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Supporting Personalized Learning Experiences on top of Multimedia Digital Libraries

Executive summary

by

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Chapter 1. MOTIVATION, GOAL, OBJECTIVES AND TAKS OF THE PHD THESIS

1.1. Motivation

Libraries have been always being an important source of knowledge. The technology evolution transformed the traditional libraries into digital libraries that arose from the need to efficiently host and serve the huge amount of information that now exists in the form of digitized content. In a multimedia digital library, the managed content is not restricted to the usually mainly textual documents, but they also contain media types like music, videos, images, maps, and mixtures of different content types (multimedia objects) for different uses. Multimedia libraries may also contain content types that were not supported in traditional libraries at all like 3D objects, executable software (e.g. computer games) or callable services. One of the main challenges for a multimedia library is to provide effective access to these types of content (based on adequate indexing) and to provide support for the "real-time" integration of different content types. [Neuhold and Niederée, 2003]

Some challenges of multimedia libraries are closely related to those of cultural heritage institutions, e.g. Galleries, Libraries, Archives, and Museums (or GLAM) that (want to) make multimedia representations of their artifacts available online [Neuhold and Niederée, 2003]. The main goal of these institutions is the digitization of tangible or intangible heritage and consequently its collection and preservation. But in addition they aim to reinforce the accessibility to large public, stakeholders' engagement and sensitization [Glushkova et al., 2015]. Cultural heritage institutions re-think their role and explore new possibilities to serve different social needs and applications, such as learning. In the last decade almost all of them use multimedia digital resources. These digital resources form a rich source of knowledge about cultural heritage, natural history, and biodiversity that could be used to serve various educational contexts and scenarios, not only to support learning "about cultural heritage" that is preserved in those institutions, but also "learning from cultural heritage" out of the scope of these institutions.

However, due to a number of barriers, an impressive abundance of multimedia content available remains largely unexploited. One one hand digital resources in some institutions are still accessed in a limited way and utilised through rather static modes of delivery. On the other hand, there is a lack of efficient support on top of existing digital libraries implementations for learning applications.

1.2. Goal, objectives and tasks of the thesis

The goal of this thesis is to provide a comprehensive approach for taking advantage of existing cultural digital materials residing in cultural heritage institutions to support the

creation and provision of effective pedagogy-driven learning experiences not only in the context of cultural heritage preserved in these institutions, but also to serve other learning contexts and scenarios. Towards this end, the thesis has the following objectives described from a stakeholders'/users' point of view:

- support the needs of institutions preserving cultural heritage through opening their cultural collections to the learning community and their visitors and supporting effectively formal and informal learning applications on top of them,

- support the educators and teachers accessing cultural digital content residing in those institutions collections and developing learning experiences to effectively support the needs of different learners in a pedagogically-sound way maximizing the learning outcome, and

- support Learners with different needs and preferences accessing cultural material in an effective pedagogy-driven personalized way.

The goal and objectives of the thesis will be realized through the following tasks:

Task 1: Study of the problem

This task is realized through the following steps:

- Study the concepts and components of digital libraries and digital objects, as well as eLearning systems and learning objects.
- Study main interoperability standards, specifications and approaches for the description, packaging and access of (cultural) digital objects and learning objects, and for repositories interoperability.
- Study personalization in Digital Libraries and learning: approaches for personalization in DL, user modeling and profiling; the characteristics of the Learner as a user and how they (should) affect personalization; instructional design and personalization; approaches for adaptive personalization in eLearning.
- Analyze in detail the problem(s) that this thesis has to address, present the envisioned scenario and compare it with current solutions.

Task 2: Modeling the environment to support pedagogy-driven personalization.

This task is realized through the following steps:

- Define the domain model; Description and structuring of the object layers to support pedagogy-driven personalization.
- Define the learner model taking into account the learner needs and preferences identified as important factors to personalization.

- Define the instructional model for the encoding of instructional strategies (abstract training scenarios).
- Define the adaptation model for the dynamic construction of pedagogy-driven personalized learning experience taking into account the current learner needs and preferences.

Task 3: Present the architecture to address the identified problems and meet the user requirements set, and the functionality and services of its components.

Task 4: Implementation and application of the proposed framework and architecture.

Task 5: Experimentation and evaluation of the proposed framework/architecture.

Developed services and tools will comply with the recommendations and requirements of established global standards and protocols in the field of digital libraries and eLearning to ensure interoperability with other implementations as much as possible, and flexibility, variability, extensibility and sustainability.

Chapter 2. STUDY OF THE PROBLEM

Supporting pedagogy-driven personalized learning experiences on top of multimedia digital libraries is a complex problem with two poles and many dimensions. The aim of this chapter is to study this problem, and in specific:

- Study the concepts and components of digital libraries and digital objects, as well as eLearning systems and learning objects.

- Study main interoperability standards, specifications and approaches for the description, packaging and access of (cultural) digital objects and learning objects, and for repositories interoperability.

- Study personalization in Digital Libraries and learning: approaches for personalization in DL, user modeling and profiling; the characteristics of the Learner as a user and how they (should) affect personalization; instructional design and personalization; approaches for adaptive personalization in eLearning.

- Analyze in detail the problem(s) that this thesis has to address, present the envisioned scenario and compare it with current solutions.

2.1. Digital Libraries

A digital library mediates between the information needs of its user community and the globally available content. This is achieved by contributions in four areas [Niederée, Steffens, Hemmje, 2002]:

- Content pre-selection: The library selects high-quality content potentially relevant for the members of its user community;
- Content structuring: The library structures the content according to the predominant domain understanding of its user community;
- Content enrichment: Domain and library experts as well as community members enrich content objects with descriptive and value-adding metadata;
- Library services: Services for content retrieval, access, annotation, etc. support the identification of relevant material and facilitate content access;

DELOS reference model for digital libraries identifies six key areas that are expected to cover the design of any digital library: content, architecture, users, functionality, quality and policies [Candela et al., 2008]. The model also identifies three different types of systems operating in the Digital Library universe:

- Digital Library (Digital Library) - organization, including virtual, which collects, manages and preserves the long term rich digital content and offers different types of users specialized functionality to access such content in accordance with well-defined quality criteria explicit policies;
- The software system of digital library (Digital Library System) - a software system based on a specific architecture that provides functionality required by a specific digital library. End users "communicate" with digital library using this system;
- The management system for digital library (Digital Library Management System) - a software platform that provides the necessary infrastructure for the construction and administration of the software system of digital library and opportunities to integrate additional software, allowing expansion and enrichment of supported functionality.

According to this reference model there are three types of end-users characterizing the the operation of the Digital Library service: (i) Content Creators – the "producers" of the DL Content; (ii) Content Consumers – the "clients" of the DL Content; and (iii) Digital Librarians – the "curators" of the DL Content.

In this thesis, the following definitions will be used [Sotirova et al., 2012]:

- A **Repository** consists of digital objects, organized in collections sets, which are stored and managed in computer networks and described with metadata.
- A **Digital Library** is a fully packed repository, with relevant user interface and services to support the needs of different communities. Digital library is domain and institutionally specific;
- An **Aggregator** is a repository, which ingests and manages digital content from different sources into a repository. It does not obligatory have user oriented interface; does not provide services; is not obligatory a heritage holder. Aggregator could be only a technical mediator between the holder institution and

its digital library. The process of data ingesting/management follows technical and technological requirements of a specific project.

2.1.1. Digital Objects

In the broad sense, a digital object is an information object that has a digital form (at least one) and is described with metadata. Digital objects may be audio-visual objects, e.g. images, text, web pages, sound, animation, etc., which are usually grouped into collections to certain criteria and are stored in special storage facilities together with their meta-descriptions. These, according to the Library of Congress, are:

- **Descriptive metadata**: information relating to the intellectual contents of the object, akin to much of the content of a standard catalogue record: this enables the user of a digital library to find the object and assess its relevance.
- **Administrative metadata**: information necessary for the manager of the electronic collection to administer the object, including information on intellectual property rights and technical information on the object and the files that comprise it.
- **Structural metadata**: information on how the individual components that make up the object relate to each other, including the order in which they should be presented to the user: for example, how the still image files that comprise a digitized version of a print volume should be ordered.

Any object, physical or digital, could be described and discussed in possibly infinite ways, depending on the context. This depends on the perspective from which one approaches the digital object (e.g. cultural, historical, artistic etc.). The choice of metadata terms used to describe content of a digital object in any collection is (and has to be) based on implicit or explicit assumptions or beliefs about how, when and where the asset is likely to be used and by whom. Different metadata models have emerged in order to be able to describe different aspects of digital objects and contextualize them depending on the intended use of those objects [IEEE LOM, 2002; CIDOC CRM, 2006, etc.].

2.2. eLearning systems

Generally, the infrastructure of an eLearning system can be divided into a Learning Content Management System (LCMS) and a Learning Management System (LMS). A Learning Content Management System (LCMS) focuses on content creation, reuse and management and can compress the lifecycle of capturing, delivering, managing and measuring knowledge and learning content reuse in many different ways. A Learning Management System (LMS) focuses on delivering, tracking and managing training/education. Despite this distinction, the term LMS is often used to refer to both an LMS and an LCMS. [Lennox, 2001]

2.2.1. Learning Objects

In eLearning environments the material is cut into smaller independent pieces that can be used as they are or in combination with other material to form higher level objects covering the learning needs of the users on demand at any place and at the right time. In this context, the fundamental idea behind learning objects is that instructional designers can build small instructional components that can be reused a number of times in different learning contexts. Using the LEGO metaphor, where a learning object should be **Reusable, Accessible, Interoperable/portable, Durable.** An important aspect for reusability and personalization is the granularity of learning objects. However the structure and composite nature of a learning object is still open to interpretation [Metros, 2005; Knight, Gašević, and Richards, 2005]. Different content models have emerged in order to address this problem [Verbert and Duval, 2004, 2008; Balatsoukas, Moris, and O'Brien, 2008].

2.2.2. The Learnativity model

The Learnativity Content Model [Wagner, 2002] illustrates the concept of assembling content into higher-level objects (Figure 2.1). Learning objects are assembled from information objects and assets into higher-order collections such as courses and curricula. The basic components of the Learnativity content model are the following: Content Asset; Information Object; Learning Object; Learning Component; Learning Environment.

