Towards Conceptual Knowledge Reference Implementations for Context Integration and Contextualisation of Prehistory's and Natural Sciences' Multi-disciplinary Contexts

Claus-Peter Rückemann
Westfälische Wilhelms-Universität Münster (WWU), Germany;
Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF), Germany;
Leibniz Universität Hannover, Germany
Email: ruckema@uni-muenster.de

***Abstract*—This paper delivers contributions towards new conceptual knowledge reference implementations and the results of the requirements study on a new context integration system for conceptual contextualisation of prehistory's and natural sciences' universal multi-disciplinary contexts. The conceptual knowledge reference implementations focus on general multi-disciplinary coherent conceptual knowledge integration, for case studies here especially on prehistory-protohistory and archaeology. The conceptual knowledge reference implementations can be used in flexible ways, e.g., creating and employing a frame of component reference implementations. The methodology provides a coherent conceptual knowledge integration, fostering consecutive coherent analysis based on information science fundaments. The methodological approach enables an inclusion of new insight and newly created knowledge, e.g., via deployment of knowledge resources and structures. The programmatic approach and new conceptual knowledge reference implementation span multi-disciplinary knowledge in a coherent, consistent, and multilingual way. The methodology to consistently integrate knowledge context from prehistory and archaeology disciplines with knowledge in natural sciences and humanities is accompanied by ongoing multi-disciplinary case studies implementing the required methods. The focus of this research is on knowledge-based methodologies and deployment of information science methods, especially, universal conceptual knowledge, for the goal of creating and developing conceptual knowledge reference implementations towards coherent and general multi-disciplinary contextualisation and context integration, targeting further future creation of new insight, strategies, and perspectives.**

***Keywords*–Conceptual Knowledge Reference Implementations; Prehistory; Natural Sciences; Humanities; Contextualisation; Conceptual Knowledge.**

I. INTRODUCTION

Multi-disciplinary context integration and contextualisation are relevant for most scientific disciplines. This paper presents new conceptual knowledge reference implementations and the results of the requirements study on a new context integration system for conceptual contextualisation of prehistory's and natural sciences' universal multi-disciplinary contexts. The conceptual knowledge reference implementations focus on multi-disciplinary coherent conceptual knowledge integration, e.g., on prehistory-protohistory and archaeology natural sciences, and humanities. The paper delivers practical development stages of future Conceptual Knowledge Reference Implementations (CKRI) and the results of previous and ongoing research initiatives, which integrate based on information science fundaments for a coherent conceptual integration, enabling consecutive coherent analysis. The conceptual knowledge reference implementations can be used in a flexible way, e.g., employing a frame of component reference implementations.

This paper is an extended presentation of the research based on the publication and presentation at the INFOCOMP 2021 conference in Valencia, Spain [1]. When dealing with context, the signification of the terms 'complex' and 'complicated' is often mixed up. Complexity is a concomitant phenomenon of context, which, when not well comprehended, appears complicated. Both, complexity and context, are linked by manyfold inter-dependencies and often experienced together. Context is witness-context in many cases, in prehistory and natural sciences. Understanding context and gathering complexity in a coherent, consistent, and methodological way are therefore important fundaments, which can lead to consequent systematical instrumentalisation, consecutive coherent analysis, and aspiring new insight.

The new conceptual knowledge reference implementations are employed in practical and presented regarding their methodological and systematical fundaments and components for implementing a multi-disciplinary integration of prehistory and its context. The paper summarises the results of immanent milestones and, based on these, proposes the next complementary methodological and practical resources' developments. Further, details on complements and results of specific application scenarios will be discussed in separate extended papers.

The rest of this paper is organised as follows. Section II introduces into the information science fundaments. Section III gives the essential background of motivation resulting from different disciplinary views. Section IV introduces to disciplinary background and requirements. Section V presents the methodological fundaments and components. Section VI presents a short overview of component implementations for integration. Section VII delivers the results and state of major coherent conceptual knowledge reference implementations. Section VIII presents a practical example of an integration case scenario. Sections IX and X discuss the lessons learned and summarise conclusions and future work.

II. FUNDAMENTS

The fundaments of terminology and understanding the essence of knowledge are layed out by Aristotle, being a central part of 'Ethics' [2]. Information sciences can very much benefit from Aristotle's fundaments and a knowledge-centric approach [3] but for building holistic and sustainable solutions, supporting a modern definition of knowledge and subsequent component instrumentation [4], they need to go beyond the available technology-based approaches and hypothesis [5] as analysed in Platon's Phaidon. Aspects of meaning can be described using knowledge complements, e.g., considering factual, conceptual, procedural, metacognitive [3], and structural knowledge. Especially, conceptual knowledge can relate to any of factual, conceptual, and procedural knowledge.

To a comparable extent, metacognitive knowledge can relate to any of factual, conceptual, and procedural knowledge. Knowledge complements are a means of understanding, e.g., enabling advanced contextualisation, documentation, prospection, integration, and analysis. From an information science point of view, the classical fundaments of episteme, techne, and doxa are intrinsically tied complements. However, knowledge complements, when consequently applied, do not make the creation and development of resources instantaneously easier. They do not make problem solving algorithms simpler. Knowledge complements do not make scientific contexts obsolete, they do neither make qualified expertise unneeded nor do they lead to faster education or cheaper gain of research results and insight.

The focus of this research is on knowledge-based methodologies and deployment of information science methods, especially universal conceptual knowledge, for the goal of creating a component framework of reference implementations for coherent and general multi-disciplinary contextualisation targeting the creation of new insight, strategies, and perspectives. This research is part of several extensive long-term strategies and concentrating on contextualisation and context integration for prehistory, protohistory, archaeology and their associated contexts, especially natural sciences and humanities. Contexts in prehistory are special in a way that there are no direct historical sources and respectively no literary reference and documentation. Contextualisation is therefore a main intrinsic task in prehistory and protohistory. From the knowledge point of view, also when looking on methodological conditions, prehistory shares many characteristics and factual conditions with natural sciences, e.g., geology and soil science. A coherent conceptual knowledge approach can enable to establish ties and building bridges between contributing knowledge, including future methodologies and contributions from disciplines.

