Personalized E-Learning in a re-usable Way: A Proposed Cultural Heritage Management System Design - The Architecture

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Abstract: *Nowadays cultural heritage is under threat and danger (pollution, natural disasters, wars, etc.). In this domain, cultural heritage management (CHM) as the art, vocation and practice of managing cultural heritage resources and as a multi-discipline research area has a vital role. In recent years, the innovations, improvements and rapid advances in traditional and geographic (GIS) databases, design computing, digital architecture and archaeology, imaging sensors and scanners, computer modeling software, haptic equipments and e-learning technology, as well as the affordability and availability of many powerful graphics workstations, make metadata and 3D modeling techniques for CHM with e-learning and haptic rendering (virtual reality) functionality feasible. This paper addresses the application research issue of incorporating metadata and modeling in a CHM case study and discusses the related e-learning functionality. So, in this article, a practical project is used to demonstrate the functionality and the performance of the proposed 3D modeling metadata based CHM methodology. In particular, the processing steps from image acquisition to the 3D geometric and semantic description of the Galerius Palace "Octagonon" (Thessaloniki, Greece), in a 3D digital environment are presented. Also, emphasis is put on documenting the new term 3D modeling metadata for CHM, and on discussing as an open issue the concept personalized e-learning CHM scenarios. The proposed methodology has* 10^{-2} *modeling accuracy (i.e. 1% relative inaccuracy) and it is of interest for archaeology, architecture, virtual reality, e-learning, e-culture and virtual tourism.*

Keywords: *Cultural heritage management, e-Learning in cultural heritage, Historical sites digital documentation, Community cultural information systems.*

1. Introduction

Nowadays cultural heritage is under threat and danger (pollution, natural disasters, wars, etc.). In this domain, c*ultural heritage management* (CHM) as the art, vocation and practice of managing cultural heritage resources, as well as a multi-discipline research area has a vital role. In recent years, the innovations, improvements and rapid advances in traditional and spatial (GIS) databases, design computing, digital architecture and archaeology, imaging sensors and scanners, computer modeling software, haptic equipments and e-learning technology, as well as the affordability and availability of many powerful graphics workstations, make metadata and 3D modeling techniques for CHM with e-learning and haptic rendering (virtual reality) functionality feasible.

This paper addresses the application research issue of incorporating metadata and modeling in a CHM case study and discusses the related e-learning functionality. So, in this article, a practical project is used to demonstrate the functionality and the performance of the proposed 3D modeling metadata based CHM methodology. In particular, the processing steps from image acquisition to the 3D geometric and semantic description of the Galerius Palace "Octagonon" (Thessaloniki, Greece), in a 3D digital environment are presented. Also, emphasis is put on documenting the new term *3D modeling metadata*, and on discussing the concept *personalized e-learning CHM scenarios* as an open research issue.

The accuracy evaluation shows that the proposed metadata and amateur image-based methodology is suitable for CAAD modeling applications regarding mainly semi-demolished archaeological or historical sites when the required modeling accuracy is less than 10^{-2}, i.e. 1% relative inaccuracy (e.g. 20 cm metric error for a 20 m facade or masonry wall; included the metric data inaccuracy). Obviously, this accuracy is not acceptable for detailed restoration or renovation projects, but it is acceptable for e-culture, e-tourism and for promotion-oriented cultural heritage digital documentation applications regarding the ruins of the demolished or semi-destroyed historical sites.

Conclusively, in this article, a personalized e-learning CHM methodology framework, within a metadata-based 3D virtual environment, is proposed to give active roles to many different users (archaeologists, architects, history researchers, students, etc.) by integrating metadata and 3D modeling with synchronous, asynchronous and cooperative learning environments. The proposed methodology is of interest for archaeology, architecture, design computing and modeling, virtual reality, haptic rendering, e-learning, e-culture and virtual tourism.

1.1. Needs, concepts, open issues & requirements

CHM needs

In CHM, a number of communities with different educational, cultural and professional background (staff, scientists, students, e-tourists) are interested in analysis, monitoring, evaluation and learning regarding the cultural heritage resources, in low-cost, accurate, portable, friendly and flexible graphical-user interface (GUI) interactive environments.

Obviously, in this domain, the *interdisciplinary cooperation* among all these users working in different disciplines and using different terminologies is a need. Another need seems to be the *personalized e-learning courses*, as long as the e-culture and the e-tourism are Web/Internet developing applications. Even more, the *historic incoherent evidence data enrichment* for architectural reconstruction hypothesis formulation, the *Web-based concurrent CHM* and the *spatio-temporal CHM databases* could be regarded as additional CHM needs.