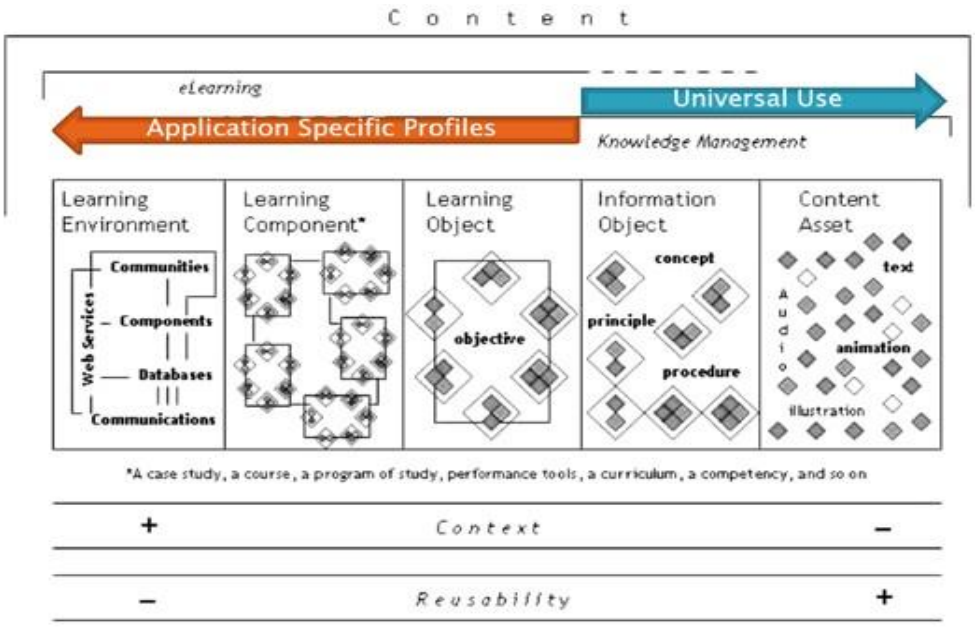

Figure 2.1 The Learnativity content model [Wagner, 2002]

2.3. Standards for description and packaging of (cultural) digital objects

Reports in the context of ATHENA [McKenna and De Loof, 2009], MINERVA [Fernie, Francesco, and Dawson, 2008] and PrestPRIME [Schreiber, 2010] projects, and [Sotirova et al., 2012] provide extensive surveys on standards and specifications for the description of (cultural) digital objects. The most widely used standard for the discovery and interpretation of digital objects: Dublin Core (DC) [DC, 1999], ISO/IEC MPEG7 "Multimedia Content Description Interface", Metadata Encoding Transmission Standard (METS).

2.3.1. Related work on accessing cultural digital material

Important projects have been launched to propose digital platforms and provide access to cultural digital material [Glushkova et al., 2015], such as Athena (Athena, 2011), ECHO - European Cultural Heritage Online Initiative (Echo-Cultural Heritage Online, 2014), CAN (Collections Australia Network, 2011), and Google Art Project (Google Art Project, 2013). The data is also made available as Linked Open Data, it is represented in the European Data Model (EDM) and the described resources are addressable and dereferencable by their URIs (Halshofer, Isaac 2011). [Glushkova et al., 2015]

2.4. Standards for description and packaging of learning objects and higher learning units

The most widely used standards for the description and packaging of learning objects are the IEEE 1484.12.1 – 2002 Standard for Learning Object Metadata [IEEE LOM, 2002] , the IMS Question & Test Interoperability specification [IMS QTI, 2005] and the Sharable Content Object Reference Model (SCORM) [SCORM, 2004].

2.5. Standards for digital repositories interoperability

There are several standards for the interoperation of digital repositories, such as the IMS Digital Repository Interoperability (IMS DRI) [IMS DRI, 2003], the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) [OAI, 2008], the Edusource Communication Language [Hatala et al., 2004], the OAI-Object Reuse and Exchange [OAI-ORE, 2014] etc.

2.6. Personalization in Digital Libraries and learning

In this work we see personalisation as "the ways in which information and services can be tailored to match the unique and specific needs of an individual or a community. This is achieved by adapting presentation, content, and/or services based on a person's task, background, history, device, information needs, location, etc., essentially the user's context" [Callan et al., 2003].

2.6.1. User modeling and profiling

User modelling can be defined as the process of acquiring knowledge about the user in order to provide services, adaptive and personalized information flow/s following its specific requirements in the DL domain. Main questions asked are [Arapi et al., 2016]:

- User interests: What is the user interested in? What needs to be done or accomplished?
- User preferences: How is something done or accomplished?
- User goals and intents: What the user actually wants to achieve?
- User motivation: What is the force that drives the user to be engaged in observation activities?
- User experience: What is the user's previous experience that may have an impact?
- User activities: What the user does in the DL environment, etc.

Building a user model for a DL involves defining: the "who" (the degree of specialization); the "what" (the cognitive goals, plans, attitudes, capabilities, knowledge, and beliefs of the user); the "how" (the model is to be acquired and maintained); and the "why" (whether to elicit information from the user, give assistance, provide feedback, or interpret the user's behaviour. [Arapi et al., 2016]

2.6.2. Understanding the Learner user

"One size fits all" solutions are not enough to satisfy different learners. There are a number of factors that can influence the extent of learning and when taken into account learning experiences and the learning outcome can be positively affected:

- Learning styles: Learning styles can be generally described as "an individual's preferred approach to organizing and presenting information" [Riding & Rayner, 1998]. Learning styles can affect both the construction of the learning plan and the selection of learning objects in a learning experience.

- Learner Goals/Objectives: Goals about what would be desirable to learn are central to making required decisions about what and how to learn [Ram and Leake, 1995].

- Previous knowledge: Wisniewski and Medin [Ram and Leake, 1995, chap. 6] show that prior knowledge and intuitive theories can also influence learning [see also Murphy and Medin, 1985].

- Educational Level and difficulty: It is important for a learning experience to be aligned with the educational level of the target Learner.

- Technical and other preferences: E.g. learner's devices, internet connection, language, learning provider etc.

The representation of the user model can follow developed standards and specifications (e.g. IEEE Personal and Private Information (PAPI) and IMS Learner Information Package), maximizing its reusability and portability.

2.6.3. Pedagogy-driven personalization

Personalization of the learners' learning experience was connected with the adaptation of the learning process and its content to the personal characteristics and preferences of the learner, as much as possible. Instructional Design is part of Instructional Science, which encompasses theories, models, methodologies and tools for instruction [Mizoguchi & Bourdeau, 2000]. Instructional Design is an engineering activity for which the artifact is some instructional product to help a learner acquire some knowledge or skill [Merrill, 2001]. This activity applies strategies and techniques derived from behavioral, cognitive, and constructivist theories to the solution of instructional problems [Mizoguchi & Bourdeau, 2000]. Instructional Design is a methodology for systematic planning and developing curriculums, courses and educational media. It helps teachers, educators and training professionals to design effective, efficient and appealing instruction that meets requirements of specific learning goals, learners' characteristics and organizational needs.

2.6.3.1. Pedagogical patterns/educational templates

However, the instructional design process is usually performed completely by regular teachers lacking advanced pedagogical skills resulting in scenarios, where a sound pedagogical approach (the "how") is absent and the focus is mainly on "what" to teach putting the learners and their individual learning needs on the sidelines.

The role of the instructional designers could be to create pedagogical patterns (learning designs without specific learning content), as prescriptions for designing instructional products to optimize the learning outcome. Pedagogical Patterns capture best practice in particular educational domains [Eckstein et al., 2013]. These pedagogical patterns are based on instructional design theories. The teachers, based on these patterns (educational templates), could create a number of educational scenarios for various educational contexts.

2.6.3.2. Instructional strategies to support Honey and Mumford learning styles

Learning styles affect both the construction of the learning plan and the selection of learning objects and this is highly dependent on the taxonomy that is used in a specific environment for the definition of learning styles.

Important characteristics of Honey and Mumford learning styles [Honey et al., 1992] could be a helpful guide when constructing instructional strategies to support each of

those learning styles (building the instructional plan + building appropriate learning objects).

2.6.3.3. IMS Learning Design (IMS LD) specification

IMS Learning Design specification [IMS LD, 2003] is a development of the Educational Modeling Language [Hummel, Manderveld, Tattersall and Koper, 2004] (designed by the Open University of the Netherlands (OUNL) to enable flexible representation of the elements within online courses; not just the materials but also the order in which activities take place, the roles that people undertake, key criteria for progression, and the services needed for presentation to learners. The IMS Learning Design specification allows many different pedagogies in e-learning to be expressed. It allows different pedagogical approaches to be integrated into a single "learning design" where different approaches may be appropriate for different types of learners.

2.6.4. Approaches for adaptive personalization in eLearning

Within the field of technology enhanced learning, adaptive educational systems offer an advanced form of learning environment that attempts to meet the need of different students. To describe **adaptive learning systems**, one may distinguish between the following major concepts: the **domain model**, the **learner model**, the **context model**, the **instruction model**, and the **adaptation model.**

Major shortcomings of existing adaptive educational systems are:

Pedagogy (the how-to-teach) is not taken into account. Even if it is taken into account, important parameters as learning objectives, educational level, previous knowledge, etc. are not always taken into account. Although adaptivity in eLearning has become one of the key aspects in Adaptive eLearning Systems, such adaptivity has tended to focus on adaptive content retrieval and (simple) content sequencing based on domain models, or more recently ontologies [De Bra et al., 2003].

The instructional model is bound with the domain model (content) or the adaptation model (adaptation engine) [Brady, Conlan, and Wade, 2004]. In these cases, adding new or different pedagogical models to the content model is more difficult and involves a re-authoring of the content model.

Some Adaptive eLearning Systems are dependent on a specific learning style approach that is usually bound/incorporated in the adaptation strategy (algorithm) or the domain model, (e.g. in 3DE Project [Sarrikoski et al., 2000]). *Lack of generality, i.e. capability of the system to support any teaching domain* [Surjono, 2007]. Most current AES have fixed knowledge domains which are not easily expandable or adaptable to other subject matter [Carver et al., 1999; Wu, De Kort, and De Bra, 2001].

Complexity, cost and effort required to develop adaptive eLearning experiences is very high [De Bra et al., 2000; Dagger, Conlan and Wade, 2003a; Conlan and Wade, 2004].