III. Motivation

Complexity is carrying information. Therefore, from information science point of view, we should take care not to loose complexity whenever dealing with information. The complexity of appearing context is commonly even increased when applying methods from multiple disciplines. So far, there are no other comparably holistic and systematical approaches and implementations on conceptual contextualisation known and published besides the presented approach. Contrary, during the last decades, it has become common practice to tackle challenges regarding knowledge and related content solely with procedural approaches, contrary to the fact that creation processes, handling, and management may allow more effective and efficient measures in context of analysis, long-term development of resources, computation, and processing, Common ways of implementing procedural approaches as plain technical solutions are often neither effective nor efficient. In addition, such approaches often lack long-term adaptability and scalability.

How can we create a suitable, practical system of coherent knowledge? Such a system has to conform with information science fundaments and universal knowledge and has to enable an integration of the required components from methodologies to realisations for knowledge representations of realia and abstract contexts [6]. Many facets of knowledge, including prehistory, need to be continuously acquired and reviewed [7]. Knowledge itself is part of cognitive processes and requires an understanding of epistemological fundaments, depending on participated disciplines and views [8], [9].

We should therefore create a system of balanced fundaments of sustainable, complementary solutions based on information science and contextualisation-aware methodologies and complements [10], which allows the application of coherent conceptual knowledge in theory and practice. The conceptual knowledge approach should provide facilities expressing instances of mental concepts and the state of research of their perception. The creation of object types may be influenced by criteria, e.g., by education, experience, and social context. The approach should enable further development of practical disciplinary terminology assignment, e.g., adaption and synchronisation of terminology.

IV. Consideration of Disciplinary Background

Prehistoric context, even for chorologically, chronologically, and thematically restricted object groups [11], [12], [13] comprises of a wide and highly variable spectrum of knowledge, applied approaches, and formalisation, including abstraction [14] and documentation [15]. Almost all knowledge is further referring to complex contexts of many associated disciplines and views.

In complex scenarios, like multi-disciplinary prehistoric realia founded contexts, we should utilise as much complexity and structure with knowledge complements as possible in order to achieve a high level of integration of factual, conceptual, and structural but also of procedural and metacognitive knowledge. In practice, these approaches are often not followed. In many cases, simple convenience of workflow tasks might suggest to integrate ‘data’ available as is. Even standards and implementations may not be optimal, they can result from the fact that information and data are often determined by technological means. The result may be a limitation regarding the fundamental coherence of knowledge and it may limit the applicability and use of methods and algorithms.

Basic deficits of simplified approaches and many commonly used frameworks (e.g., context-unaware approaches for maps/earth services) make these approaches undesirable for a general and coherent scientific and methodological realisation.

Further, the application of not well satisfying approaches and methodological deficits, especially in multi-disciplinary context, are often fragmented, heterogeneous, and lacking required coherence and precision [16] or require unnecessary estimations and approximations [17].

Further, in addition to such contrary practice there are multifold cases, which should direct to more feasible approaches, e.g., in situations

- when terminology does –in any case– not reflect the context of respective findings,
- when relocated objects require contextualisation and descriptive conceptual knowledge,
- where indications of resources are available without respective artefacts,
- isolated findings of various levels exist,
- when objects with presently isolated contexts require coherent chronology.

Examples of associated, guiding questions are: How can existing and emerging knowledge from prehistory and other disciplines be methodologically integrated? Which multi-disciplinary contexts and approaches can be considered on a coherent, consistent information science base? What are context areas of special characteristics, e.g., where are possible regions of interest and further research? Which fundaments and component implementations should be in focus of contextualisation?

A basic approach for prehistoric contextualisation should be characterised by modular components and premises, namely,

- a coherent, multi-disciplinary methodology, spanning disciplines and fields,
- an overall coherent and consistent knowledge base,
- principle concepts for knowledge description,
- implementing the state of the art in information science and knowledge,
- considering long-term time ranges for continuous developments,
- enabling wide context integration,
- enabling representation of different views,
- enabling representation of different actual perceptions,
- allowing to complement terminology where required,
- and integration of standards and frameworks.

The premise of coherency of the knowledge base is important in a way that solutions should not be restricted to procedural components and interfaces, which intrinsically require additional multi-level formalisation. The coherent approach can provide required descriptive complements to otherwise prescriptive terminologies. The integration should be aware of cognitive visualisation aspects. The contextualisation should further enable to continuously integrate results of past and ongoing research of prehistoric on-site context surveys.

A means of choice in order to achieve overall efficient realisations even for complex scenarios, integrating arbitrary knowledge, is to use the principles of Superordinate Knowledge. The core assembly elements of Superordinate Knowledge are methodology, implementation, and realisation [18]. The presented implementations strictly follow the fundamental methodological algorithm base of the the Conceptual Knowledge Pattern Matching (CKPM) methodology [6], providing and accessing knowledge object patterns based on the Superordinate Knowledge Methodology, which allows systematical use and thorough processing. Respective results from a methodology targeting structures, including implementation, and knowledge-aware application of the methodology were layed out and are available with practical examples [19].

