Describing, Instantiating and Evaluating a Reference Architecture: A Case Study

Paris Avgeriou
University of Cyprus
Department of Computer Science
75 Kallipoleos Str., P.O. Box 20537CY-1678 Nicosia, Cyprus
Email: pavger@cs.ucy.ac.cy

Abstract. The result of a domain maturing is the emergence of reference architectures that offer numerous advantages to software architects and other stakeholders. However there is no straightforward way to describe a reference architecture and in sequence to design instances for specific systems, while at the same time assuring the quality of the end product. This paper presents an approach of describing a reference architecture, instantiating it into a software architecture by making implementation decisions and evaluating it with respect to quality attributes. A case study for the approach is drawn from the domain of Learning Management Systems which is maturing and would greatly benefit from a reference architecture. This work is based upon the IEEE standard for architectural description, on well-established software engineering practices, and on the empirical results of designing, developing and evaluating Learning Management Systems.

Keywords: software architecture, reference architecture, architectural design, Learning Management Systems, quality attributes, evaluation of software architecture.

1 Introduction

As a specific domain of software systems ages and matures, more and more systems are developed from different organizations, and their functionality, structure and behavior becomes common knowledge. At some point, a critical mass of systems has been built, and then, models, or designs or in general *abstractions* of the systems surface that represent their common denominator [6, 23]. For example the domain of compilers is quite mature and instead of re-inventing the wheel when developing a new compiler, we can find such an abstraction that can guide us somehow into building the compiler. At a software architecture level, this kind of abstraction is called a **reference architecture**. A reference architecture is in essence a software architecture at a higher level of abstraction that does not contain implementation details. It specifies the decomposition of a system into subsystems, the interaction among those subsystems and the distribution of functionality between them [6]. A reference architecture can be instantiated into a software architecture by refining it, extending it and in particular, specifying implementation decisions [6, 12, 23]. Each such instance conforms to the reference architecture and also increments it by adding details that are particular to the specific implementation.

There are three issues that arise from the above:

- How should we describe reference architectures? Should we use the same techniques as in the description of software architectures, and if so, which ones?
- How should we generate instances of the reference architecture for specific implementations? What should we change and what should we add in the description of the reference architecture in order to come up with one of its instances?
- How do we know that we have designed a high-quality reference architecture? How do we know that the implementations of the reference architecture will satisfy certain desirable qualities?

This paper proposes an approach to tackle these issues. It proposes a description for reference architectures, demonstrates how the latter can be instantiated into a software architecture instance, and suggests an evaluation framework for the assessment of the reference architecture with respect to quality attributes. The description of the reference architecture and its instances is based on a combination of the IEEE 1471-2000 Recommended Practice for Architectural Description of Software-Intensive Systems [15], and the widely-adopted Rational Unified Process [20, 21, 24]. In particular, the description conforms to the IEEE standard, but also utilizes some concepts from the RUP such as the views, the implementation decisions, architectural patterns etc. As far as the description of an architectural instance, this is performed by showing the differences between the two descriptions and elaborating on the extra elements contained in the description of the instance. Finally the evaluation framework is based on well-established software engineering techniques that regard quality evaluation of architectures.

The entirety of the approach is elucidated through a case study for the domain of Learning Management Systems. A *Learning Management System* is aimed at managing an e-learning environment, establishing the organization and delivery of content, administrating resources and tracking learning activities and results [11, 22]. The domain of LMS is over a decade old and we are presently witnessing the maturing of this domain. The plethora of LMS offered today to the market of educational or training organizations and the booming development of Learning Management Systems is an irrefutable proof of the maturing of the domain. This has lead to a research trend, attempting to define but also standardizing reference models and reference architectures for LMS, in order to provide a more systematic development process for these systems. This increasing research effort is coming from academic research teams, from the corporate world and from international standardization bodies.

The structure of the paper is as follows: Section 2 deals with the description of the reference architecture per se and Section 3 describes a software architecture instance with its corresponding architectural prototype. Section 4 introduces a brief discussion about the evaluation of this approach. Finally, Section 5 contains conclusions about the added value of our approach and future plans.

2 The Reference Architecture

2.1 About the architectural description

The description of the reference architecture and its derived instances is based on three facets:

- ➢ It adopts the format of the **IEEE 1471-2000 Recommended Practice for Architectural Description of Software-Intensive Systems** [15]. This standard dictates that the first step in designing a software architecture is to explicitly define the *stakeholders* of a system under development and any *concerns* that they may have with respect to any possible aspect of the system. The description of the architecture per se is organized into different *views*, where each view addresses one or more of the stakeholders' concerns. Also each view conforms to a *viewpoint*, in the sense that a viewpoint determines the conventions, according to which a view is created, illustrated and analyzed. Therefore viewpoints need to be defined, before we can start designing diagrams for each view.
- ➢ It adopts and customizes a big part of the **Rational Unified Process (RUP)**, a well-established, software engineering process [20, 21]. The RUP proposes certain elements that should be contained in an architectural description, such as a specific set of views, architectural patterns, desirable quality attributes, implementation constraints (e.g. development and run-time platform, legacy code, third-party software). It is also noted that Rational Unified Process considers only the use case view and the logical view as mandatory in the architectural design while all the rest are optional.
- ➢ It uses the widely-adopted **Unified Modeling Language** [7, 25], which is a de facto standard in the software industry, to design the diagrams of the architectural views.

This approach combines the above, and proposes that a description of a *software architecture* should contain the following:

- The *system stakeholders*, and the *concerns* that they may have regarding any possible aspect of the system.
- The definition of the *viewpoints* that will address the stakeholders' concerns, and prescribe the methodology used and the contents of corresponding views.
- The *views* (i.e. the most important or architecturally significant modeling elements) of the models described in the RUP (use case model, analysis model, design model, de-

ployment model, implementation model). These views must conform to the previously defined viewpoints.
 The *architectural patterns* that characterize parts of the architecture.
 The *quality attributes* that are desirable for the system and must be supported by the architecture. The requirements might or might not be described by use cases.
 A brief description of the implementation constraints, i.e. the *platform*, the *legacy systems* and the *third-party software*.
 Other issues that are of particular importance to the specific system being designed. For the case of Learning Management Systems an extremely significant issue is the *adoption of international Learning Technology standards* that should be adopted and implemented into systems, in order to achieve the quality of interoperability.

Consequently, all these constituents should be included in the description of the software architecture instances. As far as the description of the reference architecture, this should remain at an abstract level, and details that concern particular implementations must be left out. Such details are:
 The views that concern the system implementation and in particular the implementation view and the data view.
 The implementation decisions (platform, legacy systems, third-party software etc.).