2.7. The problem of interoperability between (cultural) digital libraries and eLearning applications

Ouksel and Sheth identify four types of heterogeneity which correspond to four types of potential interoperability [Ouksel and Sheth, 2004]: system (incompatibilities between hardware and operating systems), syntactic (differences in encodings and representation), structural (variances in data-models, data structures and schemas), and semantic (inconsistencies in terminology and meanings). To support eLearning applications on top of museums' cultural collections we have to deal with challenges related with all the above interoperability types, making this a complex and multilevel problem.

We could also define two axes of interoperability based on the layers of objects defined in Learnativity model as presented in Figure 2.2:

- Horizontal Interoperability: Access and use of objects at the same level, and
- Vertical Interoperability: Access, use and "transform" objects at one level to build objects at a higher level (re-purposing, contextualization)

Interoperability on both axes can be seen from the view of objects, standards, infrastructures, users and personalization.

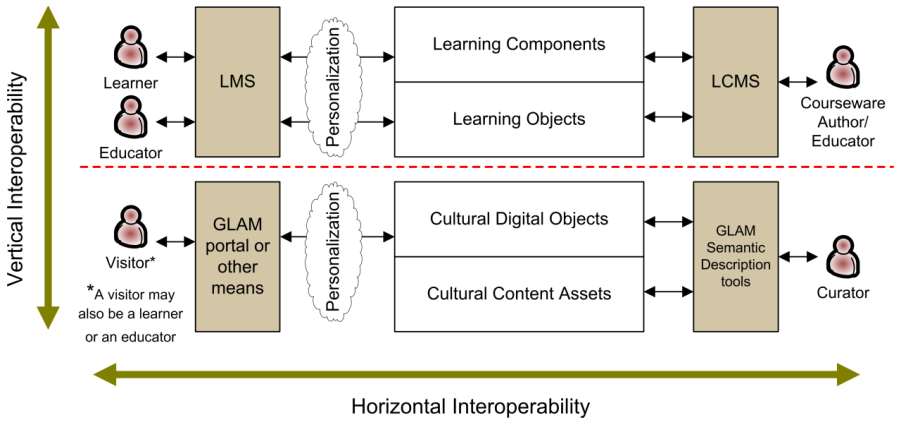

Figure 2.2 Horizontal and vertical interoperability

After the analysis performed in the previous sections, we can see that to support the goal of the thesis, a complex problem of interoperability should be solved. We saw that much work has been done in terms of standards, approaches and implementations to support interoperability on the horizontal level. Main problems of interoperability arise on the vertical axis, while little work has been done in this direction. This thesis mainly deals with the vertical axis, taking also into account the related standards and work to support horizontal interoperability at each level.

In the following sections we will analyze the problem of interoperability on the vertical axis from an objects, infrastructures and personalization point of view.

2.7.1. An objects point of view

A digital object can have many educational uses and these determine whether it can become a learning object or not [Warwick University group, 2004]. A digital object cannot become a learning object (LO), unless it has a clear pedagogical purpose (learning outcome/objective) that is appropriately linked to the object through learning metadata and it has the right granularity and content for the target pedagogical purpose. However, we cannot predict all possible educational uses of digital objects. Afterwards, these LOs should be assembled to higher level learning units (Learning Components). However, the way these LOs should be assembled depends on the current learning context and needs. From the above, it turns out that transforming digital content to learning experiences is not a straightforward and one-to-one mapping process. Depending on the target educational contexts, digital content should be firstly adapted and contextualized with the use of appropriate learning metadata to form learning objects, and then used and assembled in proper ways to learning experiences taking into account the different learning needs and preferences of the target learners. This process is known as "repurposing" or "reauthoring. However, this re-authoring process is a multi-step and complicated activity that is not sufficiently and efficiently supported on digital libraries.

2.7.2. An infrastructures point of view

Based again on Figure 2.2 we can see the problem of interoperability of cultural digital libraries and eLearning applications from an infrastructures point of view from a top-down and bottom-up perspective.

From the perspective of (cultural) digital libraries, (cultural) digital resources are ingested and annotated by curators using different standard or non-standard schemes and/or domain ontologies/taxonomies/vocabularies. However, these descriptions, for the context and from the point of view of curators may be not useful as they are to support different educational contexts. To be able to support learning, these cultural digital objects should be first re-purposed to create LOs and further used for the development of higher learning units to be delivered in the form of learning experiences. However, on one hand this repurposing process is not supported on top of cultural digital libraries and on the other hand museum staff, but also teachers out of the scope of these museums, lack the pedagogical knowledge to develop LOs and learning experiences to effectively support the needs and preferences of different Learners.

From the perspective of eLearning systems the authoring procedure that is currently followed for the creation of courseware is similar to the procedure followed in traditional learning environments. The author defines a number of learning objectives and activities

that may be supported by LOs that should be followed in order for the target goal to be accomplished. Thereafter, the author is trying to find appropriate learning content to create learning LOs to support these activities. An Author for the creation of LOs through an LCMS either discovers and reuses existing LOs that may be stored in Learning Object Repositories that (s)he repurposes depending on the target educational context or (s)he starts to create a new ones. In both cases (s)he may need to find appropriate (Cultural) Digital Objects. But, in order for these (Cultural) Digital Objects to be accessible and edited through the LCMS, they should be represented and described according to eLearning standards (e.g. SCORM, LOM) and stored in a learning objects/assets repository providing services for their discovery and access. However, although LOs must be described with educational metadata from their nature, this does not happen with cultural digital objects, which have been described from the context of the museum curator using several standard or non-standard schemes that are different from those used for the description of LOs and provided through different services (or not). For that reason, finding (Cultural) Digital Objects to be used in the construction of LOs can not be done through an LCMS, but the author has to use a number of different tools and services, e.g. those provided by GLAM web sites and/or cultural digital libraries. But even when the author finds the right cultural digital objects to be included in a LO, they will lose their useful (semantic and technical) descriptions when retrieved and incorporated in the LO. This happens because the author of the LO actually downloads and uses the physical content of the digital object leaving back its metadata. However, these characteristics (e.g. technical) may be important for the use and delivery of this object, even if it has been incorporated in the context of a larger object (e.g. cross-media delivery).

2.7.3. A personalization point of view

Learners access courseware and learning experiences developed by courseware authors through LMS. In terms of personalization supported, several approaches presented have implemented in eLearning systems (but rarely integrated with LMSs), to adapt the learning experience according to the Learners' needs and preferences. However, there are several shortcomings in these approaches already described in Section 2.6.4.

In terms of access and personalization supported on top of (cultural) digital libraries, this is not directly targeted to learners. In (cultural) digital libraries some times personalization is considered and connected with functionality for visualization of the content e.g. by means of Linked Data or functionality provided to allow visitors (who may be also learners or teachers) create their own collections of cultural digital objects or creating their own paths on digital objects [Ferrara et al., 2013; Ferrara et al., 2014; Agirre et al., 2011; Canada museum, 2017]. However, no real-time integration of content is supported to deliver to Learners learning experiences taking into account their cognitive preferences, such as their learning styles (pedagogy-driven personalization).

2.8. The envisioned scenario of this thesis and comparison with existing approaches

The envisioned scenario of this thesis is presented in Figure 2.3.

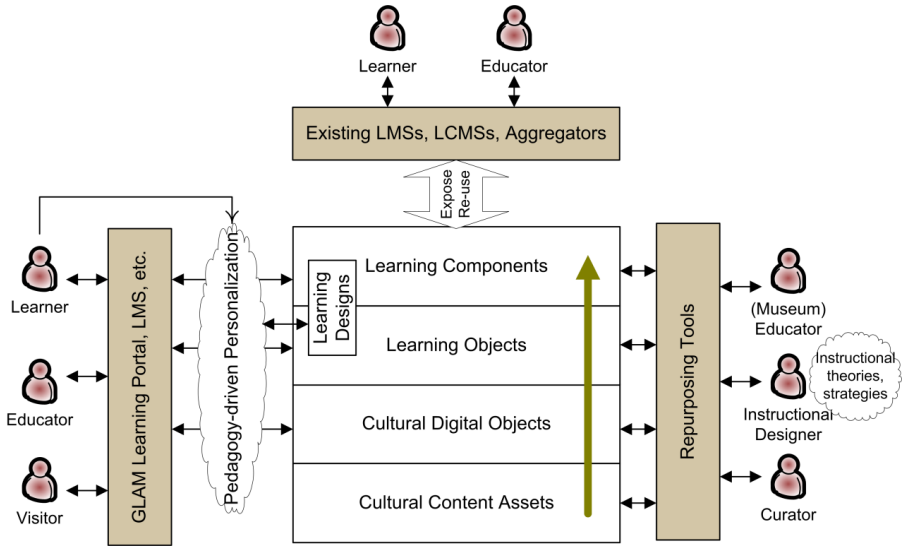

Figure 2.3 Envisioned scenario of the thesis

This scenario supports the thesis goal and objectives, by:

- Allowing curators, museum educators, and teachers repurposing multimedia content, to cultural digital objects, to learning objects and learning experiences.
- Helping museum educators and teachers develop pedagogically-sound personalized learning experiences to fit the needs of different learners with the use of pedagogical templates (Learning Designs) encoding instructional strategies developed by instructional design experts statically or dynamically.
- Allowing learners access learning objects and learning experiences developed by museum educators and teachers and providing them with pedagogy-driven personalized learning experiences fitting their individual needs and preferences.
- Supporting interoperability with existing LMSs, LCMSs, and repositories/aggregators.

So, in the next sections the envisioned scenario to be supported in this thesis is compared partially with solutions for repurposing multimedia digital objects to learning objects aiming to support eLearning applications on top of multimedia digital libraries and with solutions related with the aspect of adaptive pedagogy-driven personalization.

2.8.1. Comparison with approaches for repurposing multimedia digital objects to learning objects

To support eLearning applications on top of multimedia digital libraries there are several efforts, which, in order to re-purpose multimedia digital objects to learning objects, integrate or use in cooperation eLearning standards and A/V standards, such as Video Asset Description (VAD) Project [Bush et al., 2004], MultImedia Learning Object Server [Amato et al., 2004] and Virtual Entrepreneurship Lab (VEL) [Klamma, Jarke, and Wulf, 2002] and [Pascual, Ferran, and Minguillón, 2006]. Most of these approaches [Amato et al., 2004; Klamma, Jarke, and Wulf, 2002] use mappings between standards (e.g. MPEG7 and LOM) or propose integration of them by adding MPEG7 elements to SCORM elements [Bush et al., 2004] or adding LOM descriptions to MPEG7 standard [Pascual, Ferran, and Minguillón, 2006]. However, as it is explained in [Yoshinov, Arapi, Christodoulakis, and Kotseva, 2016], using mappings between those standards or mixing them creating application profiles is not an efficient solution to solve the interoperability problem between multimedia digital libraries and eLearning applications. The framework proposed in this thesis follows a different approach that is more generic and has not been developed as yet another local solution with the above problems.