V. Methodological fundaments and components

The methodological and systematical fundaments for contextualisation of prehistory, protohistory, and contexts require modularity and flexibility with structure levels and multi-dimensional knowledge context, especially regarding

- prehistoric object groups,
- prehistoric objects,
- inter-object group context and references,
- chorological and chronological context,
- context correlation for soil context,
- material context, and
- toponymic context,

with further natural and environmental context, regarding methods and extendability, valorisation, analysis, and potential for new insight. At these conditions and based on the previous research and project practice, basic fundaments are:

- Universal, coherent, and consistent conceptual knowledge system.
- Integration of scientific reference frameworks from disciplines and contexts.
- Formalisation for complements, coherence, consistency.
- Methodologies, general problem solution, workflow integration. Implementation and deployment of methods and algorithms.
- Prehistory and protohistory knowledge resources and complements.
- Natural sciences knowledge context resources and complements.
- Inherent representation groups of context resources.
- Scientific context parametrisation.
- Universal structures and data standards.
- Facilities for analysis.
- Spatial mapping.
- Symbolic representation of context information.
- Facilities for automation.
- Long-term development and sustainability.

Besides obvious reasons, e.g., spatial ranges, serious dependencies are made up by conditions of required mathematical algorithms and the context of available data. These dependencies cannot be overcome in many cases as, e.g., it is not possible to get direct data from the original context of a prehistorical site. Targeting contextualisation, the conceptual implementation should integrate knowledge for natural conditions and processes, soil-affine and respective soil-related, e.g., agricultural or geoforensic, contexts. The implementation should consider different systems of chorologies and chronologies, e.g., prehistorical and geological time frames, palaeolithic to neolithic in coexistence with Pleistocene to Holocene and other conceptual and absolute chronologies. The achieved results of respective developments and implementations of the components will be discussed in the following sections.

VI. Methodological component implementations

Focus is on required methodological, conceptual, non-procedural, non-interactive, and non-technical components. Practical components for systematical and methodological implementations are defined and developed according to the analyses in already realised projects and case studies of practical scenarios as cited here and described in the references.

These items can only give a minimal necessary background for CKRI development editions regarding the component groups of an implementation frame. Overall results on a fully compatible respective component reference implementation frame are to be published including details on component implementations and realisations [20]. The next sections briefly summarise components used for addressing knowledge with multi-disciplinary Knowledge Resources (KR).

A. Conceptual knowledge frameworks

Examples of frameworks developed and used in practice with ongoing long-term research and applied for multi-disciplinary KR are stages of the future prehistory-protohistory and archaeology Conceptual Knowledge Reference Implementation (CKRI), including multi-disciplinary contexts of natural sciences and humanities (E.0.4.4) [10], an environmental information systems conceptual knowledge framework [21], and a mathematical and computational conceptual knowledge framework [22].

The methodology allows to address any other references on a coherent information science knowledge base, e.g., geoscientific knowledge from natural sciences KR components. Further, the reference implementation enables to address chorology on the coherent knowledge base.

Table I shows a general overview containing an excerpt of major references of coherent conceptual knowledge, relevant for the case scenario. Universally consistent conceptual knowledge is based on UDC references [23] for demonstration cases of references implementations and examples.

B. Conceptual knowledge base

The Universal Decimal Classification (UDC) [24] is a general plan for knowledge classification. UDC is also the world's foremost document indexing language in the form of a multi-lingual classification scheme covering all fields of knowledge and constitutes a sophisticated indexing and retrieval tool. UDC-based references in this publication are taken from the multi-lingual UDC summary [24] released by the UDC Consortium under a Creative Commons license [25].

C. Integration of scientific reference frameworks

The integration includes relevant scientific practices, frameworks, and standards from disciplines and contexts, e.g., natural sciences. Geosciences and soil science are continuously delivering updated insight on state of the art research, including the geodiversity and standardisation [26] as required for contextualisation. Essential base context sources should provide worldwide homogeneous and consistent data [27] allowing extrapolation and interpolation in various dimensions.

D. Formalisation

All integration components, for all disciplines, require an explicit and continuous formalisation [28] process in order to conform with the information science principles according to the practices in the disciplines. This includes knowledge objects and entities as well as procedural components and addressing aspects of discipline related parole [29]. Components can deploy Perl Compatible Regular Expressions (PCRE) [30] syntax for specifying common string patterns.

E. Methodologies and workflows integration

Methodologies for creating and utilising methods include model processing, remote sensing, spatial mapping, high information densities, and visualisation. The respective contextualisation of prehistoric scenarios should each be done under individual prehistoric conditions, supported by state-of-the-art methods, especially, consistent sources of standard algorithms [31], multi-dimensional criteria, spatial operations, interpolation geodesic computation [32], triangulation [33], gradient computation [34], and projection [35]. Workflow integration also includes the overall spectrum of problem solving, e.g., mathematical algorithms, mathematical processes, filter processes, but also phonetic and linguistic context support [36].

F. Prehistory Knowledge Resources

Common sources of information in many disciplines are often not yet aware of universal knowledge concepts and multi-lingual approaches, not sufficiently coherent, consistent, and structured and more often they show to be fragmented and heterogeneous. In order to be independent of these basic shortcomings, all of the objects, entities, and respective conceptual knowledge references' excerpts and examples are taken from The Prehistory and Archaeology Knowledge Archive (PAKA). PAKA has been in continuous development for more than three decades [37] and is released by DIMF [38].

G. Natural Sciences Knowledge Resources

Sources of information regarding natural sciences and contexts are provided by Natural Sciences Knowledge Resources, an implemented system of major natural sciences' context object groups from KR realisations [24], [19].

H. Inherent representation groups

Most relevant data in participated disciplines is addressed in defined ways regarding structure and form. According to their inherent representation and common utilisation, major discipline and context object groups can be referred by conceptual knowledge.

I. Scientific context parametrisation

Scientific context parametrisation of prehistoric targets can use the overall insights, e.g., from geoscientific disciplines [39], [40]. A relevant example is contextualisation with palaeolandscapes [41]. In case of prehistory, parametrisation depends on the prehistorical context, e.g., the geoscientific parametrisation and geoscientific contextualisation depend of the respective selected prehistorical object groups and associated properties.