The collection of all these elements for the reference architecture is quite voluminous, and can't be included in this paper for practical reasons. Instead, a summarized version for all the elements will be provided and a suggestive diagram in each view. A full description of the reference architecture can be found in [5], while a description of a software architecture instance that derives from the reference architecture can be found in [4].

2.2 Identification of stakeholders and concerns

The system stakeholders are either individuals, groups, or organizations, that have interests or concerns about the system being developed. Every system has several such stakeholders that deeply affect its design and development [6]. The stakeholders considered in this architectural description are the following:

a) **Users of the system,** which include students, professors, administrative staff of the educational institute, teaching assistants, courseware authors, system administrators.
b) **Acquirers of the system,** which include universities or in general higher educational institutions, K-12 educational institutions, and companies or organizations that perform employee training.
c) **Developers and maintainers of the system,** which could be academic research staff or software development companies.

Every stakeholder has certain concerns with respect to the system being developed, i.e. issues about the development, operation, function or any other system aspect that is of relevance to a particular stakeholder. The concerns identified in this architectural description are the following:

(a) What is the purpose or missions of the system?
(b) What is the appropriateness of the system for use in fulfilling its missions?
(c) What is the feasibility of constructing the system?
(d) What are the risks of system development and operation to users, acquirers, and developers of the system?
(e) What are the quality attributes that the system must support?
(f) Who are the external actors that interact with the system?
(g) What are the tasks or functionalities that the system offers to those external actors?
(h) What is the modularity of these tasks?
(i) What are the computational elements of a system and the organization of those elements?
(j) What are their interfaces?
(k) How do they interconnect?
(l) What are the mechanisms for interconnection?
(m) How do they dynamically interact?
(n) What is the system topology with respect to computational nodes?
(o) What are the protocols used for communication between the physical nodes?
(p) How are the components distributed among the physical nodes?
(q) What are the implementation level components and how are they layered?
(r) What are the data stored in the system?
(s) How are the data stored in the system (XML, file system, Data Base)?

2.3 Definition of the viewpoints

A viewpoint specifies the conventions, with which a view is created, depicted in diagrams and analyzed. In this sense a view conforms to a viewpoint. The viewpoints in specific, determine the language used for the description of the view and any other modeling method or technical analysis applied for the representation of the corresponding views. The choice of viewpoints that follows is based on the specification of stakeholders and concerns, presented in the previous sub-section.

2.3.1 The Use-Case Viewpoint

This view addresses three types of stakeholders: users, acquirers, and developers and refers to concerns (a), (b), (c), (d), (e), (f), (g) and (h). The constructed views shall use the

Unified Modeling Language [7, 25] as a modeling language and especially use-case diagrams. They shall also use the modeling techniques, specified in the Rational Unified Process. Specifically they will present a subset of the Use-Case Model, presenting the architecturally significant use-cases of the system. They will describe the set of scenarios and/or use cases that represent some significant, central functionality, as seen from external actors. They will also describe the set of scenarios and/or use cases that have a substantial architectural coverage (that exercise many architectural elements) or that stress or illustrate a specific, delicate point of the architecture.
This viewpoint is selected because it shows how the system interacts with the external environment that it inhabits in.

2.3.2 The Logical Viewpoint

This view addresses two types of stakeholders: developers, maintainers and deals with concerns (i), (j), (k), (l), and (m). The constructed views shall use the Unified Modeling Language [7, 25] as a modeling language and especially Sequence, State, Collaboration, Activity, Class, and Object diagrams. They shall also use the modeling techniques, specified in the Rational Unified Process. Specifically they will present a subset of the Design Model which presents architecturally significant design elements. They shall describe the most important classes, their organization in packages and subsystems, and the organization of these packages and subsystems into layers. They shall also describe the most important use-case realizations, for example, the dynamic aspects of the architecture.
This viewpoint is selected because it shows the decomposition and behavior of the system in a logical level of abstraction.

2.3.3 The Deployment Viewpoint

The stakeholders to be addressed by the viewpoint, are the developers and maintainers, while the corresponding concerns are (n), (o), and (p).
The constructed views shall use the Unified Modeling Language [7, 25] as a modeling language and especially deployment diagrams. They shall also use the modeling techniques, specified in the Rational Unified Process. Specifically they will present the Deployment Model which presents the physical nodes and the interconnection between them. They will describe one or more physical network (hardware) configurations on which the software is deployed and run.
This viewpoint is selected because it shows the physical topology of the system.

2.3.4 The Implementation Viewpoint

The stakeholders to be addressed by the viewpoint are developers, maintainers and the only concern addressed is (q). The constructed views shall use the Unified Modeling Language [7, 25] as a modeling language and especially component diagrams. They shall also use the modeling techniques, specified in the Rational Unified Process. Specifically they will present the decomposition of the software into layers and subsystems in the implementation model. They will describe an overview of the implementation model and its organization in terms of the components in implementation subsystems and layers, as well as the allocation of packages and classes (from the Logical View) to the implementation subsystems and components of the Implementation View.
This viewpoint is selected because it shows the artifacts of code that comprise the system.

2.3.5 The Data Viewpoint

The stakeholders to be addressed by the viewpoint are developers, maintainers and the concerns tackled are (r) and (s). The constructed views shall use the Entity-Relationship Diagrams which is the standard notation for relational databases. Specifically they will present the architecturally significant persistent elements in the data model. They will describe an overview of the data model and its organization in terms of the tables, views, indexes, triggers and stored procedures used to provide persistence to the system. They will also describe the mapping of persistent classes (from the Logical View) to the data structure of the database.
This viewpoint is selected because it shows the persistent data that are stored and manipulated by the system.

2.4 The views

2.4.1 The use-case view

The elements from this view have been extracted from a business model, which is described in [1] and is based on the IEEE LTSC standard for Learning Technology Systems Architectures [13]. As an example, Figure 1 depicts the use cases initiated by a professor.

