Museum Education using XR technologies: a survey of metadata models

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***Abstract* — Museum education is a constantly evolving field that adapts to the changing needs and expectations of learners. By combining the unique assets of museums with innovative educational practices, the field continues to create enriching and engaging learning experiences. eXtended Reality technologies play a key role in this evolution, allowing museums to extend their reach and create more immersive, inclusive, and accessible educational experiences for a broader audience beyond their physical walls. Embracing well-structured and standardised metadata modelling is vital in achieving this vision. It can serve as the foundation that enables widespread interoperability and seamless integration of systems as well as in fostering synergies among the domains of cultural institutions, education, and XR technologies. This work surveys the historical and current state-of-the-art advancements on metadata models for each pillar of the work's theme, namely the domains of education, cultural institutions, and XR while also details the key steps of metadata model amalgamation as a promising direction towards creating robust metadata frameworks from constituent models.**

***Key words* — Metadata models; Cultural institutions; Education; Museum education; eXtended Reality; Metadata models' amalgamation;**

I. Introduction

Museums have evolved beyond their traditional roles of expanding, preserving, documenting, studying, and promoting their collections [1]. While those core functions remain essential, modern museums have embraced broader missions and new approaches to engage with their audiences and communities through their resources, collections, and exhibitions [1], [2]. Moreover, for cultural bodies such as museums, the Web 2.0 era ushered significant changes at their roles in the context of a digitised society [3]. It is thus evident that museums play a crucial role in educating, inspiring, and engaging the public while contributing to broader cultural, social, and educational objectives [4]. "Museum education", also known as museum-based learning [5], refers to the knowledge and understandings that are acquired by the audience through a set of programs and activities that take place under the auspices of museums and other cultural institutions [2].

This latest evolution of museums coincided with wider penetration of the "eXtended Reality" (XR) domain, an umbrella term that encompasses the breadth of virtuality and reality including Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and other immersive technologies. These technologies aim to blend the physical and digital worlds, providing users with interactive and engaging experiences [6], promoting deeper understanding and engagement [7]. Thus, by embracing the nowadays ubiquitous XR technology, museums have the potential to transform visitors' experience, empowering them to personalise and even co-create their own encounters with art, history, science, and culture [8], [9].

This current ubiquitousness of ICT methods within the museums' realm brought both opportunities and challenges to the preservation, dissemination, and exploration of museums' and Cultural Heritage institutions' (CH) assets in general [10]. One such prominent alteration, is that now metadata models play an even more significant role in preserving CH by organising, describing, and providing access to the vast array of artifacts, artworks, historical documents, and other cultural resources within CH institutions. A metadata model is a framework or structure for organising and describing data, 67making it easier for users to discover, access, and manage information effectively [11]. Dublin Core (DC), Europeana Data Model (EDM) and Categories for the Description of Works of Art (CDWA) [12], to name but a few popular among numerous others, are commonly used in the CH sector to ensure quality, consistency, and interoperability. It its thus by the employment of standardised metadata schemas and practices, that museums can ensure efficient ICT-based organisation, preservation, and dissemination of their CH resources, promoting cultural appreciation, research, creation, and education for the generations to come.

A. Motivation & Contribution

The integration of XR technologies in cultural institutions opens up exciting possibilities for enhancing educational journeys and fostering deeper connections with CH. To realise the full potential of XR in museum education, a well-designed data model is crucial for ensuring interoperability between systems and organised data collection, storage, retrieval, use, customisation, and re-distribution. Existing research works in the discrete pillars of cultural institutions present both maturity & standardisation as evident by numerous popular such metadata models, while for education and XR do not present maturity not standardisation. Moreover, to the best of our knowledge, no work exists that unifies the three thematic pillars as far as the model of metadata is concerned.

The synergies and interoperability between XR technologies and cultural institutions represent far more than

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just an exciting development; they are, in fact, a catalyst for a profound and transformative shift. XR technologies redefine the way we approach preservation, education, and engagement with our CH. They offer immersive experiences that not only captivate but also educate, and this reimagining of CH preservation and education is the very essence and driving force behind our research.

Accordingly, this work stresses the significance of robust data models that will serve as the foundation for effective data management in museum education using XR. Such data models while also enable efficient data handling and analysis, contributing thus significantly to advancing educational experiences within the context of XR technologies, ultimately enriching the engagement of visitors with CH. To this end, this work's contributions are:

1) A detailed presentation of the generic, historical, and current state-of-the-art advancements on metadata models for each pillar of the work's theme, namely the education, cultural institutions, and XR.
2) Presentation of the key steps of metadata model amalgamation as a promising direction towards creating robust frameworks from constituent models in general and herein for seamless XR integration in cultural institutions, ultimately enhancing educational experiences and cultural heritage engagement.

The rest of the work is organised as follows: Section II presents the historical background of metadata models, one prominent instance, the Dublin Core and other notable such models. Section III details metadata models used in educational scenarios and focuses on two such key models, the "Learning Object Metadata" and the "Educational Modelling Language". Section IV discusses metadata models for cultural heritage institutions with focus on the "Europeana's Data Model" as well as other notable such models. Section V presents a few early attempts for metadata models for eXtended Reality in addition to extensive efforts on the domain's standardisation. Section VI details the key steps of models' amalgamation leading towards a seamless integration of constituent models. Finally, the work is concluded in Section VII that discusses the key arguments of this work and potential future directions for related research.