J. Structures and symbolic representation standards

The deployment of long-term universal structure and data standards is essential. Relevant examples of sustainable implementations are NetCDF [42] based standards, including advanced features, hybrid structure integration, and parallel computing support (PnetCDF).

VII. Coherent Conceptual Knowledge Reference Implementations (CKRI)

Relevant knowledge can be referenced, e.g., from the implemented development stage prehistory-protohistory and archaeology CKRI (E.0.4.4) [10]. The methodology allows to address any other references on a coherent conceptual knowledge base, e.g., geoscientific knowledge from natural sciences KR components (Table I). The following sections present excerpts of the development stages of the long-term

TABLE I. CONCEPTUAL KNOWLEDGE REFERENCE IMPLEMENTATION: COHERENT CONCEPTUAL KNOWLEDGE DEPLOYED FOR CREATION OF CONCEPTUAL KNOWLEDGE REFERENCE IMPLEMENTATIONS, CONTEXT INTEGRATION, AND CONTEXTUALISATION, SELECTED UDC CODE REFERENCES (EXCERPT, INCLUDING PREHISTORY-PROTOHISTORY AND ARCHAEOLOGY CKRI DEVELOPMENT STAGE E.0.4.4).

Code / Sign Ref.	*Verbal Description (EN)*
UDC:0	Science and Knowledge. Organization. Computer Science. Information. Documentation. Librarianship. Institutions. Publications
UDC:004	*Computer science and technology. Computing.*
UDC:1	Philosophy. Psychology
UDC:2	*Religion. Theology*
UDC:3	Social Sciences
UDC:5	Mathematics. Natural Sciences
UDC:52	*Astronomy. Astrophysics. Space research. Geodesy*
UDC:528	Geodesy. Surveying. Photogrammetry. Remote sensing. Cartography
UDC:528.2	Figure of the Earth. Earth measurement. Mathematical geodesy. Physical geodesy. Astronomical geodesy
UDC:528.3	Geodetic surveying
UDC:528.4	Field surveying. Land surveying. Cadastral survey. Topography. Engineering survey. Special fields of surveying
UDC:528.5	Geodetic instruments and equipment
UDC:528.7	Photogrammetry: aerial, terrestrial
UDC:528.8	Remote sensing
UDC:528.9	Cartography. Mapping (textual documents)
UDC:53	Physics
UDC:539	Physical nature of matter
UDC:54	Chemistry. Crystallography. Mineralogy
UDC:55	Earth Sciences. Geological sciences
UDC:550.3	Geophysics
UDC:550.7	Geobiology. Geological actions of organisms
UDC:550.8	Applied geology and geophysics. Geological prospecting and exploration. Interpretation of results
UDC:551	General geology. Meteorology. Climatology. Historical geology. Stratigraphy. Palaeogeography
UDC:551.44	*Speleology. Caves. Fissures. Underground waters*
UDC:551.46	Physical oceanography. Submarine topography. Ocean floor
UDC:551.7	Historical geology. Stratigraphy
UDC:551.8	Palaeogeography
UDC:56	Palaeontology
UDC:6	Applied Sciences. Medicine, Technology
UDC:63	Agriculture and related sciences and techniques. Forestry. Farming. Wildlife exploitation
UDC:631	Agriculture in general
UDC:631.4	*Soil science. Pedology. Soil research*
UDC:7	The Arts. Entertainment. Sport
UDC:8	Linguistics. Literature
UDC:9	Geography. Biography. History
UDC:902	*Archaeology*
UDC:903	*Prehistory. Prehistoric remains, artefacts, antiquities*
UDC:904	Cultural remains of historical times
UDC (1/9)	Common auxiliaries of place
UDC:(1)	Place and space in general. Localization. Orientation
UDC:(2)	Physiographic designation
UDC:(20)	Ecosphere
UDC:(21)	Surface of the Earth in general. Land areas in particular. Natural zones and regions
UDC:(23)	*Above sea level. Surface relief. Above ground generally. Mountains*
UDC:(24)	*Below sea level. Underground. Subterranean*
UDC:(25)	Natural flat ground (at, above or below sea level). The ground in its natural condition, cultivated or inhabited
UDC:(26)	Oceans, seas and interconnections
UDC:(28)	Inland waters
UDC:(3/9)	Individual places of the ancient and modern world
UDC:(3)	Places of the ancient and mediaeval world
UDC:(4/9)	Countries and places of the modern world
UDC:(4)	*Europe*
UDC:"..."	Common auxiliaries of time.
UDC:"6"	Geological, archaeological and cultural time divisions
UDC:"62"	*Cenozoic (Cainozoic). Neozoic (70 MYBP - present)*

results of CKRI realisations, which are used in this context with ongoing research:

- Prehistory-protohistory and archaeology contexts.
- Natural Sciences.
- Soil diversity.
- Inherent representation groups.

A. CKRI: Prehistory-protohistory and archaeology contexts

The Prehistory-protohistory and Archaeology CKRI (E.0.4.4) can, in future, address all facets, referencing multi-disciplinary prehistory-protohistory and archaeology contexts.

Table II shows examples of prehistory and protohistory ritual/burial objects and subgroups, and conceptual view groups, an excerpt of UDC:903.. . .:2 groups [24] for prehistory and protohistory.

TABLE II. CKRI: PREHISTORY-PROTOHISTORY AND ARCHAEOLOGY, VIEW GROUPS [24] (EXCERPT, E.0.4.4).