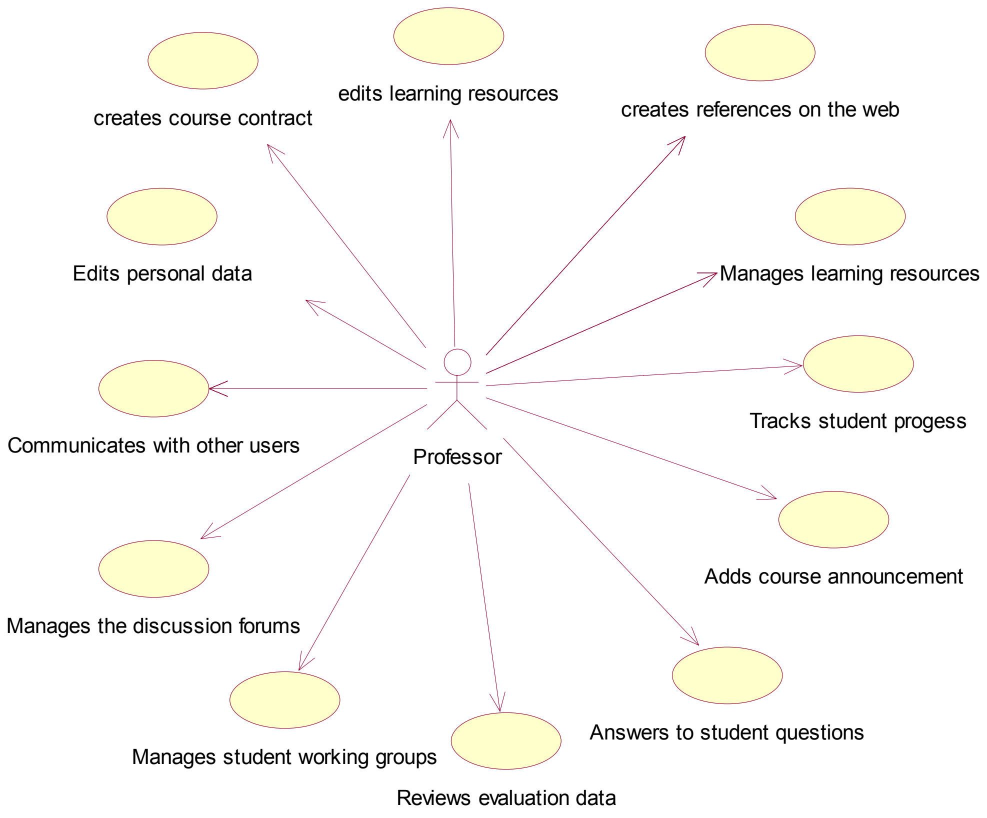

creates course contract
edits learning resources
creates references on the web
Edits personal data
Manages learning resources
Communicates with other users
Tracks student progess
Professor
Adds course announcement
Manages the discussion forums
Answers to student questions
Manages student working groups
Reviews evaluation data

Figure 1 – Use cases initiated by a professor

2.4.2 The logical view

In the RUP's logical view, the decomposition of the Learning Management System is performed by specifying the discrete subsystems and the connectors between them in the design model, as they have derived from the use case and analysis model. The decomposition is combined with the enforcement of the "Layered Systems" architecture pattern [6, 9, 26], which helps organize the subsystems hierarchically into layers, in the sense that subsystems in one layer can only reference subsystems on the same level or below. The communication between subsystems that reside in different layers is achieved through clearly defined interfaces and the set of subsystems in each layer can be conceptualized as implementing a virtual machine [6]. The most widely known examples of this kind of architectural style are layered communication protocols such as the ISO/OSI, or operating systems such as some of the X Window System protocols.

The RUP utilizes the aforementioned architectural pattern by defining four layers in order to organize the subsystems in the design model. According to the RUP, a *layer* is a set of subsystems that share the same degree of generality and interface volatility. The four layers used to describe the architectural structure of a software system are [20]:

- *Application-specific:* A layer enclosing the subsystems that are application-specific, in our case, specific to LMS and are not meant to be reused in different applications. This is the top layer, so its subsystems are not shared by the subsystems of other layers.
- *Application-general:* A layer comprised of the subsystems that are not specific to a single application, such as an LMS, but can be re-used for many different applications within the same domain or business.
- *Middleware:* A layer offering reusable building blocks (packages or subsystems) for utility frameworks and platform-independent services for things like distributed object computing and interoperability in heterogeneous environments, e.g. Object Request Brokers, platform-neutral frameworks for creating GUIs.
- *System software:* A layer containing the software for the computing and networking infrastructure, such as operating systems, DBMS, interface to specific hardware, e.g. TCP/IP.

The proposed layered architecture for a Learning Management System is depicted in Figure 2, which is a first-level decomposition in the design model. This diagram, besides identifying all first-level subsystems and organizing them into layers, also defines dependencies between them, which are realized through well-specified interfaces. This list of first-level subsystems has been produced by a list of patterns described in [3].