II. Metadata Models

A. Historical Background

Metadata models have evolved over time to meet the changing needs of information organisation and management [13]. The concept of organising information through metadata can be traced back to ancient libraries [14] where librarians categorised and organised scrolls, manuscripts, and books using basic descriptive elements, including titles, authors, and subjects. In the 1960s and 1970s [13], libraries began adopting computer-based cataloguing systems. The MARC [15] format was a major advancement in metadata organisation as it was developed to facilitate the exchange of bibliographic data between libraries and to enable automation in cataloguing processes.

With the growth of the Internet and digital resources in the 1990s, the need for standardised metadata increased. The Dublin Core[1] Metadata Element Set (DCMES) was introduced as a simple and widely applicable metadata standard for describing digital objects on the web [16]. It was based on the idea of using a limited set of elements that were easily understood and widely applicable. Since then, numerous domain-specific metadata models have emerged to cater to specialised information needs. Examples include IPTC[2] for media and journalism, EAD for archival collections [17], and CCO [18] for cultural heritage objects.

In recent years, the related concept of linked data and the semantic web has gained traction [19], [20]. Link data research aims to connect and enrich data through the use of standardised ontologies, enabling systems to understand and process metadata more effectively.

B. Dublin Core

The Dublin Core Metadata Initiative (DCMI) is a widely adopted standard developed to facilitate the sharing and description of web resources, and its scope extends significantly beyond the focus of this work, i.e. education to various domains, including CH institutions [12]. It offers a simple and yet flexible set of metadata elements that are commonly used to describe diverse resources, including CH resources such as artifacts, artworks, historical documents, photographs, audiovisual materials, and more.

The Dublin Core's (DC) elements can convey essential information about CH resources, such as title, description, creator, date, subject, and format, among numerous others as shown in Fig. 1. These elements play a crucial role in organising, indexing, and providing access to the vast array of materials available in digital libraries, museums, archives, and even CH institutions.

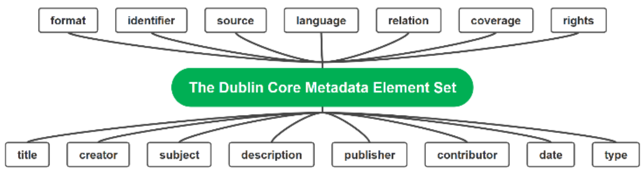

Fig. 1. The Dublin Core Metadata Element Set.

Dublin Core's simplicity and ease of use make it accessible to a wide range of CH institutions, regardless of their size or technological infrastructure. Accordingly, it has been widely adopted in the CH domain, making it easier to share and exchange CH metadata across different platforms and systems. However, some domains, such as CH institutions like libraries, archives, and museums, often deal with complex and diverse collections. These collections may require more specialised metadata standards to capture and convey rich contextual information about the resources they manage [21]. To address these specific needs, CH institutions may choose to complement DC with more specialised or domain-specific metadata.

The semantics expressed by DC's elements can vary depending on the type of resource being described, including CH resources such as artifacts, artworks, buildings, monuments, historical documents, books, folklore, traditions, language, knowledge, etc. This heightened variability can

[1] https://www.dublincore.org/

[2] https://www.iptc.org/

make it challenging to achieve a consistent and comprehensive understanding of resources across different domains. By incorporating ontologies that define and relate the meanings of DC's elements to specific CH domains, the interoperability and semantic richness of CH's metadata can be enhanced, providing a more comprehensive understanding of the resources, and improving the overall user experience [22].

C. *Other Notable Metadata Models*

Various metadata models have been developed over the years in order to cater to the needs of specific domains, industries, and types of content. Each model provides a standardised way to describe and manage information, facilitating effective organisation, discovery, and interoperability. Some of the most prominent such models are presented in the sequel.

ONline Information eXchange (ONIX) [23] is a widely used metadata standard for publishing. It enables the efficient exchange of information about books, e-books, journals, audiobooks, and other types of publications between publishers, distributors, retailers, libraries, and other stakeholders in the book supply chain. Among other things, it describes various attributes of publications, such as titles, authors, publication dates, prices, formats, and availability. Through ONIX, accurate and consistent publication-related information can be shared, enhancing discoverability and accessibility of published content, while also providing accurate information for consumers and researchers.

The Federal Geographic Data Committee (FGDC) Metadata Standard [24] is a comprehensive and structured framework developed by the United States' Federal Geographic Data Committee. The primary objective of this standard is to provide a consistent, interoperable, and effective way of describing geospatial data and resources, ensuring consistency, interoperability, and effective management of geographic data by both technical and non-technical users. In addition to supporting efficient cataloguing and searching of geospatial resources, it is also compatible with a wide range of platforms and applications.

Ecological Metadata Language [25], developed by the Ecological Society of America, is a specialised metadata standard for describing and documenting ecological and environmental data. Use of this standard facilitates the effective management, sharing, and understanding of ecological data, which are often characterised by complex relationships and dependencies. Thus, it contributes to advancing ecological and environmental research by ensuring crucial contextual information is accurately captured and shared alongside datasets.