Major Object Reference Group	*Conceptual View Group*
Earthworks	UDC:[903,902]. . . .
Settlements	UDC:[903,902]. . . .
Fortifications	UDC:[903,902]. . . .
Architectures	UDC:[903,902]. . . .
Structures and arrangements	UDC:[903,902]. . . .
Timber	UDC:[903,902]. . . .
Stone	UDC:[903,902]. . . .
. . .	UDC:[903,902]. . . .
Rock art	UDC:[903,902]. . . .
Sculptured objects	UDC:[903,902]. . . .
Resources (usage, mining, etc.)	UDC:[903,902]. . . .
Ritual places, burials	UDC:[903,902]. . . .
Cemetery	UDC:[903,902]. . . .
Barrow	UDC:[903,902]. . . .
round	UDC:[903,902]. . . .
long	UDC:[903,902]. . . .
Cist	UDC:[903,902]. . . .
Dolmen	UDC:[903,902]. . . .
Tomb	UDC:[903,902]. . . .
chamber	UDC:[903,902]. . . .
court	UDC:[903,902]. . . .
portal	UDC:[903,902]. . . .
rock cut	UDC:[903,902]. . . .
wedge	UDC:[903,902]. . . .
Pithos burial	UDC:[903,902]. . . .
Cave	UDC:[903,902]. . . .
Body finding	UDC:[903,902]. . . .
Urn	UDC:[903,902]. . . .
. . .	UDC:[903,902]. . . .
Relics, organic and non-organic	UDC:[903,902]. . . .
Organic	UDC:[903,902]. . . .
Metal	UDC:[903,902]. . . .
. . .	UDC:[903,902]. . . .
Artefacts, organic and non-organic	UDC:[903,902]. . . .
Organic	UDC:[903,902]. . . .
Metal	UDC:[903,902]. . . .
. . .	UDC:[903,902]. . . .
. . .	UDC:[903,902]. . . .

The conceptual view group is prehistory and archaeology, including prehistoric remains, artefacts, and antiquities. Context integration and contextualisation include multi-disciplinary contexts, e.g., natural sciences and humanities.

The reference groups and CKRI (E.0.4.4) can be referenced in any knowledge resources, e.g., the shown groups are practical examples from the PAKA [37], [38]. Objects are selected from a major object group, including subgroups.

B. CKRI: Natural Sciences

The Natural Sciences CKRI development stage (E.0.2.6) can address all facets, referencing multi-disciplinary natural sciences' contexts. Table III shows a plain representation excerpt of an implemented system of major natural sciences' context object groups from respective KR realisations employing a system of context object groups and conceptual views groups [24], [19].

TABLE III. CONCEPTUAL KNOWLEDGE REFERENCE IMPLEMENTATION: NATURAL SCIENCES / NATURE CKRI, VIEWS GROUPS [24] (EXCERPT, E.0.2.6).

Major Object Reference Group	*Conceptual View Group*
Landmarks	UDC:55+539. . .
Height	UDC:55+539. . .
Depth	UDC:55+539. . .
. . .	UDC:55+539. . .
Caves	UDC:55+539. . .
Natural resources	UDC:55+539. . .
Rock outcrops	UDC:55+539. . .
Well springs	UDC:55+539. . .
Soil features	UDC:55+539. . .
Volcanological features	UDC:55+539. . .
Impact features	UDC:55+539. . .
. . .	UDC:55+539. . .

The conceptual view group is earth sciences and geological sciences, physical nature of matter, including geophysics, historical geology, and palaeogeography, soil science and research.

The reference groups and CKRI can be referenced in any KR realisations e.g., the shown groups are practical examples from the Natural Sciences Knowledge Resources, which provide sources of information regarding natural sciences and contexts.

C. CKRI: Soil diversity

The Soil Diversity CKRI development stage (E.0.6.2) provides an implemented and realised soil type conceptual reference system compilation (UDC:631.4. . . base), shown in Table IV. The Soil Diversity CKRI (E.0.6.2) can be seamlessly integrated with respective prehistory and archaeology contexts.

The soil type reference system is based on soil diversity standards and universal conceptual knowledge. The reference system deploys implemented and realised World Reference Base (WRB) standard soil type reference groups and soil type specifications for soil resources [43], [44].

Associated information, e.g., on soil drainage, wetness, pH status, base saturation, chloride, subsoil organic material, and stiffness can be found as reference in the World Reference

Base (WRB) for soil resources [43], [44] from the Food and Agriculture Organisation (FAO), United Nations.

For this research, the created reference system is based on standard soil references and UDC, both enabling a systematic and coherent approach. In this context, the conceptual references are referring to the respective categories, e.g., UDC:631.4. . .:903+"4. . .". The conceptual view group is soil science, pedology, and soil research.

Soil diversity groups are relevant for prehistorical and archaeological objects and contexts. Contextualised soil diversity groups are referenced in a consistent, standardised way.

Properties based reference systems can be created from this base compilation, e.g., a properties based reference system for further contextualisation, parametrisation, and processing with the ongoing research on soil diversity for prehistory and archaeology.

D. CKRI: Inherent representation groups

The Inherent Representation CKRI (Table V) development stage (E.0.2.2) refers to conceptual knowledge of inherent representations objects, e.g., objects used for implementations and realisations of structure and form in disciplines, processing, symbolic representation, and scientific analysis.

TABLE V. CONCEPTUAL KNOWLEDGE REFERENCE IMPLEMENTATION: INHERENT REPRESENTATION CKRI, VIEW GROUPS [24] (EXCERPT, E.0.2.2).

Major Object Reference Group	*Conceptual View Group*
Points, (Points of Interest, PoI)	UDC:52+004. . .
Polygons	UDC:52+004. . .
Lines	UDC:52+004. . .
Digital Elevation Model (DEM) repr.	UDC:52+004. . .
z-value representations	UDC:52+004. . .
Distance representations	UDC:52+004. . .
Area representations	UDC:52+004. . .
Raster	UDC:52+004. . .
Vector	UDC:52+004. . .
Binary	UDC:52+004. . .
Non-binary	UDC:52+004. . .
. . .	UDC:52+004. . .