2.8.2. Comparison with existing approaches for adaptive pedagogy-driven personalization

The framework presented in this thesis clearly separates pedagogy from content in order to exploit reusability of abstract training scenarios in various learning situations. In [Capuano et al., 2005] a similar approach is followed to represent pedagogy in order to support run-time resource binding. The thesis approach differs in that it takes into account the learning style, the educational level and learning goals of the Learners, supporting the representation of different learning paths (Training Methods) for training on a specific subject. In [Meisel et al., 2003], although the need for supporting different training methods for the same subject is recognized, these methods are not connected as in our approach with the learning styles and educational levels of the Learners. Moreover, description of appropriate learning objects characteristics beyond semantics is not supported. [Karampiperis and Sampson, 2006] propose an approach based on competencies on top of a model supporting learning objectives built using domain ontologies. Again, the same shortcomings can be identified related to the lack of reference to learning styles and other pedagogical parameters explicitly used in our case. Azevedo et al. [2006] use IMS-LD based templates and domain ontologies to contextualize and reuse Learning Objects in different learning experiences but do not explicitly focus on personalization and do not support alternative packaging of courseware as in the framework proposed in this thesis.

The closest work to the approach presented in this dissertation regarding personalization is the multi-model, metadata driven approach to adaptive hypermedia services for

personalized eLearning [Conlan et al., 2002]. This approach has a clear separation of content, learner and narrative models, and a generic adaptive engine that employs a multi-tiered AI model to achieve adaptation according to the learner's requirements. The authors propose extension of LOM standard in order to include an adaptivity element for the adaptive selection of learning objects. Possible values of the adaptivity are: learningstyle, competencies.taught, competencies.required. This approach has two shortcomings: *1) Extending LOM leads to interoperability problems, 2) Associating a learning resource with a specific learning style prohibits its exploitation in other learning styles or even in other learning styles approaches*. Moreover, in this approach the courseware author should define sets of candidate learning resources at design time. This significally reduces the scope of candidate learning objects that can be selected at run-time and bound to the training scenario to satisfy the learner's needs. The advantage of the approach presented in this thesis is that it does not modify LOM in order to achieve adaptive selection of learning objects, but it appropriately uses existing LOM elements to encapsulate the needed for the adaptation process information. Moreover, learning objects, as defined in this framework, are not associated with a specific learning style, but a number of metadata elements (e.g. learningResourceType, semanticDensity, interactivityType, interactivityLevel) are used at run-time to check their appropriateness depending on the requirements expressed in each activity of the abstract training scenario (learning design). Finally, learning objects or sets of them are not bound to the training scenario at design-time, but are selected and retrieved from repositories at run-time according to the needs of the Learner and the special requirements given at the training scenario's activities.

Chapter 3. MODELING THE ENVIRONMENT TO SUPPORT PEDAGOGY-DRIVEN PERSONALIZATION

In this chapter, the modeling of the environment is described in order to support repurposing of cultural digital content to pedagogically-sound personalized learning experiences in a static or dynamic way [Arapi et al., 2007a; Arapi et al., 2007b; Arapi et al., 2007c, Arapi et al., 2008]. Towards this end it defines and describes the following models: domain model, learner model, instructional model and adaptation model.

3.1. Domain modeling - From digital archives to learning experiences

Following the Learnativity Model it was defined how learning experiences can be gradually developed from digital content assets coming from multimedia archives. Such a categorization is important to define the granularity of these objects and their characteristics to support personalization. The detailed representation of these objects and their relations was developed using the METS digital library standard as the basis for combining various schemata necessary to describe Digital Objects, reusable Learning

Objects, Assessment Objects and Learning Components (Figure 3.1). The use of METS to support the hierarchical approach in the categorization and development of objects has the following advantages: a) It makes possible the reusability of lower level objects from higher level objects and reduces the development cost of learning content; b) It efficiently supports the gradual development of learning resources starting from existing media that reside in external digital archives, while in parallel supports the delivery of this material using multiple delivery channels; and c) It makes possible the exploitation and delivery of the underlying objects to different channels (devices). The above are possible, since this approach allows for: a) Integrated description of objects at each level using several appropriate (metadata) schemes to represent the different aspects of objects, and b) References to objects residing at lower levels without repeating their information at the current level. Moreover, this flexible representation of objects allows for appropriate adaptation/transformation of objects at run-time in order to support cross-media delivery of learning experiences.

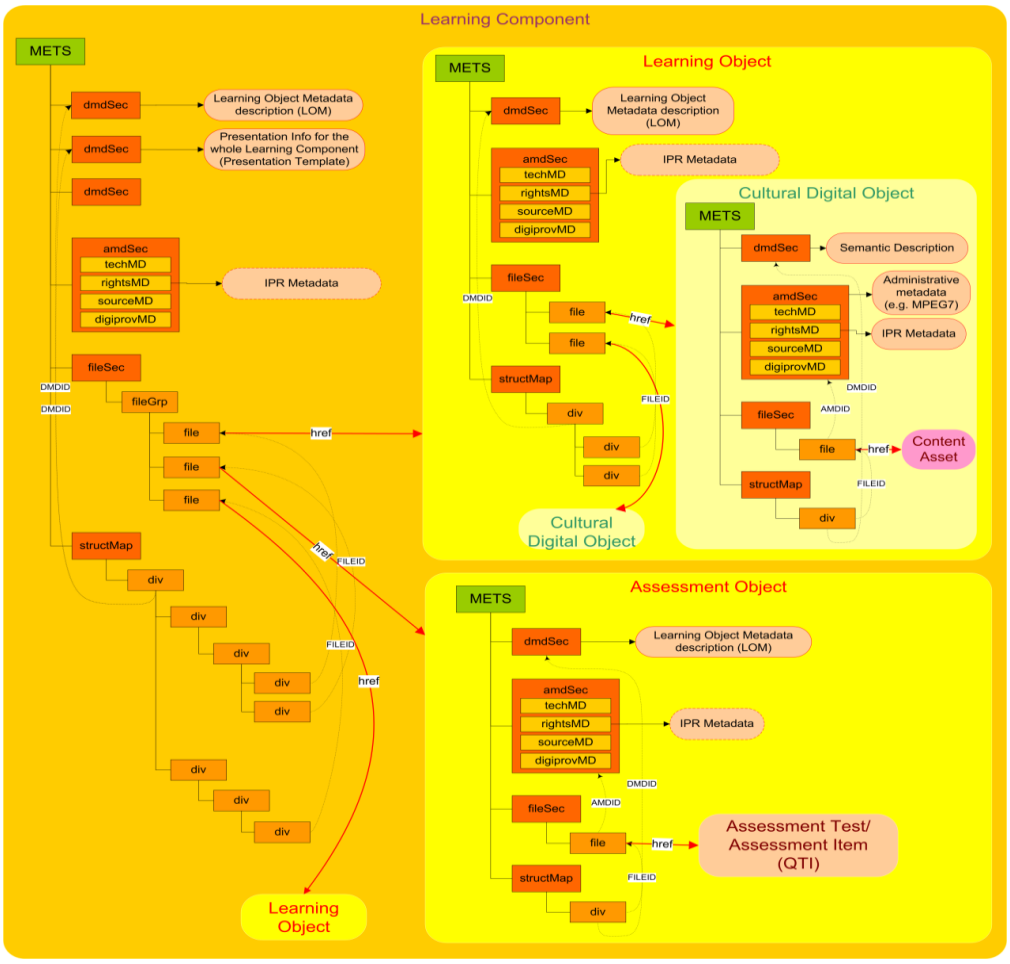

Figure 3.1 Representation of LCs, LOs, AOs, CDOs and Content Assets and their relations using METS

3.1.1. The authoring process

From a user's point of view, one could imagine various authoring scenarios in order to create courseware for Learners using content residing at cultural digital archives. The

most simple and straightforward scenario that is described here is the bottom-up scenario that describes the gradual development of higher level objects from lower level ones, starting from the creation of Cultural Digital Objects from Content Assets.

The editing process starts from the creation (digitization) or selection of Content Assets and the selection or creation of domain ontologies/taxonomies (i.e. conceptualizations of certain domains). These form the basis of creating Cultural Digital Objects that are further used to create higher level objects such as Learning Objects and Learning Components. As soon as Content Assets, representing interested material coming from museums' content archives/collections, and appropriate ontologies/taxonomies are available, it is possible to create Cultural Digital Objects by attaching appropriate metadata to Content Assets (or parts of them) including semantic annotations that are created using the available ontologies/taxonomies. Using the Cultural Digital Objects created, one can further create Learning Objects as collections of related Cultural Digital Objects (or from only one Cultural Digital Object) that can be used to accomplish a certain learning objective. The collection is enriched with LOM metadata. The creation of Learning Components using Learning Objects can be done in two ways: First of all one can statically create Learning Components by defining hierarchies of Learning Objects and by specifying their sequencing and presentation characteristics. This is the most straightforward option. Another option comes into play when one wants to support personalization statically or dynamically. In that case, appropriate Learning Designs (educational templates) should be defined first. The final activity in the authoring process is the storage or publishing of Learning Components in order to be ready for consumption by the Learners.

3.1.2. Pedagogical aspects of learning/assessment objects to support personalization

Learning Objects are built in order to fulfil certain learning objectives, while Assessment Objects are built and used to assess the satisfaction of certain learning objectives (previous knowledge). In order to support personalization as proposed in this framework it is important to consider some pedagogical properties for the description of Learning Objects and Assessment Objects.

Learning Objectives of Learning/Assessment Objects are defined as pairs consisting of a verb taken from the Bloom's taxonomy and a topic referencing a concept or individual of a domain ontology. In LOM, Learning Objectives can be expressed following this approach using its classification element. Similarly, the classification element of LOM can be used for the Educational Level of Learning Objects. The difficulty and the provider of a Learning Object are represented in educational.difficulty and lifecycle.contribute elements of LOM respectively.