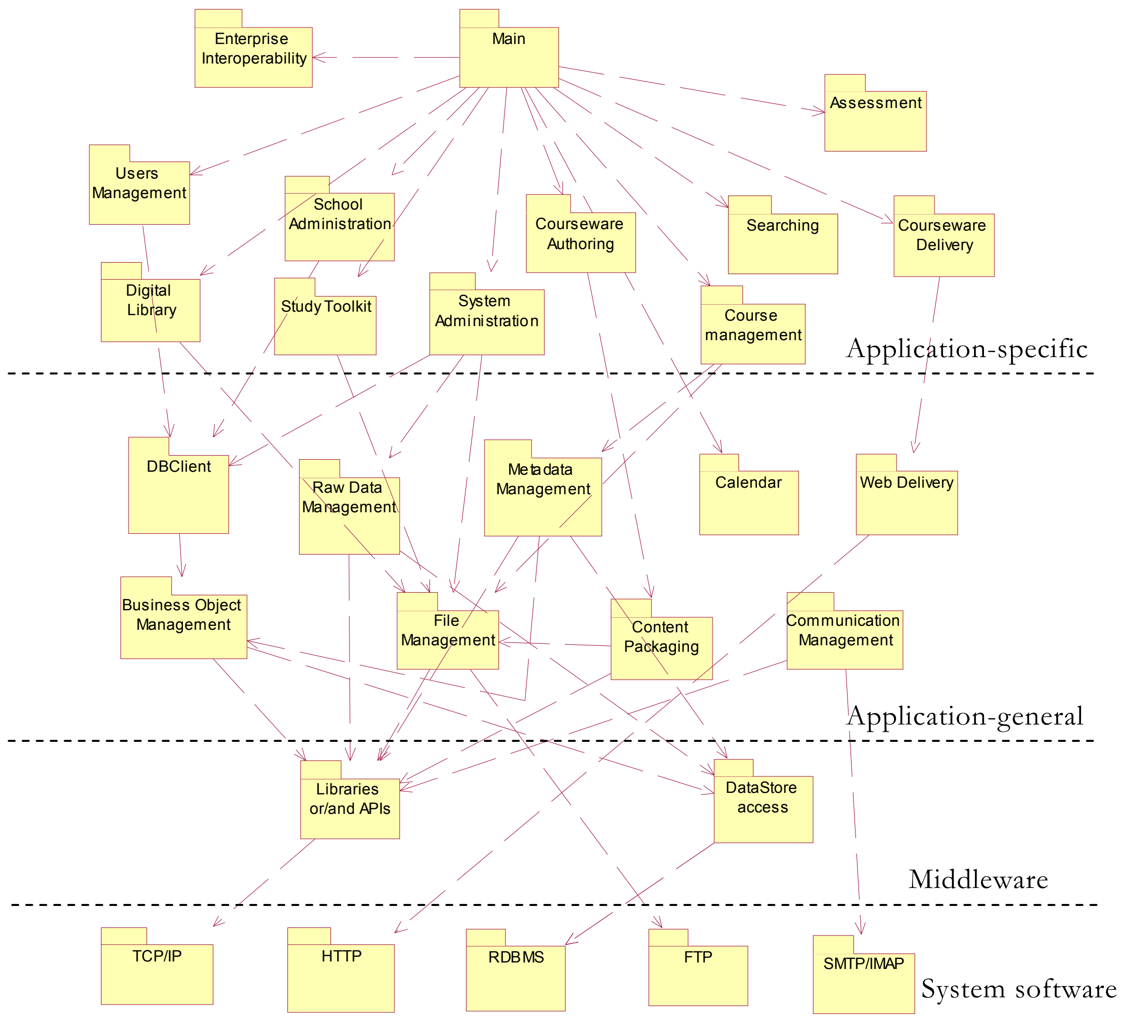


Figure 2**.** The layered architecture of the component-based Learning Management System

These subsystems are further elaborated by identifying their contents, which are design classes, use-case realizations, interfaces and other design subsystems (recursively).

2.4.3 The deployment view

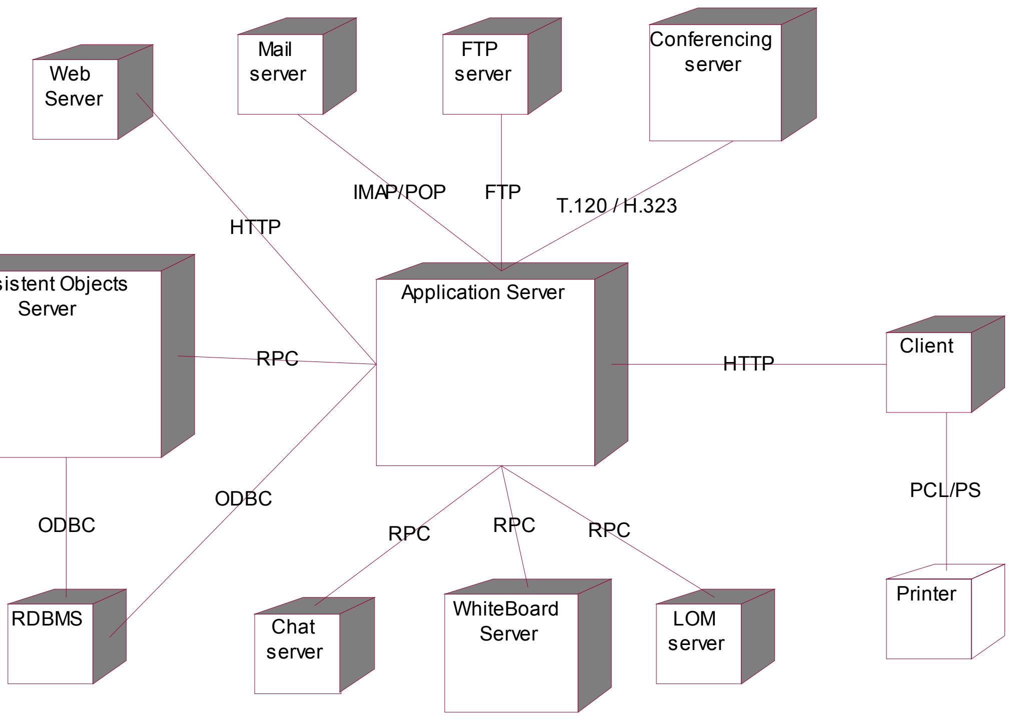


Figure 3 The deployment diagram

The deployment diagram in Figure 3 depicts all the system servers that are connected to the application server through appropriate protocols. The application server is assigned with all the components that do not belong to the other servers, and acts like the ‘glue’ between all the other parts.

This deployment diagram is part of the reference architecture and therefore is meant to be as generic as possible. Therefore all the servers have been placed in different computational nodes. However in software architecture instances derived from the reference architecture, this topology is expected to change in the sense that more than one servers will be placed in the same computational node.

2.5 Architectural patterns

The architectural patterns that have been used, as seen in the catalogue composed in [6, 9, 26] include: the *layered* style as aforementioned; the *Client-Server* style in several components and especially in the communication management components (e.g. e-mail, chat); the *Model-View-Controller* style in the Graphical User Interface design; the *blackboard* style in the mechanisms that access the database in various ways; the *event systems* style for notification of GUI components about the change of state of persistent objects.

2.6 Qualities supported by the architecture

Another significant concern that needs to be addressed in this architectural description is the choice of desirable *qualities* for LMS, selected from the list of qualities described in [6]. The complete evaluation of the reference architecture can be found in [2, 5], but in this subsection, it will suffice to mention the quality attributes that are important for this specific category of systems and therefore should be supported by the reference architecture.

The quality attributes that are of paramount importance for Learning Management Systems are **interoperability, modifiability, portability, usability, reusability** and **integrability**. LMS are required to **interoperate** with each other or other systems so that they can exchange student records, learning resources and their metadata, assessment tests and so on. They need to be easily **modifiable** and **extensible**, so that they can be adapted to emerging technologies and pedagogical models and thus increase their lifetime. They need to be **portable** to multiple clients, so that their users can operate them through a web interface, independently of the client platform. They must be **usable,** because students must concentrate on learning processes rather than being cognitively overloaded by a dysfunctional user interface. They must be able to be constructed by **integrating** existing components, and reversely they should be able to offer their components to be **reused** in future applications. On the other hand, other qualities like **security** and **availability** are given lower priority, since LMS are not 'mission-critical' applications and thus need not be highly secure or continuously up and running.

2.7 Standards Adoption

This reference architecture emphasizes, as aforementioned, on the adoption of international Learning Technology standards, in order to achieve interoperability which is currently a major issue in the domain of LMS [2, 27]. In particular the goal is to map particular standards to individual components of the architecture, in order to provide a guide of standards adoption and implementation to LMS vendors. This is meaningful and useful since Learning Technology standards are still quite at an immature level and there exists much confusion about the nature and application of each standard. Table 1 depicts the mapping of standards to individual components of the reference architecture. It is noted that a single component may implement more than one standards. For example, the Courseware Delivery Component may implement the IMS Content Packaging standard, as well as the IMS Simple Sequencing standard.