The excerpt shows a plain representation of major discipline and context object groups regarding their inherent representation and common utilisation using a system of context object groups and conceptual view groups [24]. The conceptual view group is astronomy, astrophysics, space research, and geodesy, computer science and technology, computing, and data processing, including earth measurement, field surveying, photogrammetry, remote sensing, data processing, interpretation, mapping, data representation, data handling, and computer languages. The reference groups and CKRI can be referenced in any KR realisations e.g., the shown groups are practical examples used with the case scenarios.

VIII. INTEGRATION CASE EXAMPLE

The integration may be illustrated by a compact case example of contributions, which employs the presented

- coherent conceptual knowledge reference implementations, with realised KR components and
- systematical chorological knowledge for multi-disciplinary contexts, e.g., arbitrary group representations, classification based representations, and geospatial representations, with further components.

A. Contributions from implementations and realisations

A means of choice in order to achieve overall efficient realisations even for complex scenarios, integrating arbitrary knowledge, is to use the principles of Superordinate Knowledge. The core assembly elements of Superordinate Knowledge are methodology, implementation, and realisation [18]. In the following example solution [1], [45], scenario targets with required contributions are named in the following listing.

- *Contexts of prehistoric cemeteries and burials*
- *at the North Sea coast, in North-Rhine Westphalia, Lower Saxony, and The Netherlands.*
- *Integration targets are natural sciences and*
- *speleological contexts, caves and cave systems*
- *in North-Rhine Westphalia, Lower Saxony, and The Netherlands,*
- *soil diversity, and overall integration with*
- *chorological, symbolical, spatial context representations, e.g., place, spatial planning,*
- *auxiliary subdivisions for boundaries and*
- *spatial forms,*
- *administrative units, and*
- *resources suitable for computing,*

for all of which knowledge needs to be created, continuously developed, and re-used [1], [45] A prominent prehistoric valorisation example using auxiliaries is the swimming reindeer [46], included in detail in [10]. Therefore, this integration case, considers the major conceptual references. Specific research can address further detail on any contexts and properties, e.g.,

- prehistoric object groups,
- object characteristics, and
- object properties,
- topographic properties,
- soil properties, and many more.

B. Multi-disciplinary coherent knowledge integration

An excerpt, deploying CKRI based reference facets of coherent knowledge, of an implemented and realised multi-disciplinary target contextualisation for a case scenario is shown in Table VI. The case scenario integrates facets for references from a number of respective reference implementations the prehistory-protohistory and archaeology CKRI (E.0.4.4), the natural sciences CKRI (E.0.2.6), the soil diversity CKRI (E.0.6.2), the inherent representation CKRI (E.0.2.2), and auxiliary tables.

TABLE IV. CONCEPTUAL KNOWLEDGE REFERENCE IMPLEMENTATION: SOIL DIVERSITY CKRI, VIEW GROUPS (UDC:631.4...), IMPLEMENTED AND REALISED WRB STANDARD SOIL TYPE REFERENCE GROUPS AND SOIL TYPE SPECIFICATIONS (CKRI EXCERPT, E.0.6.2).

Soil Type Reference Group	*Soil Type Specification Name in WRB 2006 / WRB 1998*	*Conceptual View Group*
Acrisol	Haplic / Ferric, Gleyic, Haplic, Humic, Plinthic	UDC:631.4...
Alisol	Plinthic	UDC:631.4...
Albeluvisol	Haplic / Endoeutric, Gleyic, Haplic, Histic, Stagnic, Umbric	UDC:631.4...
Andosol	Aluandic / Dystric, Humic, Umbric, Mollic, Vitric	UDC:631.4...
Anthrosol	Anthrosol, Plaggic	UDC:631.4...
Arenosol	Albic, Haplic, Protic	UDC:631.4...
Calcisol	Aridic	UDC:631.4...
Chernozem	Calcic, Haplic, Gleyic, Haplic, Luvic	UDC:631.4...
Cambisol	Haplic / Calcaric, Haplic / Chromic, Haplic / Dystric, Haplic / Eutric, Gleyic, Haplic, Mollic, Vertic	UDC:631.4...
Fluvisol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Gleyic, Haplic, Histic, Mollic, Salic, Thionic	UDC:631.4...
Gleysol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Haplic / Haplic, Histic, Humic, Mollic, Thionic	UDC:631.4...
Gypsisol	Haplic / Aridic	UDC:631.4...
Histosol	Histosol, Hemic / Dystric, Hemic / Eutric, – / Fibric, – / Gelic, – / Sapric	UDC:631.4...
Kastanozem	Calcic, Haplic, Luvic	UDC:631.4...
Leptosol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Haplic / Haplic, Haplic / Humic, Rendzic, Lithic	UDC:631.4...
Luvisol	Albic, Haplic / Arenic, Calcic, Haplic / Chromic, Haplic / Dystric, Haplic / Ferric, Gleyic, Haplic, Vertic	UDC:631.4...
Phaeozem	– / Albic, Haplic / Calcaric, Gleyic, Haplic, Luvic, Haplic / Sodic	UDC:631.4...
Planosol	Haplic / Dystric, Haplic / Eutric, Haplic	UDC:631.4...
Podzol	Haplic / Carbic, Haplic / Entic, Gleyic, Haplic, Leptic, Placic, Haplic / Rustic, Umbric	UDC:631.4...
Regosol	Haplic / Calcaric, Haplic / Dystric, Haplic / Eutric, Haplic	UDC:631.4...
Solonchak	Gleyic, Haplic, Haplic / Takyric, Mollic	UDC:631.4...
Solonetz	Gleyic, Haplic, Mollic	UDC:631.4...
Umbrisol	Arenic, Gleyic	UDC:631.4...
Vertisol	Haplic / Chromic, Haplic, Haplic / Pellic	UDC:631.4...

TABLE VI. CKRI BASED REFERENCE FACETS OF MULTI-DISCIPLINARY TARGET CONTEXTUALISATION (EXCERPT).