In order to support different learning styles and perform adaptive selection of learning objects as proposed in this framework, this framework uses the following elements of LOM, as the most appropriate ones for this purpose: learning resource type, interactivity type, interactivity level, and semantic density, in addition to the learning objective as described before using classification element. Using these elements in learning objects' metadata for their adaptive selection according to learning styles, learning objects remain independent from the learning style approach used and can be re-used to support different learning style categorizations and learning scenarios. This is an advantage of this framework in contrast with other approaches mentioned in Chapter 2, where the learning style value for which a learning object is appropriate has been incorporated in its metadata prohibiting the exploitation of those learning objects to support other learning style categorizations.

The important metadata for Assessments are the learning ResourceType (=exercise for Assessment Items, =questionnaire for Assessment Tests), the Learning Objective (expressed via classification element), the difficulty and the educational level.

3.2. Learner modeling

The parameters described in Chapter 2 as important to personalization processes and their relations are normalized within the conceptual model illustrated in Figure 3.2.

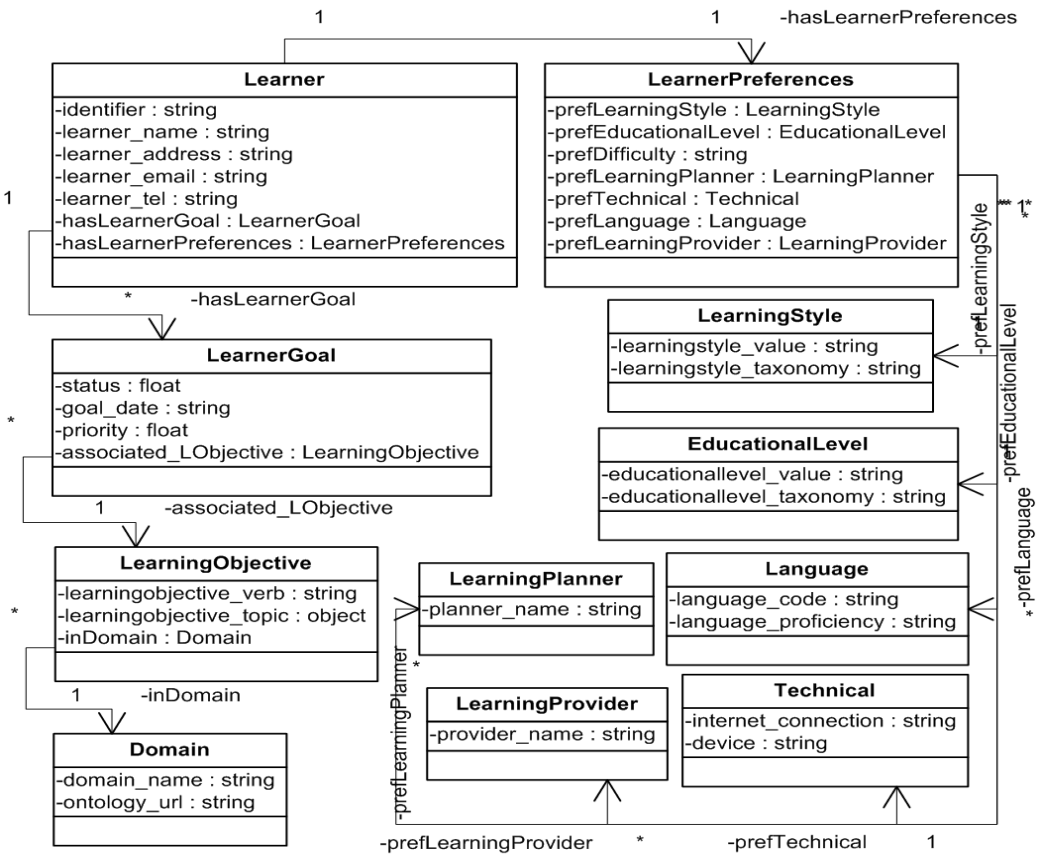

Figure 3.2 Learner Profile classes related with the dynamic creation of personalized learning experiences

These can be considered as a part of a Learner Profile, since they describe in some extent a Learner. A Learner Profile may contain more information, but here we just focus on what is considered as important in this framework for the dynamic creation of personalized learning experiences.

For most learning style approaches, a corresponding assessment instrument in the form of questionnaire is provided, in order to be able to detect the learning style of a Learner [Karagiannidis and Sampson, 2004]. This assessment instrument, after its completion by the Learner, will reveal the Learner's dominant learning style(s) according to the current each time learning style approach.

3.3. Instructional modeling - Learning Designs

The pedagogy-driven personalization is based on abstract training scenarios (Learning Designs) that capture the pedagogical approach/strategies to teach a subject taking into account the individual learning styles, educational level, preferred difficulty and other preferences of the learners. The definition and representation of these abstract training scenarios was based on a specific instructional ontology (Figure 3.3) that takes into account related standards and overcomes their shortcomings.

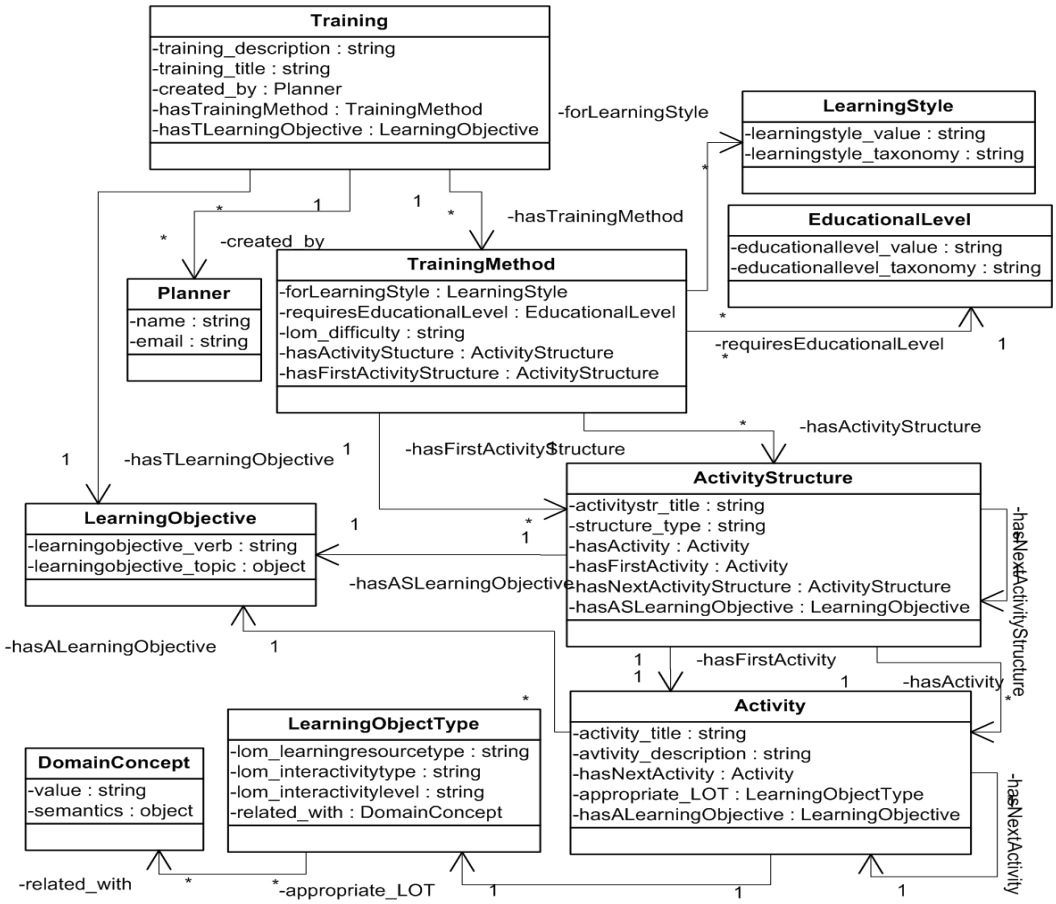

Figure 3.3 The instructional model used in the construction of Learning Designs

These learning designs are reusable and separated from content, allowing appropriate learning resources according to the Learner's profile to be bound to the training scenario at run-time.

3.4. Adaptation modeling

The adaptation process is encapsulated in an appropriate personalization algorithm that takes into account the knowledge provided in the Learner model and the available Learning Designs to dynamically create personalized learning experiences. Specifically, the goal is to find an appropriate Training Method of a Learning Design that will be used thereafter to construct a learning experience adapted to the Learner's needs. Appropriate learning objects are bound to the learning scenario at run-time. The generated learning experiences are stored as Learning Components and they can be further transformed to SCORM packages for their delivery to eLearning systems. The procedure of constructing an adaptive learning experience is illustrated in Figure 3.4. In each step several parameters of the Learner Profile (given in brackets in Figure 3.4) are taken into account:

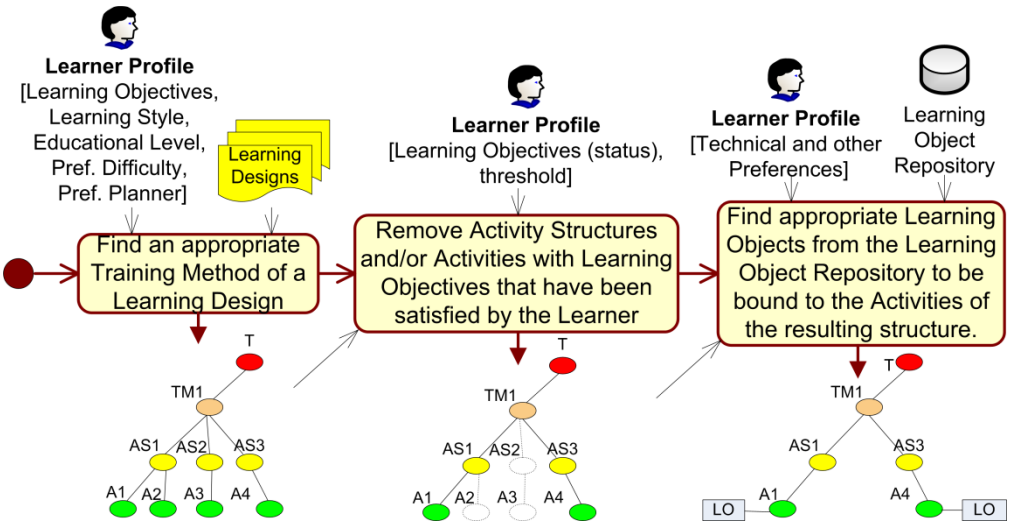

Figure 3.4 The procedure of dynamic construction of personalized learning experiences

Chapter 4. ARCHITECTURE

In this chapter, an integrated service-oriented architecture is proposed based on the models presented, meeting the user requirements and addressing the interoperability problems described in Chapter 2. The functional components of this architecture are described, as well as their functionality and services. The architecture illustrated in Figure 4.1 exploits widely-accepted standards and protocols and integrates repositories, tools and other components to support access, use and re-purposing of the cultural digital content residing in cultural heritage institutions for the development of learning experiences to support different learning needs and contexts. Integral part of this

architectures are components to support the development of pedagogically-driven personalized learning experiences statically or dynamically, as they have been modeled and described in the previous chapter.