Table 1 – Mapping between LT standards and architectural components

Component	Standard
All components (Business model)	IEEE LTSC LTSA
School Administration	IMS Learner Information Package
	School Interoperability Framework
	IMS Reusable Competency Definition
Enterprise Interoperability	IMS Enterprise
Assessment	IMS QTI
Searching and Metadata management	IEEE LTSC LOM
Courseware delivery	IEEE LTSC Computer Managed Instruction
	IMS Content Packaging
	IEEE LTSC Digital Rights Expression Language
	IMS Simple Sequencing
	ADL SCORM
Study toolkit	IMS Learning design, EML
Content packaging	IMS Content Packaging

3 A Software Architecture Instance

The reference architecture presented in the previous section does not delve into specific implementation details. This matter will be dealt with in software architectures that will be instances of the reference architecture and will refine and extend the concepts defined in the reference architecture. Such a software architecture instance was designed for the development of a prototype Learning Management System, called 'Athena', as described in [4]. This particular instance has employed Java as an implementation platform. The full description of the software architecture instance cannot be elaborated here but it will suffice to discuss the differences between the reference architecture and the software architecture instance for the 'Athena' LMS, as illustrated in Table 2. In the next subsections, these differences will be outlined and the architectural prototype will be briefly introduced.

Table 2 – The differences between the reference architecture and the software architecture instance for the ‘Athena’ LMS

Type of architecture / Part of the architectural description	Reference Architecture	Software architecture instance for the ‘Athena’ prototype LMS
Stakeholders and their concerns	The stakeholders are described in a generic fashion.	The stakeholders are specific to the ‘Athena’ LMS and there are extra issues concerning its mission, appropriateness and feasibility
Implementation decisions (platform, legacy systems, third-party software)	There are no implementation decisions	Implementation decisions are concretely defined
Architectural views	Logical and deployment view completely lack implementation details. Implementation and data view are omitted.	There are implementation details in all 5 views.

3.1 Stakeholders and concerns

The stakeholders in the software architecture instance are specific for the particular LMS. In particular the acquirer of the system is a university, the developers of the system are a consortium of academic research labs and a software development company, and all these are explicitly identified. The maintenance team is decided to be the same as the development team.

Furthermore in the software architecture instance, some issues about the context of this particular system in terms of mission, appropriateness and feasibility are identified:

1) The system is intended to be used in the context of open and distance learning courses provided by a higher education institution.

2) The system is appropriate for use in the identified mission, because the acquirer has already used a commercial similar product, named WebCT, that has served such missions adequately.

3) It is feasible to construct the system since the development team has long experience in this kind of systems, both in using them and developing them. The development team also has vast knowledge of the implementation language and platform.
4) The risks of operation of the system concerns issues of performance since the technology used for development has certain performance problems.
5) Since the development team is the same with the maintainers of the system, the same team will perform maintenance, deployment and evolution of the system.

3.2 Implementation constraints

The implementation decisions are a determinant for the development of a system and therefore should be taken during the architectural design and not during the next phases of the lifecycle. In the 'Athena' software architecture instance, certain implementation decisions are proposed, in particular the development platform and the third-party software to be used, that are considered to be the most suitable. Also the legacy code is taken into account.

The technologies chosen implement the **component-based paradigm** using object-oriented techniques, specifically the Unified Modeling Language, and the Java programming languages. The Java platform was chosen because it is an open technology, based on international community standards (Java Community Process, http://www.jcp.org/), rather than proprietary, and it is also based on a Virtual Machine, thus promoting portability.

The various components of the 'Athena' LMS, according to their functionality and whether they are located at the client-side or the server side, are to be implemented as:

1) **Applets**, for the components that are required to implement a thick client because they offer extensive user-system interaction, e.g. the metadata management system.
2) **Servlets** and **Java Server Pages**, for the server-side components, that correspond to the majority of the system.
3) **Java Beans**, for the implementation of reusable components of the Graphical User Interface.
4) **Enterprise Java Beans**, for the implementation of session components, as well as persistent business objects.

The specific Java APIs chosen are the JFC/Swing, RMI, JDBC, 2D Graphics, Java Media Framework, Reflection, SAX and Java Application Framework. The eXtensible Markup Language (XML) is chosen as the default language for the representation of data that are not stored in the database.

For this particular system, there is some legacy code, inherited from a past attempt to build the ‘Athena’ LMS, and it is required to reuse the components of this code in order to speed up the development process. This code is written in Java so it will be easier to modify it and extend it in order to implement the software architecture. However this legacy code is not well documented, therefore some man-days have to be spent in creating Java Documentation for this code.

The artifacts from the design model that is sub-systems with UML-defined interfaces are the starting point for the component implementation. The next step is to transform the UML interfaces into the implementation platform, in our case Java. This forward engineering process was easily automated with the Rational Rose CASE tool [http://www.rational.com/rose] that generates abstract code from UML models.

After the component interfaces are concretely defined in the programming language, they can either be constructed from scratch, or acquired from existing implementations and possibly modified to exactly fit their interfaces. The result is the implementation of the sub-systems as Java components, i.e. web components (servlets and JSP), JavaBeans and Enterprise JavaBeans (EJB). The possible re-use of components is one of the areas where the component-based approach thrives. The final step is to integrate the components through an integration and testing process into the final outcome, i.e. the Learning Management System.

For this architectural instance, several third party components have been chosen, especially for the roles of the various servers. More specifically the components of the layered architecture illustrated above that were acquired from third parties are: WWW Server and servlet engine (Resin) [http://www.caucho.com], WWW browser with Java plug-in (Sun 1.3.1 Java Run Time Environment), FTP Server (ProFTPD) [http://www.proftpd.net/], Mail Server (SendMail) [http://www.sendmail.org/], RDBMS (mySQL) [http://www.mysql.com], Audio/Video Conferencing client (Microsoft Netmeeting), Java Virtual Machine on the server (Sun 1.3.1 Java SDK).

3.3 Implementation details in views

3.3.1 The logical view

The implementation decisions in the logical view concern the specification of some components, that need to be customized in each instance. For example in the first level decomposition, these specific components are:

- In the middleware layer, one more component has been added, the Java Virtual Machine, which is the result of implementation into the Java language.

- The RDBMS component is replaced by the MySQL component.
- The "Libraries and/or APIs" component has been replaced by a component named Java APIs.

3.3.2 The implementation view

This view exists only in the software architecture instance and uses UML component diagrams to show the organization of executable code modules. Since Java has been decided to be the implementation platform, the component diagrams depict Java classes, interfaces and packages.