Code / Sign Ref.	*Verbal Description (EN)*
	Geography. Biography. History
UDC:903....	Prehistory, prehistoric remains, artefacts, antiquities
...:2	referring to religion and rituals
...,"62..."	from Holocene
...,(4...DENW)	... in North-Rhine Westphalia, Germany
...,(4...DENI)	... in Lower Saxony, Germany
...,(4...NL)	... in The Netherlands
	Earth sciences, geological sciences
UDC:551.44	Speleology, caves, fissures, underground waters
	Applied sciences, agriculture in general
UDC:631.4	Soil research data
	Geodesy. Photogrammetry
UDC:52...,(23)	Remote sensing data, above sea level
UDC:52...,(24)	Remote sensing data, below sea level
	Contextualisation Place
UDC:(4)	Europe
	Organization. Computer Science
UDC:004...	Computer science and technology. Computing.

Respective sketch maps for various practical examples, considering major conceptual references, have been recently published [45], [47]. Conceptual sketch views can result in levels of arbitrary numbers of different integrations of complements and associated properties as resulting from the integrated KR. The individual possibilities of views and contextualisation are literally unlimited.

C. Knowledge Resources and components

The knowledge integration for prehistoric, natural sciences, and spatial contextualisation for excerpts of prehistoric cemeteries' and caves' distributions, remote sensing data, and soil properties with respective knowledge references [1], [45] is achieved by following major reference implementation components as given. The knowledge integration enables universal conceptual knowledge for all components, a wide range of knowledge contextualisation and high flexibility for implementation and realisation. Especially, the methodology allows flexible component realisations for integration of contexts, enabling management of KR, symbolic representation, and projection. In this integration case, the coherent multi-disciplinary contextualisation employs a base of the following contexts:

- Knowledge objects and contexts are provided by The Prehistory and Archaeology Knowledge Archive (PAKA) [37] [38].
- New soil system reference development / (UDC:631.4...), WRB standard,
- reference contexts are defined, especially for UDC:903....:2,551.7+"628"....,
- prehistorical, protohistorical time & artefacts related to religion and rituals,
- geology, especially stratigraphy and
- palaeogeography, quaternary, especially late glacial and Holocene.
- The integrated natural sciences KR further provide information on caves in the respective region.
- The reference implementations allow for flexible multi-disciplinary scientific, chorological contextualisation,

e.g., Digital Elevation Model (DEM) data from satellites and drones.

For contextualisation and symbolic representation, plain Digital Chart of the World (DCW) data [48] can be used. Coastline database can be the Global Self-consistent Hierarchical High-resolution Geography (GSHHG) [49] [50], which was mainly compiled from the World Vector Shorelines (WVS) [51], the CIA World Data Bank II (WDBII) [52], and the Atlas of the Cryosphere (AC).

An equal area projection (Eckert IV) is advised due to the type of discipline knowledge representation. The compilation can use the World Geodetic System (WGS).

The symbolic representation of the contextualisation can be done via LX Professional Scientific Content-Context-Suite (LX PSCC Suite) deploying the Generic Mapping Tools (GMT) [53] for visualisation.

IX. Discussion

Many measurements and and contexts in prehistorical archaeology and natural sciences cannot be 'sensed' directly and require further endeavours. [20]. Multi-disciplinary scenarios often require to consider a wide range of contexts with disciplines put to their level. It is the coherent knowledge of contexts, which is most relevant for new insight. Therefore, contextualisation should not be done without considering multi-disciplinary coherency and expert views from different disciplines put on a par with respective further scientific collaboration and support.

The range of application scenarios of the presented coherent conceptual knowledge reference implementations is far beyond any examples, which might be given. Nevertheless, the presented practical conceptual knowledge reference implementations and conceptual knowledge base are in continuous long-term development.

The status of integration potentials and the outlook on concrete targets were reviewed based on the lessons learned from the methodological component implementations. The component related processes are challenging and not trivial, especially formalisation and parametrisation. This is the more true for the integration processes. The resulting bases, CKRI and CRI, are the start of a continuous long-term integration on contextualisation for prehistory and multi-disciplinary contexts. All the presented components were created, developed, and evaluated with the referred practical project results and case studies. The conceptual knowledge reference implementations, especially the prehistory CKRI and components showed that they are best choice addressing required properties and features for the tasks. The presented components' set of reference implementations and components also allows further development, targeting the integration for coherent contextualisation including required standards from information science, conceptual knowledge, prehistory and archaeology, natural sciences and geosciences, soil science, satellite and spatial data, and processing algorithms, for the purpose of contextualisation and further utilisation and prospection in prehistory and context.

It should be explicitely noticed, that the integrated methods, resources, and workflows have to support features beyond methodological compatibility, suitability, modularity, and flexibility on the task, e.g., with development, storage, transfer, and utilisation. Especially, the presented conceptual knowledge system enables to respect the rights of participated parties and conform with and adhere to intellectual properties, privacy, and licensing of resources and components, e.g., with intermediate, and resulting structures, formats, and procedural components.

In consequence, practical integration can refer to involved resources and components from all disciplines, prehistory, geosciences, soil science, remote sensing, application of reference implementations and standards, creation of knowledge, procedural realisations, e.g., algorithms and model processing, and results, e.g., symbolic representation of prehistoric context.

The conceptual knowledge reference implementations and methodologies were lately publicly presented and discussed at the Informational Modeling - Theory and Practice - International Conference, Sofia, Bulgaria [10], at the International Conference on Mathematics of Informational Modeling, Varna, Bulgaria [54], both Bulgarian Academy of Sciences, at the Delegates' Summit, Symposium on Advanced Computation and Information in Natural and Applied Sciences, Rhodes, Greece [55], and at the Machine Learning for Industry Forum hosted by the High-Performance Computing Innovation Center and Data Science Institute at the Lawrence Livermore National Laboratory, USA [56].