CHM concepts & open research issues

With regards to these CHM needs, a number of research issues like *CHM digital documentation* (CHMDD) [1,2,3,12,29] and *Community Cultural Information Systems* (CCIS) [45,46] are addressed. In this paper the issue of CHMDD is discussed in relation with the following concepts:

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- ***Metadata*** as a special kind of *"data about data"* are very useful in documentation procedures regarding temporal (time-based) structures like historical sites or monuments [2,3,37]. In particular, this kind of data organization is useful on: (a) developing machine-independent 'neutral' (not-aligned to particular discipline) structures suitable for *interdisciplinary cooperation* [1,19]; and (b), as an open research issue, on *enriched data based 3D modeling* of objects and procedures when the available metric and non-metric (qualitative) information is limited (e.g. the case of demolished or partially destroyed cultural heritage sites or monuments);
- ***3D modeling*** as the basis of the digital geometric representation (CAAD requirements for *Web-based concurrent CHM*) and semantic interpretation (learning contents and user profiles development requirements for *personalized e-learning courses*) of the cultural site [5,7,9,19,20,21,31]. Also, the *enriched metadata-based 3D modeling* open research issue, is based on: historic incoherent evidence data, enriched metadata, archive (historic) photography, imagery, metric and non-metric (qualitative) data, historic metadata analysis, and on any available spatial 3D modeling semantic information;

- ***Personalized e-learning*** as a learning methodology framework. This concept is related to the *personalized e-learning courses* CHMDD need through the e-learning and Augmented/Virtual Reality (A/VR) functionalities embedded in 3D CAAD modeling [4,29,44]. In this domain, and for the *personalized e-learning CHM scenarios* open issue, the research area for the pedagogical profit and the outcomes would be: (a) the establishment of a new reality in engineering and cultural education (design computing, digital architecture, digital archaeology, e-culture), when a moderate level realism (3D model) is acceptable; as hign modeling accuracy is not so necessary in e-courses using reusable scenarios, archaeological hypotheses and CAAD design concepts for architectural digital reconstructions; (b) the metadata analysis and interpretation and the real-time Web/Internet based collaborative and reusable interactivity for *Web-based concurrent CHM*; (c) the feedback, i.e. the learning domain 3D ontologies for materials and structures typology and semantic CAAD descriptions; and (d) the ability to develop personalized CAAD e-learning tools that could support archaeological hypotheses, architectural digital reconstructions, close-range photogrammetry virtual campaigns, e-culture scenarios and e-tourism sightseeings.

CHMDD requirements analysis

As regards the *metadata* concept, suitable multimedia and metadata standards should be used to support multimedia information search and retrieval functionalities for *interdisciplinary cooperation* GUI environments [7,15,16,18]. Also, for the case of the incoherent metadata required in the *enriched data based 3D modeling* procedures, a new metadata srtucture must be introduced and thereafter documented as a metadata standard, since -according to the available literature- there is not a 3D modeling-based metadata standard available so far (i.e. *3D modeling metadata*: an open research issue). This metadata structure (standard) should have the functionality to enrich the any available metric and non-metric (qualitative) information recorded in demolished or partially destroyed cultural heritage sites.

So, in CHMDD applications, metadata might be categorized as data for: (i) 3D modeling (*3D modeling metadata*); (ii) GIS analysis (*GIS metadata*); and (iii) encoding/decoding, description, access and delivery of CHM data and information (*multimedia metadata*). The first case, as an open issue in CHM, is defined by this article in Section 2, whilst in sub-Section 4.2 a real-world application example is given.

In the aspect of the *3D modeling* concept, generally speaking, such a modeling procedure must be able to derive semantic, pictorial, geometric, spatial, topological and learning information from the *virtual reconstructed cultural heritage site*, in such a way that it can be directly used for further metadata analysis, semantic interpretation and e-learning purposes regarding the history, the architecture, the structure and the temporal (time-based) 3D geometry of the projected site or monument [7,18,20,21,29].

Also, for the particular case of CHMDD applications regarding semi-demolished archaeological sites, the *3D modeling* has to be based on the *enriched metadata* issue, in connection with the: historic incoherent evidence data, archive (historic) photography, imagery, metric and non-metric (qualitative) data, historic metadata analysis, and any available spatial 3D modeling semantic information. So, for the CHMDD case, the learning contents and user profiles development requirements for *personalized e-learning CHM courses* should be supported. The *metadata-based 3D modeling*, as an open research issue in CHM, is defined by this article in Section 2, whilst in sub-Section 4.3 a real-world application example is given.