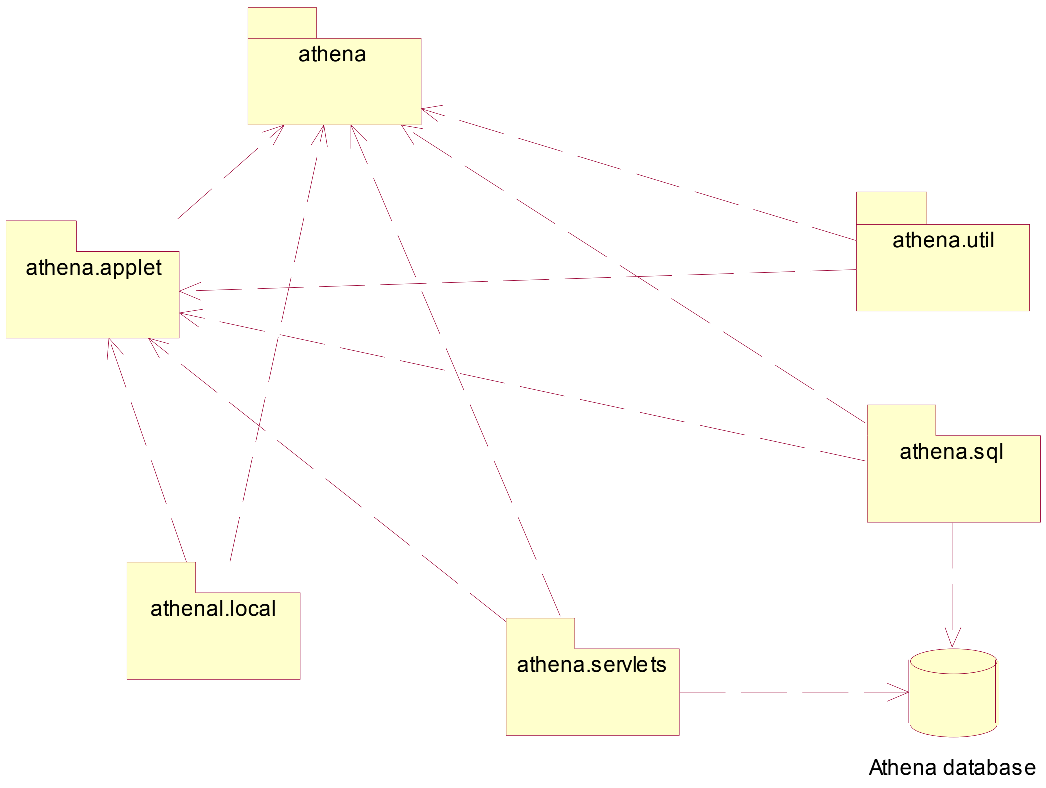


Figure 4 - The first-level components in the implementation view

Figure 4 shows that the system is decomposed on a first level in six packages:

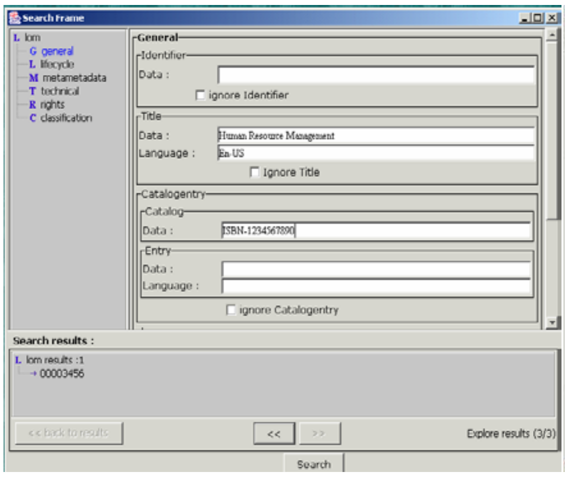
- **athena** – it corresponds to the main component of the logical view that initializes and launches all the other components.
- **athena.applet** – it contains all the applets that are executed within the client's browser.
- **athena.local** – it contains some command-line utilities that are executed locally on the server for maintenance purposes.
- **athena.servlets** – it contains all the servers and Java Server Pages
- **athena.sql** – it contains all the database access mechanisms, as well as the persistent objects management component.
- **athena.util** – it contains all the utility classes, e.g. for the construction of Graphical User Interface components.

3.3.3 The deployment view

The implementation decisions in the deployment view concern the identification of the various computational nodes and protocols specified in the reference architecture. Having in mind Figure 3, the application server is replaced by a J2EE Server, while the RDBMS node is replaced by a MySQL server. Furthermore the Remote Procedure Call (RPC) generic protocol that supports the realization of method calls to remote components, is now replaced by the Java Remote Method Invocation (RMI) API. Finally the Open Database Connectivity (ODBC) protocol for database connection is now replaced by JDBC, which is the corresponding ODBC protocol for Java.

3.4 The 'Athena' Architectural Prototype

A software architecture must be accompanied with an **architectural prototype** that implements the most important design decisions sufficiently to validate them - that is to test and measure them [8, 10, 21]. In order to assess and validate the software architecture instance discussed above, a prototype was engineered that implements the main architectural elements. Figure 5 depicts some of the features of the 'Athena' LMS in action.



Data :

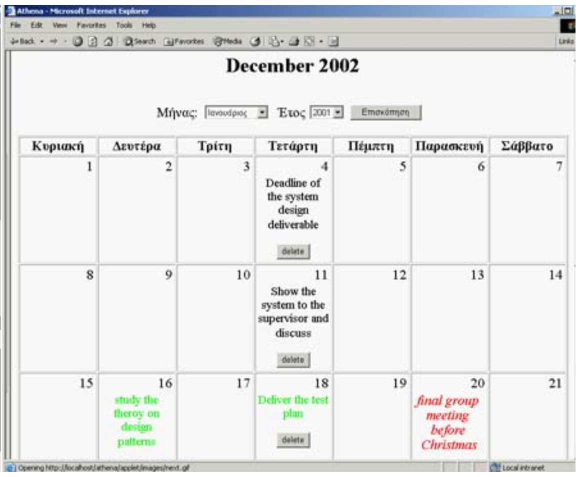
Data : Human Resource Management
Language : En-US

Data : ISBN-1234567890

Data :
Language :

L lom results :1
→ 00003456

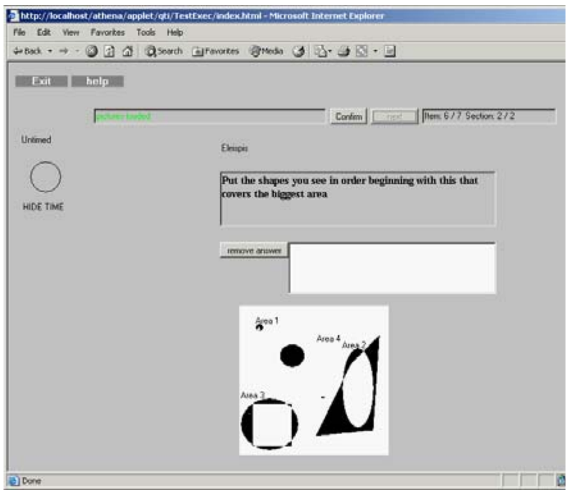
Explore results (3/3)