Practical applications and concrete developments of conceptual knowledge reference implementations and a component reference implementations frame were discussed regarding ongoing and future research initiatives in prehistory and prehistorical archaeology, natural sciences, and integrative industry applications. Conceptual knowledge solutions are recognised a fundament of future industrial learning, collaborative, and multi-disciplinary information science.

The component reference implementations frame resulting from this research has shown to provide a flexible framework for the required implementations and realisations including the multi-disciplinary coherent knowledge integration. Especially, the respective coherent conceptual knowledge reference implementations integrate seamlessly with coupled components addressed by provided Component Reference Implementations (CRI) frames [20]. The integration allows a flexible contextualisation for many peculiarities and situations, e.g., for multi-disciplinary coherent conceptual and chorological contexts.

X. Conclusion

This research successfully achieved to deliver new, widely deployable, coherent Conceptual Knowledge Reference Implementations (CKRI) from the results of the long-term requirements study on a new context integration system for conceptual contextualisation of prehistory's and natural sciences´ universal multi-disciplinary contexts.

Coherent conceptual knowledge reference implementations integrate seamlessly with Knowledge Resources and coupled components, e.g., via Component Reference Implementations (CRI) frames. The integration allows a flexible contextualisation for many peculiarities and situations, e.g., for multi-disciplinary coherent conceptual and chorological contexts. Employed resources are in continuous development. In addition, the conceptual views groups are a unique, flexible, and extendable approach of addressing multi-lingual verbal descriptions with a systematic approach and standardised implementation framework for multi-disciplinary and multi-dimensional scenarios of coherent conceptual knowledge, beyond plain representation.

This research contributed on knowledge-based methodologies and deployment of information science methods, especially universal conceptual knowledge, for contextualisation and context integration of multi-disciplinary contexts of prehistory and natural sciences, which can enable coherent future analysis. The results of long-term research projects in different disciplines leading to this publication contributed to the achieved goal to create reference implementations for coherent and general multi-disciplinary contextualisation, which represents more than its component parts. The integration enables to deal with knowledge complements, e.g., factual, structural, and formalised like time periods but also with metacognitive like experience, meaning, and symbolism. The presented results are nevertheless the start of a consecutive long-term integration project and continuing projects in participated disciplines. The presented methodological approach allows to systematically overcome conceptual fragmentation and to foster on a multi-level coherency for multi-disciplinary knowledge. The multi-lingual conceptual reference implementation allows to address problems of various language dependent fragmentation, e.g., to resolve national and local terminology fragmentation. This is increasingly relevant for coherency of inter-disciplinary knowledge in contextualisation. The new CKRI and facilities for a component reference implementations frame enable a coherent conceptual integration of prehistory and context disciplines and can foster the consideration and visibility of inherent aspects. CKRI and facilities for a component reference implementations frame allow to address, correlate, and integrate contexts of prehistory-protohistory and archaeology and context of natural sciences and related disciplines, e.g., diversity of soil and relevant properties.

Methodology and implementation allow a wide range or multi-disciplinary contexts and approaches for prehistoric context research for arbitrary regions on interest based on context knowledge, which can globally kept homogeneous and consistent as allowed by publicly available state-of-the-art resources. Examples are geoscientific and mathematical parametrisation and model computations for prehistoric scenarios. The developed reference implementations and components have been in continuous further development to address the continuous development of multi-disciplinary knowledge resources and new methodological implementations.

Overall, in result, contextualisation fosters careful and diligent scientific analysis and interpretation, besides global applicability of the methodology and implementations.

Future research targets on long-term development of a coherent consistent conceptual knowledge framework focussing on model creation and analysis of prehistory and archaeology case scenarios, taking new findings, contexts, and context integration into account. Foci are on new advanced, practical editions of a prehistory-protohistory and archaeology CKRI, a natural sciences CKRI, a soil diversity CKRI, and an inherent representation groups CKRI. That includes context-aware surveys on prehistoric object groups, multi-disciplinary contextualisation of prehistory-geodiversity scenarios, modular integration, analysis, and symbolic representation models for prehistory and context disciplines, e.g., concentrating on Central European supra-regional and on micro-regional studies in Northern Germany (North-Rhine Westphalia, Lower Saxony) and The Netherlands coast areas. The integration and priorities with information science research depend on the state-of-the-art results and development in contributing disciplines.

Acknowledgements

This ongoing research is supported by scientific organisations and individuals. We are grateful to the "Knowledge in Motion" (KiM) long-term project, Unabhängiges Deutsches Institut für Multi-disziplinäre Forschung (DIMF), for partially funding this research, implementation, case studies, and publication under grants D2018F1P04962, D2018F3P04932, D2018F6P04938, D2019F1P04998, and D2020F1P05228 and to its senior scientific members and members of the permanent commission of the science council, especially to Dr. Friedrich Hülsmann, Gottfried Wilhelm Leibniz Bibliothek (GWLB) Hannover, to Dipl.-Biol. Birgit Gersbeck-Schierholz, Leibniz Universität Hannover, to Dipl.-Ing. Martin Hofmeister, Hannover, and to Olaf Lau, Hannover, Germany, for fruitful discussion, inspiration, and practical multi-disciplinary case studies. We are grateful to Dipl.-Geogr. Burkhard Hentzschel and Dipl.-Ing. Eckhard Dunkhorst, Minden, Germany, for prolific discussion and exchange of practical spatial and drone case scenarios. We are grateful to Dipl.-Ing. Hans-Günther Müller, Göttingen, Germany, for providing specialised, manufactured high end computation and storage solutions. We are grateful to The Science and High Performance Supercomputing Centre (SHPSC) for long-term support. / DIMF-PIID-DF98_007; URL: https://scienceparagon.de/cpr .

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