thirusuakadu, Pallavanisvaram, Mellapperumpallam, Keelaperumpallam, Keezyur and Vanagiri. The evidences on submergence of Poompuhar from literatures and onshore explorations are associated and related with Poompuhar Knowledge model.

Conclusion

In this study, an integrated data model has been developed using ontology for the ancient port city of Poompuhar by integrating heterogeneous data from archaeological, geological and literary evidence. The existing properties and
classes of the cultural heritage knowledge model CIDOC CRM were reused with additional domain entities and properties to map the events of the submergence of Poompuhar. CIDOC CRM entities were mapped directly to relate events with evidence from the literature and archaeology. Indirect mapping was done to related events that occurred onshore using the new domain entities created. The experimental results were explored as knowledge graphs inferred from the knowledge base for various use cases related to the submerged Poompuhar excavated evidence. The excavation equipment and devices are not described in the mapping, which is a limitation and will be updated in the future version of the Poompuhar ontology.

Conflict of interest: The authors declare that there is no conflict of interest.


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