III. Metadata Models In Education

The concept of metadata in education began to take shape in the early 1990s [16]. In 2002, the Institute of Electrical and Electronics Engineers' (IEEE) Learning Technology Standards Committee (LTSC) finalised and published [21] a metadata standard specifically for learning objects: the Learning Object Metadata (LOM), which gained widespread adoption in the e-learning community and was used as the foundation for other related standards and specifications.

An updated version of the LOM became available later on in 2011 [22], which included revisions and clarifications based on feedback from the e-learning community and introduced support for new technologies and practices [20]. A step ahead of the Learning Object (LO) movement, was the Educational Modelling Language (EML) [26], which emerged from the need to capture the full pedagogical context and sequencing necessary to create coherent and meaningful learning experiences. The aforementioned two standards, LOM and EML, could be used to describe the relationships between learning objects, the flow of learning activities, and the overall design of the learning environment, allowing thus educators and instructional designers to create a structured and standardised representation of educational content that facilitates interoperability, customisation, reusability, and efficient management of educational processes.

A. *LOM: "Learning Object Metadata"*

The Learning Object Metadata (LOM) Data Model[3] is a standardised framework used to describe and represent educational resources (digital and nondigital) in a structured way. LOM focuses on capturing metadata about learning objects [27], [28]. Learning objects are discrete units of educational content, such as videos, articles, quizzes, simulations, etc. LOM provides standardised elements to describe various aspects of learning objects, such as title, description, keywords, educational level, and technical format among a plethora of others. These metadata facilitate the discovery, retrieval, and reuse of learning objects in different educational contexts. A detailed description of each resource is included in the annotations of the model, which are grouped by educational, legal, technical, and other characteristics. The LOM data model, as shown in Fig. 2, describes educational material in nine categories: *General*, *Lifecycle*, *Meta-Metadata*, *Technical*, *Educational*, *Rights*, *Relation*, *Annotation*, and *Classification*.

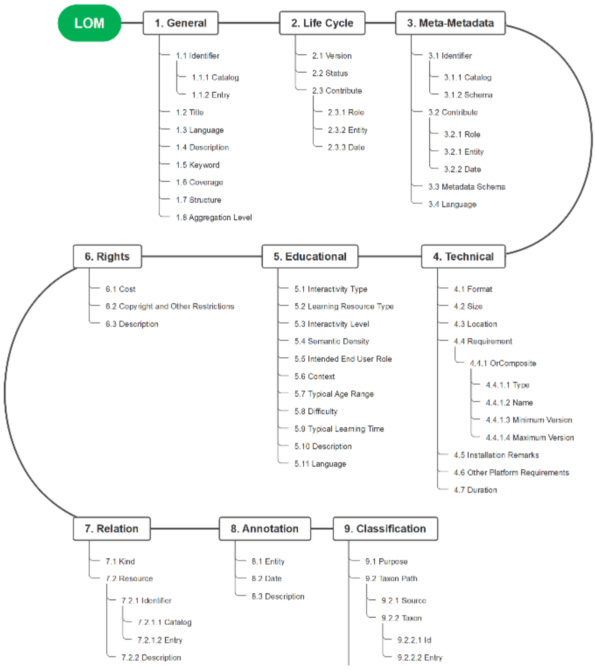

Fig. 2. The hierarchy of elements in the LOM data model.

[3] http://www.ieee.org/

In the field of education, LOM stands as an influential force, embodying the principles and expectations discussed earlier in this section as far as metadata models are concerned. By incorporating essential metadata elements like keywords and learning objectives, LOM empowers educators and learners alike to navigate the complex landscape of educational resources with precision and ease. Its role as a catalyst for seamless resource discovery and meaningful learning underscores its significance in shaping the educational experience for both educators and students [28].

In addition to describing the educational resources, LOM supports the reusability and adaptability [29] of learning objects as it enables educators to identify appropriate materials for their specific teaching contexts and adapt these for their instruction by providing detailed information about the content, format, and pedagogical characteristics of a resource. Furthermore, LOM, when combined with adaptive learning systems, can enhance the effectiveness of educational content delivery and personalisation [30]. The LOM metadata features valuable information about learning objects, helping thus the adaptive system identify and recommend appropriate resources based on learners' preferences and learning styles. For instance, an adaptive learning system can use LOM data to suggest relevant learning objects based on a student's interests, prior knowledge, and learning goals. Additionally, the LOM may include information about the difficulty level and alignment with learning objectives, which can be useful for an adaptive system in adjusting the content difficulty and pacing to match the learner's proficiency level [31].

The LOM standard has indeed received some criticism as far as its inclusion of ambiguous concepts [32]. As highlighted by Cechinel et al. [33], certain elements or terms may be open to interpretation or have multiple possible meanings, leading to confusion or inconsistent understanding among educators and users. For example, an educator might encounter a resource described as a "learning object", but it may not be clear whether this resource refers to a comprehensive educational activity or a reusable piece of content that can be integrated into their own teaching materials. This ambiguity can hinder educators' ability to find and use appropriate resources that match their specific instructional needs. It might also affect the interoperability and exchange of educational resources between different platforms or systems, as the interpretation of LOM metadata could vary from one context to another.

Another drawback of LOM is the limited coverage of learning activities as a specific type of learning resource [32], [34]. While LOM provides a comprehensive framework for describing various aspects of learning objects, it does not offer specific elements or fields to adequately represent and describe learning activities. Learning activities play a crucial role in the learning process [35], as they involve the active engagement of learners and facilitate the application of knowledge and skills. These activities can include interactive exercises, simulations, quizzes, discussions, group projects, and practical tasks, among others. However, the absence of dedicated metadata elements for learning activities in LOM can lead to challenges in effectively representing and managing them within the metadata framework [32].