Athena - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Μήνας: Ιανουάριος Έτος 2001 Επιστροφή
delete

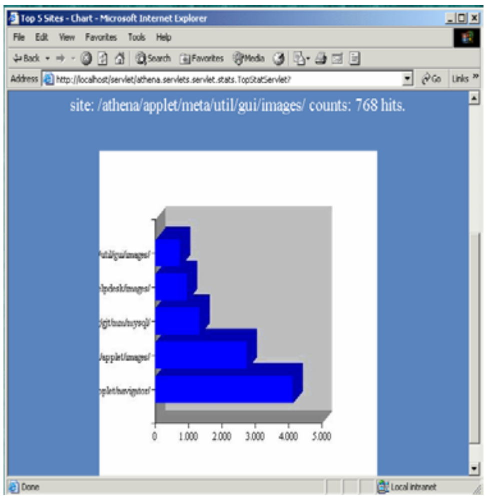
December 2002

Κυριακή	Δευτέρα	Τρίτη	Τετάρτη	Πέμπτη	Παρασκευή	Σάββατο
1	2	3	4 Deadline of the system design deliverable	5	6	7
8	9	10	11 Show the system to the supervisor and discuss	12	13	14
15	16 study the theroy on design patterns	17	18 Deliver the test plan	19	20 final group meeting before Christmas	21

Search through metadata (conforming with LOM) Calendar


http://localhost/athena/applet/qti/TestExec/index.html - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Exit
help
Confirm
next
Item: 6 / 7 Section: 2 / 2
Untimed
HIDE TIME
Ellipsis
remove answer
Area 1
Area 4
Area 2
Area 3
Done

Put the shapes you see in order beginning with this that covers the biggest area


Top 5 Sites - Chart - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://localhost/servlet/athena.servlets.servlet.stats.TopStatServlet?
site: /athena/applet/meta/util/gui/images/ counts: 768 hits.
/util/gui/images/
/hpdesk/images/
/gtthmahuyyoj/
/applet/images/
/applethavigator/
0
1.000
2.000
3.000
4.000
5.000
Done
Local intranet

Test authoring tool (conforming with QTI) Statistics for Student Tracking

Figure 5. Screenshots of the architectural prototype

About 75% of the total number of components have been implemented or acquired and put into operation. In addition to the third-party components mentioned in a previous section, the layered architecture components that were implemented from scratch are: Main Subsystem, User Management, Courseware Authoring, Courseware Delivery, Course Management, Searching, Assessment, Help Desk, Data Base client, Raw Data Management, Business Objects Management, FTP client, Metadata Management, Calendar, Communication Management (E-mail client, Chat server and client, Whiteboard server and client, Announcements tool), Data Store Access API.

Finally there was an attempt on implementing some of the international standards within the various components, as dictated by the reference architecture. For that purpose the metadata management component has been developed to conform to the IEEE LTSC Learning Object Metadata working standard [14]; the assessment component has been implemented in order to adopt the IMS Question and Testing Interoperability Standard [16]; the Courseware Delivery component has adopted the IMS Learning Design [17]; the School Administration component has adopted both the IMS Learner Information and Package [18] and the IMS Competency Definition[19]. Although most of these standards are not yet in their final form, the aim of implementing them at such an early stage was to explore the feasibility of implementing them into our components.

4 Evaluation of the reference architecture

Software architectures can be evaluated according to specific criteria and are designed to fulfill certain quality attributes [8, 10, 6]. It is noted that no quality can be maximized in a system without sacrificing some other quality or qualities, instead there is always a trade-off between the different quality attributes [8, 10, 6]. Architectures can be evaluated through special evaluation techniques. These techniques do not assess the quality characteristics of end-products but measure the architecture's ability to satisfy them and indicate where the architecture 'is at' in terms of quality.

The evaluation framework used for the assessment of the proposed reference architecture with respect to the quality attributes is comprised of a combination of two techniques adopted from [8]:

- **Scenario-based evaluation,** which is based on creating a set of scenarios, in order to evaluate a specific quality attribute. For example the interoperability quality can be evaluated by creating scenarios of exchanging data between the system under development and other systems, and evaluating the level of success in these interoperations.
- **Architectural prototype evaluation,** which is based on implementing only some of the parts of the architecture while the rest are ignored. The architectural prototype used is the 'Athena' LMS presented in the previous section.

As far as the quality criteria that were evaluated, these were adopted from [6]:

- **Run-time qualities** (performance, security, availability, functionality, usability)
- **Development qualities** (modifiability, portability, integrability, interoperability, reusability, testability).

This method is applied by examining the architectural prototype in operation and creating scenarios for the assessment of specific quality attributes. The evaluation in most of the cases was qualitative and not quantitative as there are no metrics yet for these techniques [8]. It is rather obvious that this evaluation framework does not evaluate the reference architecture per se; instead it examines the architectural prototype which is an implementation of the software architecture instance, which in turn is an instantiation of the reference architecture. Therefore, the results from the evaluation can be attributed to the reference architecture, if and only if they do not rely on implementation decisions. If they are directly based on implementation decision they can only be ascribed to the software architecture instance.

As an example of an implementation-independent evaluation result it can be claimed that the layered nature of the system supports modifiability, since the functionality is separated between layers and components can be modified without affecting components from other layers. This claim has also been proven right during the evaluation of the architectural prototype. On the other hand the layered nature of the system has a considerable cost on performance since there is a lot of communication overhead between independent components. Hence it can be claimed that the reference architecture supports modifiability but diminishes performance.

As a example of an evaluation result that relies on implementation decisions, we can consider the use of the Java programming language on the architectural prototype. Being an interpreted language and relying on a virtual machine, Java is platform-independent, thus allowing portability, at least to an extent and this has been also verified in the architectural prototype. However this evaluation result can only be attributed to the 'Athena' architectural instance and not to the reference architecture, since it directly involves an implementation decision.

The complete evaluation can be found in [2, 5]. It will suffice to say here that the architecture scored pretty high in the development qualities such as interoperability, modifiability, integrability, reusability and testability. On the other hand the architecture had a medium score in the run-time qualities such as performance, security, and availability. This result is exactly what had been sought after in the desirable qualities of the reference architecture, as aforementioned in Section 2.6. The contradiction in the evaluation results between the run-time and the development qualities makes sense from an architectural point of view, since the development qualities are often in direct conflict with the run-time qualities.