In terms of the *personalized e-learning* concept, a number of personalized online e-courses could be launched to enhance the interoperability among users from a number of different disciplines [30,45,46]. Also, offline e-courses should be synchronized into a database server [4,35,45]. Even more, in a general case, the objectives of a *e-learning cultural heritage scenario* could be [7,10,29]: (1) to facilitate and encourage the collaboration and the critical awareness between the design students, scientists and professionals (archaeologists, architects, engineers and so on); (2) to design and implement virtual spaces using different representation methods and techniques for visualization and haptic rendering, regarding archaeological ruins and sites, architectures, cultural landscapes and historical monuments; (3) to test the efficiency of the various sub-systems involved in design and restitution processes for archaeology and architecture; and (4) to support access to prior understandings regarding the history, 'pathology' (nature) and characteristics of the described demolished or semi-destroyed historical objects.

In addition, and for the *personalized e-learning CHM scenarios* open issue, the CHM database server should: (a) support learning through 3D model-based multimedia data in ways traditional CAAD, photography and video does not support; (b) allow ideas exchange (multi-disciplines collaboration environment) and support design autonomy and compatibility; and (c) promote virtual cultural heritage tourism by introducing self-directed reusable learning exercises; which lead to a critical awareness of the historical object (site), the learning process and the learner's cultural background.

The 3D modeling based *personalized e-learning CHM scenarios* and the CHM database server implementation, as open research issues in CHM, are discussed in Section 3, whilst in sub-Section 4.4 a real-world application example is given.

1.2. Literature review

The worldwide scientific work on the *metadata* concept is expanded rapidly. So, in this domain and for the *heritage data recording* case, a number of forums and institutions (research units) are activated, like: the Forum on Information Standards in Heritage (FISH, www.fish-forum.info), which supports the development of the MIDAS and INSCRIPTION metadata standards, for the content and indexing of heritage data respectively; and the English Heritage Data Standards Units (DSU), which works for the development of standards for heritage data. In literature, and for the *heritage data recording* case, G. Pavlidis *et al.* in [9] review the different methods for 3D digitization that can be applied to cultural heritage recording. So, a criteria table is created for choosing an appropriate digitization system. The methods examined are depending on the recording items, as well as the related purposes, and they are grouped in two categories: digitization of objects and digitization of monuments. Finally, the advantages and disadvantages of each method are explained. P. Arias *et al.* in [10] summarized the different metric documentation methods followed by a comparative study between them. Also, for documenting a historical agro-industrial building, an easy to use, simple close-range photogrammetric method suitable to this kind of structures in terms of accuracy, cost, speed and accessibility to non-expert users, is proposed. The survey was performed using inexpensive equipment such as: some plumb lines, a conventional digital camera, and a monoscopic photogrammetry station.

Today, there are just a few approaches on metadata based *heritage data modeling* of excavation sites, historical monuments or artefacts. The most important of these approaches, which are based on XML, are the ObjectID and Core Data Standard (by Getty Institute) and some extensions of MIDAS (for monument inventories). Also, in literature, and for the *heritage data modeling* case, Clif Ogleby in his paper [18] about the virtual reality reconstruction of architectural heritage, and A. Styliadis in [1] about the digital documentation of a monument (historical Basilica), discuss the metadata concept of the available metric information for accurate 3D modeling applications. In the *3D modeling metadata for CHM* open research issue, to our knowledge, there is no literature.

In the *3D modeling* concept, literature is rich and interesting. So, in this domain, 3D model based applications include: digital documentation of monuments and sites [3,9,12,17,28]; augmented and virtual reality [18,44]; architectural surveying [6,8,17,19]; e-learning

[4,15,29,30,32,48]; computer games; virtual tourism; forensics and inverse camera sciences; etc.