Since these concerns, as described in Cechinel [33] have been raised, efforts have been made for more specific and precise educational metadata schema using extensions and Application Profiles (APs) that build upon LOM. APs define how a metadata standard can be used and extended to better represent the educational context and meet the needs of a particular domain or community. This capability to extend and customise its schema provides motivation and flexibility propelling thus LOM as the foundation for educational metadata management [34], [36].

Despite its aforementioned challenges of LOM, its overall importance in the educational field cannot be overstated since it was the first widely accepted schema to promote reusability and adaptability of resources, providing quality assurance and evaluation, enhancing collaboration and resource sharing, and allowing students to create tailored learning experiences. However, by incorporating a more balanced approach with a focus on Learning Activities can lead to more effective and transformative learning experiences that empower learners to become active and self-directed in their educational journey [29].

B. EML: "Educational Modelling Language"

Existing learning technology specifications and standards, such as the aforementioned LOM, concentrate on the definition of learning objects, metadata, and the sequencing of these objects. Consequently, in many educational settings, the focus is often placed on the consumption of content rather than the sequence of actions and processes involved in the learning experience.

In that attitude, the "Educational Modelling Language" (EML), developed by The Open University of the Netherlands [26], is an example of a metadata model for designing learning processes. EML is an XML-based language that provides a framework for explicitly representing and designing instructional activities, interactions, and pedagogical strategies in a technology-independent manner. It enables the design of educational experiences by allowing individuals to describe what will be learned and how learners and educators will engage with educational tasks [37]. By doing so, educators have more flexibility in designing and implementing pedagogical approaches that align with constructivist and socio-cultural perspectives. These include learning activities, learning resources, social interactions, assessments, and other elements of the educational experience.

Over time, EML evolved into an official IMS[4] specification known as the Learning Design Information Model (LD) [38], generating significant optimism about its potential to advance the understanding of individual learning activities. It established a standardised modelling language that enables the representation of learning designs as descriptions of teaching and learning processes. Accordingly, these learning designs can be executed by a software system that coordinates all participants, resources, and services involved in the learning experience.

IMS LD specifies three levels of implementation and compliance: *Learning Design Level A* (shown in Fig. 3),

[4] http://www.imsglobal.org/home

Learning Design Level B, and *Learning Design Level C*. These levels are not strictly hierarchical in the sense that Level B includes everything from Level A, and Level C includes everything from Level B. Instead, each level builds upon the previous one, adding new features and functionalities to accommodate a broader range of

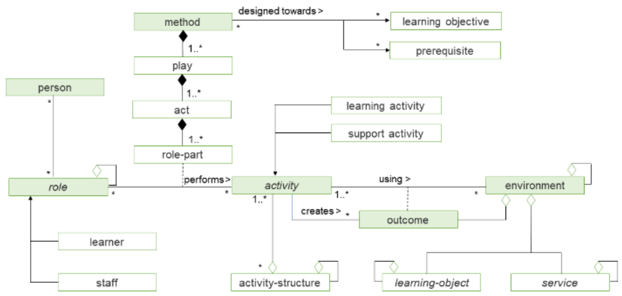

Fig. 3. IMS LD's conceptual model, Level A.

pedagogical requirements. Educators and instructional designers can choose the appropriate level of implementation based on the complexity and sophistication of the learning experiences they aim to create. Thus, the higher the level of implementation, the more expressive and adaptable the learning design can be.

IMS LD was received as a promising tool to enable the design and representation of complex and pedagogically expressive learning scenarios [39], [40], since in addition to organise resources, it models personalised learning itineraries to use them along with a methodology. However, despite the initial optimism, its widespread adoption and use in the broader education community did not materialise as expected.

Griffiths et al. [41] highlighted the limited adoption of EML and IMS LD beyond their original context, which was primarily focused on distance learning institutions. The authors therein suggested that the main reasons for this limited use are the complexity of the tools and the need for technical expertise to implement them effectively. Their study also indicates that the successful integration of IMS LD in blended learning environments would require two key conditions to be met: initially, the development of user-friendly tools that teachers can use without the assistance of technical experts, and secondly, the adaptation of the pedagogical context to effectively utilise the capabilities of the technology.

Derntl et al. [42] tested whether the assumption of the conceptual complexity of IMS LD is a key barrier to its adoption by practitioners and institutions in the field of technology-enhanced learning. Their study involved participants with little or no previous knowledge of IMS LD, and they were asked to transform a given textual design description into an IMS LD unit of learning using two different methods: (a) paper snippets representing IMS LD elements, and (b) authoring software designed for IMS LD. The goal was to see if the authoring software facilitated better solutions and whether the conceptual complexity of IMS LD hindered the authoring process. Accordingly, their work suggests that the barriers to IMS LD adoption might be related to other factors rather than the conceptual complexity of the specification while the review does not explicitly state what those other barriers might be.

The aforementioned studies, as well as others [43], provide valuable insights into the challenges of IMS LD adoption and highlight the need for further research to understand the reasons behind its limited uptake in practice and institutions. Addressing these barriers could potentially lead to increased utilisation of IMS LD in the future [41].