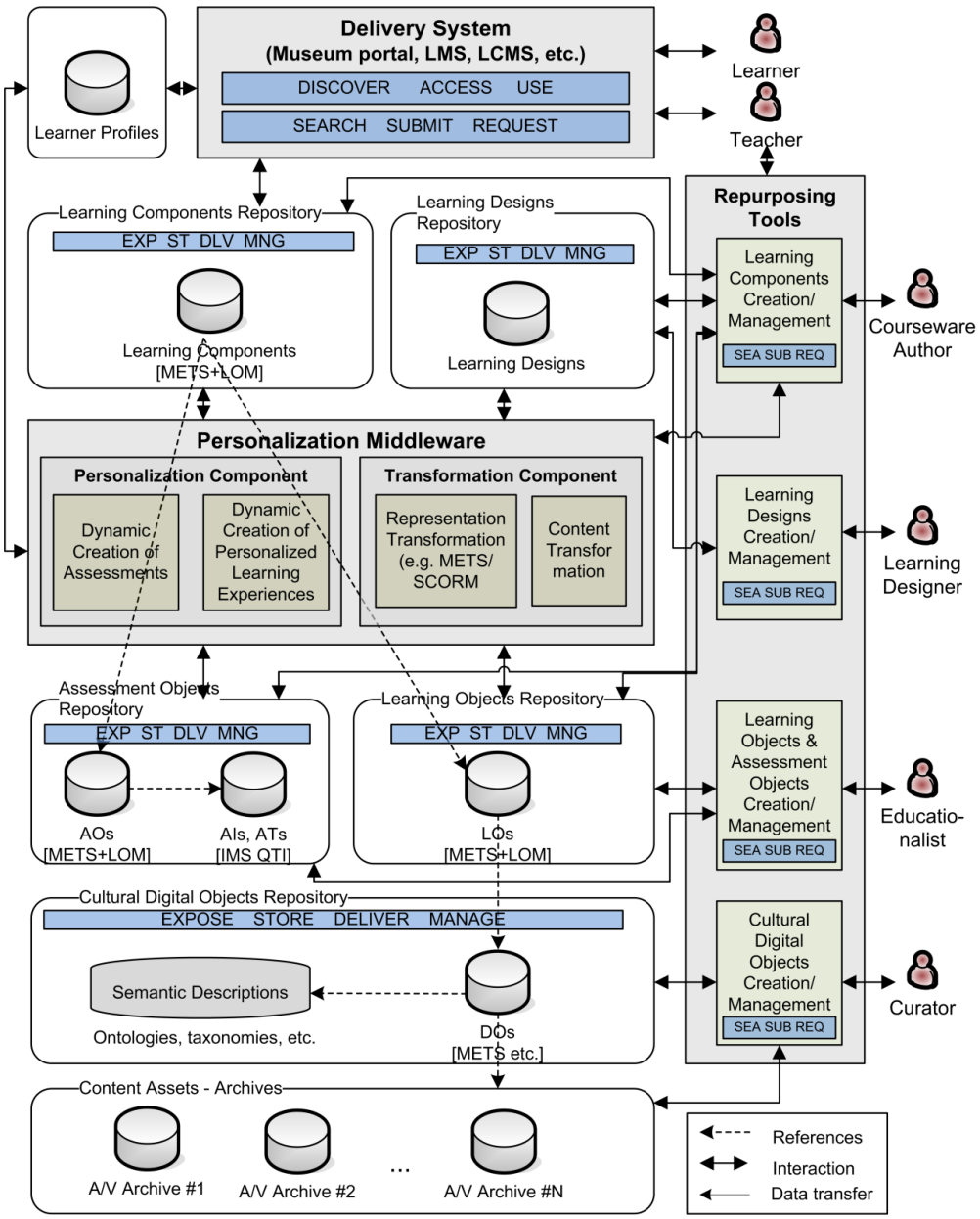

Figure 4.1 The architecture

The architecture conforms to the IMS Digital Repositories Interoperability (IMS DRI) Specification [IMS DRI, 2003] introduced in Chapter 2 providing recommendations for the interoperation of the most common repository functions enabling diverse components to communicate with one another: search/expose, submit/store, gather/expose and request/deliver.

Chapter 5. IMPLEMENTATION AND APPLICATION OF THE PROPOSED FRAMEWORK AND ARCHITECTURE

Part of the research was made and implemented in LOGOS and Natural Europe projects. Continuation of implementation and application of the PhD research is done as a series of papers published under the support of Research project No. DN02/06/15.12.2016 "Concepts and Models for Innovation Ecosystems of Digital Cultural Assets" (2016 - 2018), funded by the Bulgarian Sciences Fund.

5.1. LOGOS project

The framework and architecture proposed were applied and implemented in LOGOS project "Knowledge-on-Demand for Ubiquitous Learning" (IST-4-027451) (Figure 5.1) to support the needs of repurposing of existing multimedia material and the gradual development of pedagogy-driven personalized learning experiences in a static or dynamic way [Arapi, Moumoutzis, Mylonakis, Theodorakis, and Stylianakis, 2007; Arapi, Moumoutzis, Mylonakis, Stylianakis, Theodorakis, and Christodoulakis, 2008; Moumoutzis, Arapi, and Stockinger, 2008].

5.2. Natural Europe project

Methodology and solutions proposed in this thesis were applied and implemented in Natural Europe project to support the need of Natural History Museums to make available their cultural digital collections and support their gradual repurposing to develop pedagogy-driven learning experiences in the form of educational pathways based on educational templates encoding instructional strategies to support different learning scenarios [Mylonakis, Arapi, Moumoutzis, Christodoulakis, and Ampartzaki, 2013; Makris, Skevakis, Kalokyri, Arapi, Christodoulakis, Stoitsis, Manolis, and Leon Rojas, 2013; Makris, Skevakis, Kalokyri, Arapi, and Christodoulakis, 2013; Makris, Skevakis, Kalokyri, Arapi, and Christodoulakis, 2014].

5.3. Research project No. DN02/06/15.12.2016 funded by the Bulgarian Sciences Fund

Continuation of implementation and application of the PhD research is done as a series of papers published under the support of Research project No. DN02/06/15.12.2016 "Concepts and Models for Innovation Ecosystems of Digital Cultural Assets" (2016 - 2018) funded by the Bulgarian Sciences Fund and in specific in WP2: "Creating models and tools for improved use, research and delivery of digital cultural resources". The project conducts fundamental research in the areas of computer science, information and communication technology and partially in the humanities and social sciences with the goal of acquiring new knowledge on the fundamental causes of phenomena and observable facts in these areas without any direct commercial application or use.

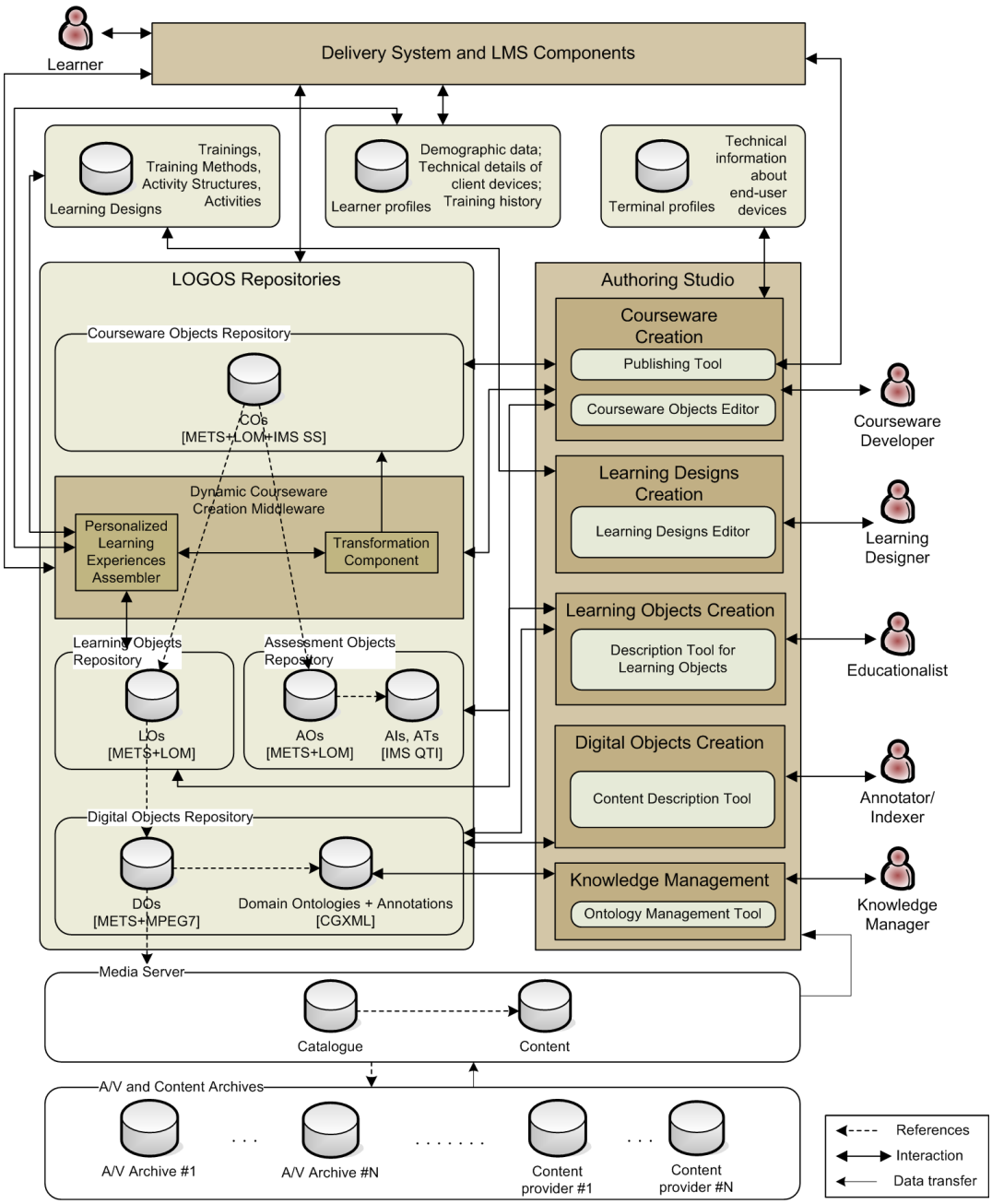

Figure 5.1 LOGOS project overall architecture

Chapter 6. EXPERIMENTATION AND EVALUATION

6.1. Introduction

Different tools have been elaborated on the base of the proposed architecture. These tools were assessed and "verified" and validated on their usability.