In this area and in the *3D modeling for CHM* concept, J.-A. Beraldin *et al.*, in [48], is dealing with three cases (Byzantine crypt, temple and bronze sculpture) in preparing multimedia products for cultural heritage interpretation and entertainment. Also, J.-A. Beraldin *et al.*, in [49], is looking at the opportunities and challenges created by new 3D technologies introduced recently in the context of virtual reconstruction of cultural heritage sites for preservation and entertainment. In this domain, A. Koutsoudis *et al.*, in [5], declare that low complexity 3D models with detailed textures provide enough realism if the main purpose of the virtual reconstruction is the promotion of the culture and not an accurate documentation for archiving or restoration purposes. In this article a 3D virtual reconstruction of a settlement has been achieved by using ordinary digital cameras and freely distributed software. Similar to the approach of Neto and Amaral [4], the data achieved was also supported by a simple Web site including a photo gallery. G. Atese *et al.*, in [6], discussed the dynamic 3D representations of architectures as a flexible design tool. Also, in this article a modeling application for an old town is presented. J. Lewin and M. Gross, in [7], have studied the limitations of 2-D sketching in traditional recording, documenting and representing methods and techniques used in archaeology. Also, in their study on 3D modeling of archaeological sites they observed insufficiency at the 2-D archaeological site drawings; because the computer-based applications in archaeological documentation are restricted to the creation of databases, image processing, artefact modeling and statistical analyses. So, in order to add more visual functionality they introduced charts, axonometric views and rendering techniques of the archaeological site. H. Yilmaz *et al.*, in [12], discuss the digital documentation of the historical shelter structures known as "caravansaries". In this article, low-cost digital close range photogrammetry equipment was used.

In the *enriched metadata-based 3D modeling for CHM* open research issue, the literature is restricted to just few papers or conference announcements. In this domain, S. Potier *et al.*, in [8], present a computer graphics methodology as an assistance tool for archaeological hypotheses. In this study, the storage and consultation of the archaeological archives, the communication functionality, the exchange of information, and finally the creation of a virtual museum for the ancient part of a historic city are presented. But, the software used, in this project, was an expensive one rich in 3D parametric modeling utilities.

In the *personalized e-learning methodology frameworks* concept, literature is expanded continuously. In particular in the common CAD/e-learning domain, a number of papers is dealing with modern, flexible and more effective CAAD tools and methodologies which could assist archaeologists and architects, and the affordances they provide do change the theory and the practice of the 3D modeling-based site documentation itself; suggesting fundamentally new ways of thinking about the modeling domain (archaeology, architecture or design) and the learning (personalized e-learning) functionalities [1,2,13,14,15,16]. In this area, P. Neto and M. Amaral, in [4], report on the CAAD/e-learning domain for architectural studies. In the *personalized e-learning CHM scenarios* open research issue, according to our knowledge, there is no literature.

Finally, more details about the paper's case study cultural site (the Galerius Palace "Octagonon" in Thessaloniki) could be found in [33,39] and particularly in [11], where I. Papayianni discusses the European Union funded restoration procedures of the Galerius Palace started in 1994 and finished in 2007. This article, published in 1999, provides valuable information for the Galerius Palace archaeological site and the "Octagonon" as well.

1.3. Paper contributions

The main contribution of this paper is:

- the presentation and documentation of a metadata 3D modeling-based CHM application case study rich in e-learning functionality (4^{th} Section).

Also, the following concepts would be regarded as additional contributions:

- the introduction and the formal definition of the new term *3D modeling metadata for CHM* (2nd Section);
- the discussion of both the *e-learning scenarios* and the *personalized e-learning methodology frameworks* suitable for CHM (3 rd Section);
- the presentation of a particular five levels *3D modeling metadata schema* for a CHM case study (4.2 sub-Section); the merging of both the 3D modeling and the learning technologies in a personalized e-learning CHM schema (4.3 sub-Section); and the development of a -specific to cultural heritage applications- HCI (Human-Computer Interface) dialog environment for virtual CAAD camera and fly-through productions (e.g. video-on-demand animation sequences, augmented and virtual reality walk-throughs, etc.) (4.4 sub-Section).

1.4. Paper organization

The remaining parts of the article are organized as follows: In Section 2 (*Cultural heritage digital documentation management: Metadata & 3D modeling*), the new term "*3D modeling metadata for CHM*" is introduced, described and defined. In Section 3 (*Cultural heritage digital documentation management: Database server implementation with e-learning functionality*), e-learning scenarios and personalized e-learning methodology frameworks, suitable for CHM, are presented. In Section 4 (*A 3D modeling metadata based CHM case study: The Galerius Palace "Octagonon" in Thessaloniki*), a CHM case study is presented related to: (a) the architectural recording (history, photography, etc.); (b) the new approach on using 3D modeling metadata in demolished or semi-demolished historical sites; (c) the 3D model-based digital documentation topics: CAAD layering (object's logical segmentation), 3D geometry (modeling) and visualization (materials, texturing, lighting and rendering); and (d) the e-learning and the HCI-dialog based VR with video-on-demand functionality.

Finally, in Section 5 (*Conclusions*), the embedded metadata and learning functionalities, the advantages and limitations, as well as the possible future extensions of the proposed *3D modeling metadata for CHM* methodology are discussed.