IV. Metadata Models for Cultural Heritage Institutions

With the advent of the internet and the exponential growth of digital information, the landscape of ICT-supported organisation of CH information has undergone significant transformation. The availability of vast amounts of digital information has brought both opportunities and challenges to the preservation, dissemination, and exploration of CH with the use of ICT.

CH's preservation requires careful monitoring of both the artifacts themselves and the environment in which they are stored or displayed. The term "cultural heritage" encompasses a wide range of tangible and intangible assets that are considered valuable and significant to a particular culture, community, or society [10]. It refers to the legacy of physical artifacts, traditions, customs, knowledge, and practices that are inherited from past generations and are passed down to future generations.

Tangible CH refers to physical objects and artifacts that have historical, artistic, archaeological, or anthropological importance. This can include monuments, art collections, artifacts, cultural landscapes, and other physical manifestations of a culture's history. Intangible CH, on the other hand, refers to the non-physical elements of culture that are passed from generation to generation through customs, rituals, music, dance, language, stories, traditional knowledge, social practices, and numerous other means.

In order to address the needs of a CH institution, such as a museum, a metadata standard should be selected based on the specific use case and requirements of the organisation. A well-matched standard ensures accuracy, consistency, interoperability, and future-proofing (within reasonable limits) leading to improved resource discovery, usage, preservation, and dissemination. Careful consideration of metadata standards empowers organisations to leverage their resources optimally and aligns with best practices in the information management domain.

With the aforementioned Dublin Core metadata standard considered as a point of reference [22], [44], several alternative metadata standards and schemas are available, each with its specific focus and use cases:

1) Metadata Encoding and Transmission Standard (METS) is a metadata standard for encoding descriptive, administrative, and structural metadata regarding objects within a digital library. It is particularly useful for organising complex digital objects, such as digitised books, images, and audio files [45].
2) Encoded Archival Description (EAD) is a metadata standard specifically designed for describing archival collections. It provides a structure for describing the content, context, and arrangement of archives [46].
3) Metadata Object Description Schema (MODS) is a

bibliographic metadata standard developed by the Library of Congress[5] of USA. It provides a more expressive and flexible schema than Dublin Core, allowing for more detailed and granular descriptions of resources [47].

4) Categories for the Description of Works of Art (CDWA) is a metadata standard designed specifically for describing works of art and cultural objects. It provides a structured framework for cataloguing and describing various types of artworks, artifacts, and cultural materials, aiming at museums, art institutions, and cultural heritage organisations to manage and share information about their collections [12].

Given the prominence of the Dublin Core metadata standard, DC is often considered a foundational or central pillar of metadata for CH institutions.

A. EDM

Europeana's Data Model (EDM) [48] is a metadata standard developed to improve the way CH artifacts are described and presented as digital entities. Through EDM, rich and diverse cultural heritage materials from institutions across Europe (and for that part, based on its adoption, from anywhere in the world) can be represented in a more flexible and expressive manner. As a result, objects and their relationships can be described and communicated in detail. EDM was designed to address the limitations of the previous metadata standard, Europeana's Semantic Elements (ESE) [49], by providing a more comprehensive and adaptable framework for describing CH artifacts.

EDM is based on a set of design principles that collectively contribute to its ability to serve as a powerful and adaptable framework for describing and presenting CH artifacts within the digital environment. A set of classes, as shown in Fig. 4 (classes introduced by EDM are shown in light green rectangles while classes in the white rectangles are re-used from other schemas), is defined in the model to represent types of entities or concepts within the CH domain. EDM also defines the properties that establish relationships between the classes, providing context and additional information about the CH objects. Various controlled vocabularies are also used in the descriptions of artifacts to ensure consistency and clarity. All these aspects facilitate better accessibility, searchability, understanding and above all interoperability of CH artifacts through the Europeana platform and all subscribers to the EDM model.

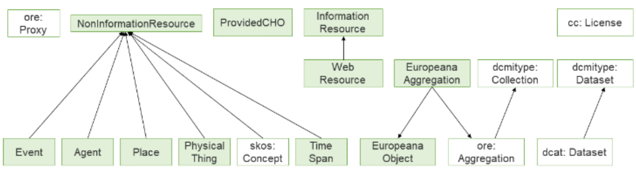

Fig. 4. The EDM class hierarchy.

A significant challenge [50] in the implementation of the EDM, and subsequently in its adoption, is the mapping / conversion of existing metadata schemas from different institutions to the EDM. This challenge derives from the variations in terminology and vocabulary across institutions, which can result in complexities and potential loss of contextual information during the mapping process. These issues can be mitigated with tools that enforce determinism and guidelines during the mapping, but a certain degree of expert judgment and manual intervention are nonetheless usually required. Thus, it is evident that achieving interoperability while preserving metadata's contextual richness during mapping is crucial. Despite these challenges, EDM's structured approach remains a valuable and quite popular contributor to enhancing accessibility and exploration to CH collections.

B. Other Notable Metadata Models

CH institutions like libraries, archives, and museums are responsible for curating and managing a variety of collections that contain a wide range of materials, ranging from ancient manuscripts to contemporary artwork, historical photographs to multimedia installations, among other materials. Rich contextual information associated with these resources can only be captured and conveyed through specialised metadata standards. This approach not only enhances the management and preservation of cultural heritage but also facilitates more comprehensive research, education, and engagement opportunities for audiences.