5 Conclusions and Future Work

This paper has proposed a description of a reference architecture, with the aid of the IEEE 1471 std., and the architecting practices of the Unified Software Development Process and the Unified Modeling Language. It has also demonstrated the differences between the description of a reference architecture and a software architecture that instantiates the former. Finally it has shown a plain evaluation framework that can be used for the assessment of the quality attributes, emphasizing on distinguishing the evaluation results among those relied on implementation decisions and those that are independent.

Describing a reference architecture for a domain of systems and instantiating it into software architectures is not a straight forward process and there is no 'silver bullet' for accomplishing it. However the benefits gained from establishing a reference architecture for a domain are highly rewarding [6, 8, 20, 7]:

- It is **reusable** in the sense that it can be adopted for the design of architectural instances and therefore the development of new systems, thus achieving a more **disciplined**, **systematic** approach in this particular domain.
- It allows the 'a priori' **analysis** and **evaluation** of quality attributes, assuring the quality of the systems that will be designed according to the reference architecture. The architectural instances that will be produced will be based on a reference architecture that has already been evaluated and consequently satisfies some desirable quality attributes. This is of major importance as it eliminates the need to perform radical changes to the systems under development during the final development stages. Such changes are not just costly, they are often not feasible.
- It isn't a blueprint for designing a single system, but a **framework** for designing a range of systems over time, thus achieving **adaptability** to new trends and technologies.
- It grants a tangible product that represents a high-level abstraction of the system, assisting to the **comprehension** of the systems under development, their subsystems, and their interactions with related systems. In this sense it can help the **training** of apprentices to programming this particular domain of systems.
- It allows for the **analysis** and **comparison** between different systems, with respect to the reference architecture.
- Since the systems based on the reference architecture will contain implementations of the components prescribed in it, a pool of such components can be established, so that these components can be **reused** in new systems being developed.
- It can be used for the **interoperation** between the systems developed since they offer the same functionality through interfaces.
- It can be used for **communication** and **dialog** between the stakeholders involved in the development process. Moreover, the stakeholders, i.e. programmers, administrators, managers, customers, can grasp the details of the system through a common language. In addition this abstract description of the system is useful not only during the development period, but during the whole system lifecycle, and can be used for the **maintenance** of the system, even when the initial architect is not present.

- It offers an effective basis for managing the development project, as it **organizes** the development process, offering the structure upon which the workload will be administered in each development iteration.

Currently we are working on designing and implementing more instances of the reference architecture, taking other implementation decisions in each case, e.g. other development platforms or different third-party components. This will further demonstrate the feasibility of the reference architecture, lead to useful conclusions, with respect to the range of possible implementations and provide valuable feedback to the reference architecture per se. It will also reveal further more the relation between evaluation results and implementation decisions, providing a more extensive test-bed.

6 References

1. Avgeriou, P., Retalis, S. and Papaspyrou, N., "Modeling a Learning Technology System as a Business System", (in press) *Software and System Modelling Journal (SoSyM)*, Springer-Verlag, 2003.
2. Avgeriou, P., Retalis, S., Skordalakis, E., "Building Quality Into Learning Management Systems – An Architecture-Centric Approach", (forthcoming volume of) Lecture Notes in Computer Science, Springer-Verlag.
3. Avgeriou, P., Papasalouros, A., Retalis, S., "Towards a Pattern Language for Learning Management Systems", *IEEE Educational Technology & Society* (accepted for publication).
4. Avgeriou, P., Architectural Description of the "Athena" Learning Management System that conforms to the IEEE 1471-2000 standard, National Technical University of Athens, Software Engineering Laboratory Technical Report CSD-SW-TR-1-02, 2002.
5. Avgeriou, P., A Reference Architecture For Open Learning Management Systems, PhD thesis, January 2003, National Technical University of Athens.
6. Bass, L., Clements, P., Kazman, R.: Software Architecture in Practice. Addison-Wesley, 1998.
7. Booch, G., Rumbaugh, J., Jacobson, I.: The UML User Guide. Addison-Wesley, 1999.
8. Bosch, J.: Design and Use of Software Architectures. Addison-Wesley, 2000.
9. Buschmann, F., Meunier, R., Rohnert, H., Sommertland, P. and Stal, M., 1996. Pattern-Oriented Software Architecture, Volume 1: A System of Patterns, John Wiley & Sons.
10. Clements, P., Kazman, R., Clein, M., Evaluating Software Architecture, Addison-Wesley, 2002.
11. Collier, G., "Elearning application Infrastructure", Sun Microsystems white paper, http://www.sun.com/products-n-solutions/edu/whitepapers/index.html, January 2002.
12. Hofmeister, C., Nord, R. and Soni, D., "Applied Software Architecture", *Addison-Wesley*, 1999.
13. IEEE Learning Technology Standards Committee (LTSC), Draft Standard for Learning Technology Systems Architecture (LTSA), Draft 9, November 2001, http://ltsc.ieee.org/.
14. IEEE Learning Technology Standards Committee, (LTSC), Draft Standard for Learning Object Metadata (LOM), Draft 6.4, 2001, http://ltsc.ieee.org.
15. IEEE Recommended Practice for Architectural Description of Software-Intensive Systems (IEEE std. 1471-2000).
16. IMS Global Learning Consortium, 2001. IMS Question & Test Interoperability Specification- Best Practice and Implementation Guide, version 1.2.1, http://www.imsproject.org/.
17. IMS Global Learning Consortium, "IMS Learning Design", 2001.
18. IMS Global Learning Consortium, "IMS Learner Information and Package (LIP)", 2002.
19. IMS Global Learning Consortium, "IMS Competency Definition", 2002.
20. Jacobson, I., Booch, G., Rumbaugh, J.: The Unified Software Development Process. Addison-Wesley, 1999.
21. Kruchten, P., 1999. The Rational Unified Process, An introduction, Addison-Wesley.
22. Oleg, S., Liber, B.: A framework of pedagogical evaluation of Virtual Learning Environments. Available online at [http://www.jtap.ac.uk/reports/htm/jtap-041.html], 1999.

23. Putman, J., Architecting with RM-ODP, Prentice Hall, 2001.
24. The Rational Unified Process, 2000, v. 2001.03.00.23, Rational Software Corporation, part of the Rational Solutions for Windows suite.
25. Rumbaugh, J., Jacobson, I. and Booch, G., 1999. The UML Reference Manual, Addison-Wesley.
26. Shaw, M., Garlan, D.: Software Architecture - Perspectives on an emerging discipline. Prentice Hall, 1996.
27. Wilson,S., The next big thing? Three architectural frameworks for learning technologies, IMS Summit, August 2001, http://www.cetis.ac.uk/content/20010828163808/printArticle