Experimentation and evaluation for repurposing and personalization in the proposed framework was conducted in the context of LOGOS project.

6.2. Experimental Setting

The validation of the LOGOS platform was illustrated in detail in [Watterson, Pemberton, and Griffiths, 2009] using combined "Formative and Summative evaluation".

Feedbacks from two target groups: authors and learners of the LOGOS system have been collected and analyzed [Corep, Eden, and UniBrighton, 2009]. The reflections of the two target groups provided feedback on usability and personalization efficiency of the LOGOS system.

6.2.1. Authors

For end-user evaluation the IsoMetric Questionnaire was used. Evaluated were the ergonomic principles, which apply to the design of dialogues between humans and information systems: suitability for the task, suitability for learning, suitability for individualisation, conformity with user expectations, self descriptiveness, controllability, and error tolerance, which showed high reliability of its subscales and gathered valid information about differences in the usability comparing different software systems.

6.2.2. Learners

Feedback from learners who used the LOGOS system via the specifically created coursewares by the LOGOS Authoring Studio was collected. After the learners performed the experiments with their selected courses, on their preferred device, they filled in the online Self-Assessment Questionnaire, where feedback on usability and acceptability issues was collected showing whatever they like, which allowed the gathering of qualitative data on acceptability and learner preference and fed in results for the expert evaluations.

Regarding learner end-user assessment, "USE" Usability questionnaire based on Nielsen's quality criteria was designed. This short self-administered questionnaire was used to measure the most important dimensions of usability for users including issues for software, services, and user support materials. It allowed meaningful comparisons of user experiences in different domains. The environment was assessed in ubiquitous situations so that digital TV, mobile phone and PC experimentations could take place at the same time.

6.3. Results

According to a general picture, the assigned Abstract Tasks have been observed as carried out with no evident difficulty from both authors and learners using the LOGOS platform and tools [Corep, Eden, and UniBrighton, 2009]. Personalization advantages have been supported both by authors and learners groups of experiment participants.

The authors' and learners' assessment results to the questions related with personalization are presented in Table 6.1 and Table 6.2 respectively.

Table 6.1 Authors assessment

If you think the statement is true, then mark the column for "predominately agree". If you find you cannot agree with the statement then mark column for "Predominately disagree". You can also indicate various degrees of agreement between these two poles by marking the corresponding column. If for some reason you cannot or do not wish to reply, you should mark the last column "no opinion".							
	Strongly disagree	**Slightly disagree**	**Neither agree nor disagree**	**Slightly agree**	**Strongly agree**	**No opinion**	**Response Count**
I consider personalization applied by LOGOS as an innovative practice	2.3% (1)	2.3% (1)	2.3% (1)	9.1% (4)	50.0% (22)	34,1% (15)	44
I think personalized learning material provided by LOGOS improves a student's learning outcomes	0.0% (0)	0.0% (0)	4.7% (2)	7.0% (3)	48.8% (21)	39.5% (17)	43
I think that learners accessing personalized materials would shorten their learning time	0.0% (0)	2.3% (1)	11.6% (5)	30.2% (13)	23.3% (10)	32.6% (14)	43

Table 6.2 Learners assessment

If you think the statement is true, then mark the column for "predominately agree". If you find you cannot agree with the statement then mark column for "Predominately disagree". You can also indicate various degrees of agreement between these two poles by marking the corresponding column. If for some reason you cannot or do not wish to reply, you should mark the last column "no opinion".							
	Strongly disagree	**Slightly disagree**	**Neither agree nor disagree**	**Slightly agree**	**Strongly agree**	**No opinion**	**Response Count**
Learning with personalized courses matched perfectly with my expectation	4.8% (2)	9.5% (4)	19.0% (8)	33.3% (4)	31.0% (13)	2.4% (1)	42
I found that it was motivating to learn with the personalized course	0.0% (0)	9.5% (4)	16.7% (7)	19.9% (8)	52.4% (22)	2.4% (1)	42
I think personalized learning materials provided by LOGOS improve a student's learning outcomes	1.4% (1)	2.8% (2)	13.9% (10)	18.1% (13)	51.4% (37)	12.5% (9)	72
In my opinion accessing personalized learning materials would shorten my learning time compared to face-to-face learning	4.2% (3)	12.5% (9)	13.9% (10)	27.8% (20)	30.6% (22)	11.1% (8)	72

I think personalized learning materials provided by LOGOS improve participation rates	1.4% (1)	2.8% (2)	16.7% (10)	16.7% (10)	47.2% (34)	15.3% (11)	72

6.4. The development of "Learning LOGOS through LOGOS" course

LOGOS domain performed ideal for testing the proposed personalization framework. Supported activities allowed direct experimentation with the tools for Activists, Walkthroughs and tasks for experimentation for Pragmatists, Video Tutorials for Reflectors, description of the tools concepts and purpose for Theorists along with manuals, tutorials and walkthroughs etc. During the tests authors were able also to play the user roles of LOGOS back-end: Knowledge Managers, Media Integrators, Annotators/Indexers, Educationalists, Courseware Developers, and Learning Designers.

A number of media (raw content) was developed or adapted from existing LOGOS material in order to create training material to support the teaching of the LOGOS domain to LOGOS Platform candidate users. The development phases of the LOGOS domain course for Honey & Mumford's learning styles (Activists, Reflectors, Theorists, and Pragmatists) were illustrated in the next sections of the thesis.

CONCLUSION

In solving the main problems leading to the achievement of the goal and the objectives of this thesis (see Chapter 1, Section 1.2. "Goal, objectives and tasks of the thesis"), made scientific and applied research and concrete results as follows:

- Developed a framework and models for supporting effective personalized learning services on top of multimedia digital libraries, by a) supporting re-purposing of multimedia digital content/archives to cultural digital objects, learning objects and higher learning units, b) supporting the construction of pedagogy-driven personalized learning experiences on top of multimedia digital archives statically or dynamically. Towards this end defined 4 models: domain model, learner model, instructional model and adaptation model.

- Developed an integrated service-oriented architecture and functional components (including repositories, tools, delivery components, applications and services) based on interoperability-standards to support repurposing of existing multimedia digital content to cultural digital objects, learning objects and higher learning units for the construction of pedagogy-driven personalized learning experiences statically or dynamically. The architecture supports interoperability and sharing of cultural digital objects, learning objects and learning experiences with existing eLearning systems and large repositories/aggregators.

- Implementation of the proposed framework and architecture in LOGOS project and application of the proposed methodology and solutions in the implementation of Natural Europe project to support the need of Natural History Museums to make available their cultural digital collections and support their gradual repurposing to develop pedagogy-driven learning experiences with the use of educational pathways based on educational templates.

In the implementation of Task 1 (Study of the problem) has achieved the following results:

- Studied the concepts and components of digital libraries and digital objects, as well as eLearning systems and learning objects and content models (see Chapter 2, Section 2.1 "Digital Libraries", Section 2.2 "eLearning systems")

- Studied main interoperability standards, specifications and approaches for the description, packaging and access of (cultural) digital objects and learning objects, and for repositories interoperability (see Chapter 2, Sections 2.4, 2.5 and 2.6 respectively)

- Studied personalization in Digital Libraries and learning: approaches for personalization in DL, user modeling and profiling; the characteristics of the Learner user and how they (should) affect personalization processes; the role of pedagogy and instructional design/strategies in personalization, pedagogical patterns, and IMS LD specification for instructional design; approaches for adaptive personalization in eLearning (see Chapter 2, Sections 2.7.1, 2.7.2, 2.7.3 and 2.7.4 respectively).

- Analyzed in detail the complex problem of interoperablity this thesis tries to address from an objects, infrastructures and personalization point of view (see Chapter 2, Section 2.8).

- Presented the envisioned scenario of this thesis; Investigated approaches and solutions related with re-purposing of multimedia objects to learning objects and adaptive pedagogy-driven personalization and compared them with the proposed solution (see Chapter 2, Section 2.9).

In the implementation of Task 2 (Modeling the environment to support pedagogy-driven personalization) has achieved the following results:

- Defined the domain model: Following the Learnativity Model defined how learning experiences can be gradually developed from digital content assets coming from GLAM archives. Such a categorization is important to define the granularity of these objects and their characteristics to support personalization.

The detailed representation of these objects and their relations was developed using the METS digital library standard as the basis for combining various schemata necessary to describe Digital Objects, reusable Learning Objects, Assessment Objects and Learning Components. LOM was selected for the representation of educational metadata for both Learning Objects and Learning Components. Semantic metadata can be represented using several metadata schemes, domain ontologies, taxonomies or vocabularies. The authoring/repurposing process and pedagogical aspects and requirements for the proper description and structuring of the object layers to support pedagogy-driven personalization were also described. (see Chapter 3, Section 3.2)

- Defined the learner model: The learner characteristics identified in Chapter 2 as important parameters to support personalization were modeled. These are exploited during the dynamic creation of personalized learning experiences in order to select appropriate training scenarios to guide the learning experiences creation process and furthermore to select appropriate reusable Learning Objects to be linked with learning activities in order to create personalized learning experiences. (see Chapter 3, Section 3.3)

- Defined the instructional model: The pedagogy-driven personalization is based on abstract training scenarios that capture the pedagogical approached to teach a subject taking into account the individual learning styles, educational level, preferred difficulty and other preferences of the learners. The definition and representation of these abstract training scenarios was based on a specific instructional ontology that takes into account related standards and overcomes their shortcomings. (see Chapter 3, Section 3.4)

- Defined the adaptation model: The adaptation process is encapsulated in an appropriate personalization algorithm that exploits information from the Learner model to firstly select appropriate abstract training scenarios matching Learner's needs and preferences and proceeds with the binding of appropriate reusable Learning Objects to the learning activities of the selected scenario. The same mechanism can be used to construct assessment tests from assessment objects that can be used for the identification of the previous knowledge of the Learner. (see Chapter 3, Section 3.5)

In the implementation of Task 3 (Architecture) has achieved the following results:

- Developed an integrated service-oriented architecture based on interoperability-standards to support repurposing of multimedia digital content to cultural digital objects, learning objects and higher learning units for the construction of

pedagogy-driven personalized learning experiences on top of existing cultural digital collections statically or dynamically (see Chapter 4, Section 4.2).