To preserve digital assets in a rapidly changing technological environment, the USA Library of Congress in collaboration with other cultural heritage institutions developed the Preservation Metadata: Implementation Strategies (PREMIS) [51] metadata model. The framework captures and manages metadata related to the preservation of digital documents, images, audio, and video over time.

Visual Resources Association Core Categories (VRA Core) [52] is a metadata standard and data model designed to describe visual resources contained in the fields of art, architecture, and other disciplines that are related to CH. The aim of VRA Core is to provide a structured framework for organising and presenting metadata about items related to the visual arts, making it easier for professionals in CH and research settings to manage and share visual content. Examples of such materials include images, photographs, artworks, and architectural elements. With VRA Core, essential information about visual resources is captured, structured, and made available for research, teaching, and scholarly purposes.

The CIDOC Conceptual Reference Model (CIDOC-CRM) [53], developed by the International Committee for Documentation (CIDOC), is a standard for CH's information conceptual modelling. Using this framework, museums, libraries, and archives can organise and manage information about their collections in a standardised and interoperable way. This enables them to describe the relationships between various entities, events, and concepts within the CH domain. A common language and structure are used to describe CH objects, their attributes, and their interactions. CIDOC-CRM is designed to be a high-level, ontological model that can represent complex relationships and contextual information.

V. Metadata Models For XR

Building on top of significant existing research and

[5] https://www.loc.gov/

successful deployments [54] as well as latest developments (the COVID-19 pandemic and the 'work from home' era it ushered as well as social medias' titan Facebook being re-branded as Meta – derived from Metaverse [55], [56]) the leap to some level of virtuality in numerous ICT-based interaction environments became the *sine qua non* of a plethora of informational systems [57].

Formally, XR, derived from "eXtended Reality" is "an environment containing real or virtual components or a combination thereof, where the variable X serves as a placeholder for any form of new environment" [58] with notable examples being the Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR).

In the same manner as the abovementioned domains of education (Section III) and CH (Section IV) are concerned, the XR domain also requires methods for interoperability aimed for organisation, indexing, and dissemination of its content. Such methods are designed for its specific requirements and address the needs of all key stakeholders of the domain, from creation to consumption.

As XR is yet too young a field, its metadata phase is still underdeveloped awaiting the prerequisite standardisation's phase maturity.

A. XR Domain Standardisation

Numerous attempts exist from various organisations as to its standardisation [59].

The "3rd Generation Partnership Project"[6] (3GPP) is a union of telecommunication organisations that work on XR-related specifications by two working groups: the Services & Systems Aspects Technical Specification Group, and the Radio Access Networks Technical Specification Group focusing on XR aspects such as services and traffic characteristics, glass-type AR implementations, VR (tele-) conferencing, immersive voice & audio services with headset interface extension, and immersive audio & video quality.

The IEEE SA[7] develops a plethora of global standards including XR-related topics such as VR/AR Standards, Audio Video Coding, Measuring Accessibility Experience and Compliance, Spatial Web protocols / architecture and governance, Interfacing cyber and physical world, Human factors for immersive content, and Global XR ethics.

The Joint Technical Committee (JTC 1) of the International Organisation for Standardisation (ISO) and International Electrotechnical Commission (IEC), through its Subcommittee 29 (SC29) including both, the JPEG and the MPEG Groups, develops *Pleno* [60] that aims in providing an organised methodology for the representation of new imaging modalities that feature texture and depth, light fields, point clouds, and holographic imaging. Furthermore, the MPEG Group has introduced sets of standards for digitally encoding immersive media (MPEG-I) and creating specifications that promote seamless interaction among virtual environments (MPEG-V).

The Standardisation Sector (ITU-T) and Radio-communication Sector (ITU-R) of the International Telecommunication Union have undertaken efforts in the field of immersive video conferencing, MR, and VR. Notably, the activities and outcomes of ITU-T's Study Groups are closely connected to XR, including transmission and distribution of immersive content over cable networks, testing procedures for AR applications, immersive media quality of experience (QoE), trusted networks for immersive media, immersive live experience systems and services, and the use of AR & VR to monitor and control IoT devices, among numerous others.

The W3C's Immersive Web Working Group[8] is dedicated to advancing the development of technologies that enable immersive and interactive experiences on the Web. Its focus lies in creating an open ecosystem for VR and AR content, ensuring seamless accessibility and interoperability across various devices and platforms. The Immersive Web Working Group's aim is at the definition of specifications and best practices that empower developers to build compelling and engaging immersive web applications that enrich users' experiences.

The aforementioned organisations are in their initial steps of standardisation and their results remain far from receiving widespread acceptance and/or adoption. When their output matures, their key contribution will be to both the enhancement of XR's interoperability (establishment of shared terminology, identification of crucial systems' and users' prerequisites, and creation of interfaces for XR services and applications) as well as the highlight of challenges in accessibility and quality of users' experience in XR [59].

B. XR in Education and CHs

Digital technologies have revolutionised the preservation, dissemination, and accessibility of CH content in recent years [61]. These technologies have opened up new possibilities for public engagement, research, and education, making CH more accessible, engaging, and relevant to audiences worldwide. XR technologies have tremendous potential in the fields of education and cultural heritage, offering innovative and immersive experiences that enhance learning, preservation, and engagement.