- Described the functionality of its components including repositories, authoring/repurposing tools, personalization component and transformation component (see Chapter 4, Sections 4.2.1, 4.2.2, 4.2.3 and 4.2.4 respectively).

In the implementation of Task 4 (Implementation and application of the proposed framework and architecture) has achieved the following results:

- Implementation of the proposed framework and architecture in LOGOS project (see Chapter 5, Section 5.2).
- Application of the proposed framework in the implementation of Natural Europe project (see Chapter 5, Section 5.3).
- Continuation of implementation and application of the PhD research as a series of papers published under the support of Research project No. DN02/06/15.12.2016 "Concepts and Models for Innovation Ecosystems of Digital Cultural Assets" (2016 - 2018) funded by the Bulgarian Sciences Fund (see Chapter 5, Section 5.4).

In the implementation of Task 6 (Experimentation and evaluation) performed experimentation and evaluation of the proposed framework in the context of LOGOS project (see Chapter 6).

CONTRIBUTIONS OF THE THESIS

Major scientific and applied contributions of the thesis are:

- Developed a framework and models for supporting effective personalized learning services on top of multimedia digital libraries, by a) supporting re-purposing of multimedia digital content/archives to cultural digital objects, learning objects and higher learning units, b) supporting the construction of pedagogy-driven personalized learning experiences on top of multimedia digital archives statically or dynamically. The following models have been defined:
    - Domain model: a) Defined the object layers from content assets, to cultural digital objects, to learning/assessment objects and learning components, and their description, structuring and relation exploiting METS, LOM and other standards to support pedagogy-driven personalization; b) Specified the authoring/repurposing process and pedagogical aspects and requirements for the proper description of

learning objects to support pedagogy-driven personalization (e.g. different learning styles) without being tied to a specific learning style taxonomy.

- Learner model: Identified important learner characteristics and preferences that should be taken into account in personalization process and encoded them in an ontology.

- Instructional model for the encoding of instructional strategies as abstract training scenarios (educational templates) taking into account related standards as IMD LD. These templates are reusable and separated from content, allowing appropriate learning resources according to the Learner profile and current context to be bound to the training scenario at run-time.

- Adaptation model: The adaptation process is encapsulated in an appropriate personalization algorithm that exploits information from the Learner model to firstly select appropriate abstract training scenarios matching Learner's needs and preferences and proceeds with the binding of appropriate reusable Learning Objects to the learning activities of the selected scenario. The same mechanism can be used to construct assessment tests from assessment objects that can be used for the identification of the previous knowledge of the Learner.

- Developed an integrated service-oriented architecture and functional components (including repositories, tools, delivery components, applications and services) based on interoperability-standards to support repurposing of existing multimedia digital content to cultural digital objects, learning objects and higher learning units and construction of pedagogy-driven personalized learning experiences statically or dynamically. The architecture supports interoperability and sharing of cultural digital objects, learning objects and learning experiences with existing eLearning systems and large repositories/aggregators.

- Implementation of the proposed framework and architecture in LOGOS project and application of the proposed methodology and solutions in the implementation of Natural Europe project to support the need of Natural History Museums to make available their cultural digital collections and support their gradual repurposing to develop (statically) pedagogy-driven learning experiences with the use of educational pathways based on educational templates.

Results from the research done in a number of **European Research & Development projects** (listed below) were combined, enriched, specialized and applied in the PhD thesis for the domain of cultural digital libraries:

- The framework presented in this thesis has been exploited in Research project No. DN02/06/15.12.2016 "Concepts and Models for Innovation Ecosystems of Digital Cultural Assets" (2016 - 2018), funded by the Bulgarian Sciences Fund, and in specific in WP2: "Creating models and tools for improved use, research and delivery of digital cultural resources". The project will conduct fundamental research in the areas of computer science, information and communication technology and partially in the humanities and social sciences with the goal of acquiring new knowledge on the fundamental causes of phenomena and observable facts in these areas without any direct commercial application or use.

- The work presented in this thesis was implemented in IST/STREP **LOGOS project** "Knowledge-on-Demand for Ubiquitous Learning" (IST-4-027451) (**common project of TUC/MUSIC with IMI-BAS**), where a Knowledge-on-Demand ubiquitous learning platform was developed, providing effective personalized learning services to support learning anywhere, anytime exploiting alternative delivery channels and related devices that go beyond the traditional web-based learning approaches. The framework and architecture proposed were applied and implemented to support the needs of repurposing of existing multimedia material and the gradual development of pedagogy-driven personalized learning experiences in a static or dynamic way. Publications in the context of LOGOS project: [Arapi, Moumoutzis, Mylonakis, Theodorakis, and Stylianakis, 2007; Arapi, Moumoutzis, Mylonakis, Stylianakis, Theodorakis, and Christodoulakis, 2008]

- Methodology and solutions proposed in this thesis were applied in the implemention of the ICT/PSP **Natural Europe project** "Natural History & Environmental Cultural Heritage in European Digital Libraries for Education" (FP7-ICT-PSP: 250579) to support the need of Natural History Museums to make available their cultural digital collections and support their gradual repurposing to develop pedagogy-driven learning experiences with the use of educational pathways based on educational templates. The author of this thesis was not only a senior researcher in the realization of the project, but also one of the main authors of Natural Europe proposal where she proposed to apply this framework methodology and solutions successfully implemented in LOGOS to support these objectives. Publications in the context of Natural Europe project: [Mylonakis, Arapi, Moumoutzis, Christodoulakis, and Ampartzaki, 2013; Makris, Skevakis, Kalokyri, Arapi, Christodoulakis, Stoitsis, Manolis, and Leon Rojas, 2013; Makris, Skevakis, Kalokyri, Arapi, and Christodoulakis, 2013]

- Parts of the methodology and tools presented in this thesis were applied to LdV/ToI **QONIAon project** "VET Qualification Practice for e-Inclusion"

(2013-1-TRI-LEO05-47585) (**common project of TUC/MUSIC with IMI-BAS**) promoting the idea for e-facilitator as instrument for e-Inclusion with it's curriculum, methodology, technology, experience, appropriate LMS, content and use case scenarios. The proposed solutions were applied to support the development of its curriculum, its description, provision and further dissemination. Publications in the context of QONIAon project: [Mylonakis, Arapi, Moumoutzis, Christodoulakis, and Ampartzaki, 2013; Mylonakis, Arapi, Pappas, Moumoutzis, and Christodoulakis, 2011]

- Finally, results of this thesis related with instructional design have been applied in ICT/PSP **Open Discovery Space project** "A socially-powered and multilingual open learning infrastructure to boost the adoption of eLearning resources" (FP7-ICT-PSP: 297229). Publications in the context of ODS project: [Stylianakis, Moumoutzis, Arapi, and Christodoulakis, 2013; Stylianakis, Moumoutzis, Arapi, Mylonakis, and Christodoulakis, 2014].

Furthermore, parts of the work done in the scope of this thesis have been published in a number of **peer reviewed journals and conference proceedings** (see "LIST OF THE AUTHOR'S PUBLICATIONS RELATED WITH PHD THESIS"): International Journal on Digital Libraries - IJDL (Springer, 2014) and International Journal of Education and Information Technologies (NAUN, 2016), 6th International Conference on Web-based Learning - ICWL 2007 (Edinburgh, UK, 2007), IEEE International Conference on Advanced Learning Technologies - ICALT 2007 (Niigata, Japan, 2007), Workshop on Cross-Media and Personalized Learning Applications on top of Digital Libraries (LADL2007) in conj. with ECDL2007 Conference (Budapest, Hungary, 2007), 2nd LOGOS Open Workshop on "Cross-Media and Personalized Learning Applications with Intelligent Content" (LAIC 2008) in conj. with AIMSA2008 Conference (Varna, Bulgaria, 2008), Metadata Semantics and Research Conference - MTSR2011 (Izmir, Turkey, 2011) and MTSR2013 (Thessaloniki, Greece, 2013), 2nd International Conference on E-Learning, and E-Technologies in Education - ICEEE 2013 (Lodz, Poland, 2013), 17th International Conference on Theory and Practice of Digital Libraries - TPDL2013 (Valetta, Malta, 2013), IEEE Interactive Mobile Communication Technologies and Learning - IMCL2014 (Thessaloniki, Greece, 2014), and International Conference on e-Learning - eLearning'16 (Bratislava, Slovakia, 2016). About 40 citations have been detected.

Future research

The work presented in this thesis can be extended or further developed in the following directions:

- Theoretical direction: 1) Extension/adaptation of the developed models towards supporting re-purposing and transformation of a digital library content and provision of personalized experiences in other domains and applications (at the same time), such as eScience, eResearch etc. This extension is possible since the proposed framework is generic enough to support multiple-context views of the content of a digital library and its transformation targeting at different applications. 2) Extension and exploitation of the framework to support the construction of Personal Learning Environments (PLEs), combining tools, services and resources, which learners use to direct their own learning and pursue educational goals.

- Applied/practical direction: Implementation and experimentation with other applications (eScience, eResearch etc.) on top of digital libraries, i.e. to offer services and tools supporting re-purposing of the underlying content, and provision of effective personalized experiences by real-time integration of content, tools and services to fit the needs of different target groups.

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6. Makris K., Skevakis G., Kalokyri V., Arapi P., Christodoulakis S. (2013): "Metadata Management and Interoperability Support for Natural History Museums", In Proc. of the 17th International Conference on Theory and Practice of Digital Libraries (TPDL2013), Springer Berlin Heidelberg, September 2013, Valetta, Malta, pp. 120-131, Print ISBN: 978-3-642-40500-6, Online ISBN: 978-3-642-40501-3, doi: 10.1007/978-3-642-40501-3_12 (**Acceptance rate for full papers was: 16%. The paper was evaluated as one of the best papers of the conference and was invited and accepted for publication in extended form in the International Journal of Digital Libraries**)

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Total number of citations to the author's publications related with the PhD thesis: **38**.

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