XR technology, particularly through the creation of accurate 3D models and representations, plays a significant role in the preservation and restoration of cultural artifacts and heritage sites [62], [63]. It offers powerful tools for experts, researchers, and CH professionals to document, study, and safeguard these valuable historical resources as long as it is combined with other preservation methodologies and expert guidance.

VR has revolutionised the way people experience CH by offering the creation of virtual museums and heritage sites. These virtual environments allow users to explore historical locations, artifacts, and cultural exhibits in a fully immersive and interactive manner, even if they cannot physically visit the museum, providing broader accessibility to cultural heritage resources [63]. Similarly, under the auspices of AR, XR offers the incredible capability to recreate historical events and scenarios through varying level of virtuality reenactments. This immersive experience allows visitors to feel like they are transported back in time, witnessing significant historical moments, and interacting with virtual and existing historical figures.

[6] https://www.3gpp.org/
[7] https://standards.ieee.org/
[8] https://www.w3.org/immersive-web/

The educational impact of XR technology is significant and far-reaching, revolutionising the learning experience for students of all ages and across various disciplines. It empowers educators to create dynamic and interactive learning environments, allowing students to explore, experiment, and learn in ways that were previously unimaginable. The integration of new display devices has significantly transformed user interactions and experiences, leading to a focus on multiple-user experience-centered design [64]. Interactive digital storytelling with XR offers a powerful and immersive narrative experience that takes storytelling to a whole new level enabling students to actively participate in the story [61]. It blurs the lines between traditional storytelling and interactive experiences, empowering students to become active participants in the narrative's journey.

As XR technologies continue to evolve and become more accessible [65], they hold immense potential to transform education based on CH. These technologies have the capacity to bridge the gap between the past and the present, breathing new life into historical narratives and artifacts. By harnessing the power of XR, CH education can inspire a new generation of learners to appreciate, preserve, and celebrate the richness of our collective human history.

C. *Existing Metadata Schemas*

The development of metadata standards for immersive technologies under the umbrella of XR, such as MR, VR, and AR is indeed a complex challenge since the immersive content comes in a loosely defined continuum with a variety of formats and experiences, each with its own unique characteristics and requirements. Moreover, the relative youth of the XR technology and the ongoing development of its standardisation further hinder the process. As a result, establishing comprehensive and effective standards can be quite complex, and thus the challenges and complexities associated with modelling XR's usage and data create a distinct set of issues that need to be addressed.

Nevertheless, there have been some notable instances of metadata development for XR applications. These few examples clearly demonstrate the potential and influence of XR across various industries and domain.

The ARCO Metadata Schema (AMS) [66], is a specialised and innovative metadata schema designed specifically for managing metadata associated with CH artifacts, with a focus on VR exhibitions. This schema provides a structured framework for describing and organising various attributes, information, and contextual details related to CH artifacts within the digital realm of virtual exhibitions.

In the AR domain, Ishikawa & Park [67] proposed a metadata schema design for augmented reality based on workflow. Therein, the authors presented an information structure that was deemed necessary to support a generic AR service. The information structure was in the form of AR service metadata schema and was implemented using XML. In order to ensure the effective and efficient information composition by their system, the authors analysed the existing AR configuration thus leading them to the design of a metadata schema.

VI. AMALGAMATION OF MODELS

Following this work's theme on the organisation of information for the scenario of "museum education using XR", the previous Sections detailed generic, historical, and current state-of-the-art advancements for each pillar of this theme, namely the education, cultural institutions, and XR. This presentation made clear that standards and metadata models, even if existing and mature, for each and every pillar, addressing the complete requirements of the integrated scenario's pillars leading to "museum education using XR" is challenging, to begin with.

Accordingly, this Section details the key steps of model amalgamation or fusion as a promising and transformative direction that will, in addition to its generality, also provide for the seamless integration of XR technologies in cultural institutions for educational purposes, enriching both educational experiences and cultural heritage engagement.

By doing so, the resulting integrated solution will be able to provide a wholistic solution that would encompass the entirety of the educational methods based on CH institutions that feature XR techniques. Moreover, such an approach would potentially be able to overcome the limitations and gaps present in individual models, providing a more efficient and seamless approach to managing metadata in the context of museum education with XR technologies. Such an integrated framework will potential be able to optimise the use of XR technologies, enhance educational experiences, and foster deeper connections with CH for museum visitors.

A number of prominent works on metadata models' merging exist and are presented in the sequel. Specka et al. [68] escribe the creation of the BonaRes metadata model for geospatial soil-agricultural research data. Therein, they initially analyse the constituent metadata models (INSPIRE and DataCite) and then identify and compare semantically equivalent metadata elements for potential mapping. Based on this mapping, they specified the new metadata model (BonaRes), and then in a third step, they add any further metadata elements necessary to match the new metadata model's requirements. In the work by Fierro et al. [69] a novel method for leveraging discrete representations to create a unified metadata model aimed at support of different stages of a building is presented. Their method is not focused on capturing all relevant metadata for every task of every stage of a building's lifecycle but only the metadata needed to support a data-driven applications. Their proposal includes a simple protocol for assembling metadata extracted or inferred from established metadata sources and a merge algorithm for detecting and reconciling differences between overlapping metadata sources. In Diamantini et al. [70] are motivated by data lakes and their diverse sources to create a uniform method for handling the heterogeneity of the metadata models of their sources. In their work, they propose a new metadata model well suited for representing and handling data lake sources, while complementing them with new ideas such as network-based and semantics-driven representation of available data. Their proposal presents high expressiveness and the ability to both "structure" unstructured data sources as well as to extract thematic views from heterogeneous source models. Following data lakes' literature their proposed method divides metadata into three categories: Operational metadata, Technical metadata and Business metadata, one which their focus is, which include business rules (e.g., the upper and lower limit of a particular field, integrity constraints, etc.). Finally, the authors of [71] propose a probabilistic framework using influence diagrams for the fusion of metadata of multiple modalities for photo annotation. Contextual information (i.e. location, time, and camera parameters), visual content (i.e. holistic and local perceptual features), and semantic ontology are combined in order to achieve the fusion process. Moreover, they show the benefits of using causal-power theory over correlation for fusing context and content and thus propose the use of causal strengths to encode causalities between variables, and between variables and semantic labels. All the above-mentioned works on metadata models' merging are case specific and thus are addressed from the point of view of the exact models and/or application domains the merging is applied on.

At the conceptual level, the merging of two or more discrete metadata models involves harmonisation and combination of the different of metadata models, achieved through the following proposed steps:

1) *Understanding Metadata Models*: As an initial step, achievement of an, as deep as possible, understanding of the metadata models to be integrated, by studying their documentation, structure, semantics, relationships, as well as their intended and actual use through case studies or equivalent applied methodologies.
2) *Mapping and Alignment*: Initially, creation of a mapping between the unambiguously corresponding elements of the constituent metadata models. This step could involve establishing equivalences, hierarchies, and relationships while ensuring that similar elements are matched accurately. Subsequently, tackling of elements with differences in schema, data types, or underlying semantics wherein the integration becomes more intricate. Application of techniques from data integration, semantic mapping, and ontology alignment can be employed to address these issues [72], [73].
3) *Normalisation*: Normalisation of the attributes of the metadata and their respective values to ensure consistency across the merged models. This includes standardising units, formats, and naming conventions across all models.
4) *Data Transformation*: Conversion of the metadata from all models into a common format, which might involve transforming XML, JSON, or other formats to a unified structure.
5) *Data Fusion Strategy*: Identification of methods to handle conflicts or overlaps between metadata from different models. Strategies might involve prioritising one model over the other (depending on the intended focus of the final amalgamated model), averaging values, generating new values based on combined information and numerous more [74].
6) *Validation and Quality Assurance*: Validation of the integrated metadata for accuracy and completeness. Usage of automated validation scripts and/or manual inspection (according to requirements) to ensure the fused metadata adheres to the intended standards.
7) *Testing and Iteration*: Test of the integrated metadata in the real-world or the intended fictional scenarios to identify any unforeseen issues. According to the results received, iteration of the *Data Fusion* and *Validation and Quality Assurance* processes, if need be.
8) *Documentation*: Documentation of the integration process, including mappings, transformations, and fusion strategies for the purposes of future maintenance, troubleshooting, and evolution of the fusion process.

VII. Conclusion

Museum education is a dynamic and ever-evolving field that continuously adjusts to the changing requirements and expectations of its learners. By synergising the distinctive attributes of museums with cutting-edge educational methodologies, this domain has the potential for consistently crafting enriching and captivating learning encounters. One pivotal driving force in this evolutionary journey is the incorporation of eXtended Reality (XR) technologies. These technologies not only enable museums to expand their influence but also empower them to construct immersive, comprehensive, and accessible educational undertakings that cater to a wider audience, transcending the confines of physical structures.

In realising this transformative vision, the adoption of well-structured and standardised metadata modelling emerges as a crucial imperative. Such a foundation proves instrumental in fostering widespread interoperability and seamless incorporation of various key-stakeholders' systems. Moreover, it serves as a catalyst for nurturing synergies among diverse spheres - ranging from cultural institutions to education and the realm of XR technologies. This research delves into the historical and contemporary advancements within metadata models, meticulously examining each of the pivotal pillars: education, cultural institutions, and XR domains.

Additionally, this work outlines the key strides required for the amalgamation of metadata models, presenting a promising trajectory towards the creation of resilient and comprehensive metadata frameworks that are composed of constituent models. By detailing the amalgamation process, this study offers a conceptual roadmap to establish a robust infrastructure that supports the convergence of various metadata models into a unified and cohesive whole. This approach not only aligns with the overarching goal of enriching museum education through innovative technologies but also reinforces the broader objective of achieving seamless collaboration and integration across interconnected, at least through their metadata models, domains.

Future trajectory of this research will be centred on the refinement of the proposed metadata models' amalgamation in terms both theoretic as well as its conversion to practical demonstration software. The augmentation of the theoretic part will make the proposal more detailed, and it will also contribute to its ability to address more diverse constituent models, while the creation of a demo of the proposal will provide for a reusable software that will amplify its outreach and applicability. In addition, the proposed metadata models' amalgamation scheme will have to undergo rigorous evaluation in order to present its effectiveness and efficiency, especially in comparison to existing, even partially matching, methodologies. Finally, the augmented metadata models' amalgamation scheme will be applied to the collection of existing state-of-the-art models of the presented pillars of the theme of the work in order to produce a unified metadata model for Museum Education using XR technologies.

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