2. Cultural heritage digital documentation management: Metadata & 3D modeling

In general, most of 3D modeling applications specify twelve requirements: high geometric accuracy; user-friendly interaction environment; all details capturing; quality photorealism; virtual video on demand; high automation and low user interaction; portability; low cost; model size efficiency; personalized e-learning functionality; networking (Web/Internet, Intranet) support; and application flexibility. The order of importance of these requirements depends on the application's objective. So, for digital geometric (or architectural) documentation applications the *geometric accuracy* and the *all details capturing* are at the top of these requirements, whilst for virtual tourism the *virtual video on demand* and the *quality photorealism* deserve special care, and for cultural e-courses the *personalized e-learning functionality* and the *networking (Web/Internet, Intranet) support* are the most important requirements.

A single system that can satisfy all these twelve requirements is still in the future. In particular, accurately capturing all details with a fully automated system for a wide range of objects remains elusive, as well as elusive remains a system for 3D virtual reconstruction of demolished buildings, when only one uncalibrated photography is available and the building capturing geometry is not rich enough. Refs. to Sabry F. El-Hakim *et al.* [19], as well as to [20,21,22,23,24,25,26,27,28] for the geometry-based, image-based and range-based available 3D modeling techniques and relative real-world applications.

In CHM, the systematic use of 3D modeling for digital documentation and conservation has started relatively recently [45,46,47,48,49]. But, so far, there is not an acceptable metadata standard, mainly, because of the difficulties to integrate and connect semi-demolished 3D-world sites with available 2D and multimedia data. Obviously, a metadata standard could be extremely powerful tool for monitoring, restoration, conservation and improving identification purposes.

In this domain, the term "*3D modeling metadata for CHM*" is introduced and is defined as "*an open architecture interdisciplinary ASCII structure, with networking functionality, of any available historic data, incoherence, evidences and 3D CAAD software routines for CHM, research, policy formation and e-education*".

Literature review

In traditional archaeological documentation projects the recorded archaeological data are not consistent (in quality, appearance, material or structural typology, etc.). So, usually, the data collected in cultural heritage excavations, are not conducive to any kind of modeling (archiving/data base, 3D, 4D, GIS, etc.). Hence, in most of the cases, the selected information is not sufficient for 3D modeling based cultural heritage digital documentation applications.

R. Kadobayashi *et al.* [21] in their project for 3D modeling of Byzantine ruins faced many problems on gathering, archiving (image data bases) and post-processing the selected data. This is because, digitizing systems and CAAD modeling methods used to document the unroofed historical sites like the desribed one, require more data and well-defined relations and conditions regarding materials and structure typology and external factors like heat, sunlight and noise.

On the other hand, the metadata analysis and interpretation of the excavated data could provide sufficient archaeological and design local knowledge [13,18]. In this domain, S. Potier *et al.* [8] explain the pre-modeling processes as follows: "*The archaeological context is analyzed, the principles of archaeological analysis are explained, and then the principles governing the studied architectural reconstruction are discussed*".

The aim of making the archaeological and architectural analyses is to determine which elements guided the original conception and construction of the structure, so that they support the accuracy of the 3D model in the following stages. Since the progress of the excavation cannot be repeated and the surroundings change continuously, the excavation has been recorded by collecting multi-temporal imagery regularly for photogrammetric documentation and modeling. So, according to H. Haggrén *et al.* [17], the objectives of a photo-realistic 3D modeling are as follows: to document the archaeological excavation; to visualize the process of the excavation during the archaeological work; to support archaeologists in their analyses; and to present the process of the excavation as a multi-temporal 3D model.

The proposed *3D modeling metadata for CHM* framework is committed to providing and maintaining any -existing or incoherent- CHM 3D modeling information in a timely and accurate manner and has four components:

a) the first component, named '**content**', is for the heritage data organized as *items* (i.e. imagery, historical documents, incoherent trace evidences, *dxf* files, etc.) and grouped together for convenience on *schemes*, like monument type, monument typology, etc. They are implemented as XML metadata documents;
b) the second component, named '**CAAD handlers**', is based on *3D models* developed by a number of specialized for CAAD routines for 3D modeling under the interchangeable ASCII format *dxf*;
c) the third component, named '**learning**', is based on the *CAAD CHM learning objects* and it is for (personalized) Internet-based e-learning support; and
d) the fourth component, named '**indexing**', is based on maintained *worldlists* and *tools* and it is for the XML application software used in comprehensive and consistent indexing of different aspects of the built and demolished heritage site, using the various *items*,

schemes, *3D models* and *CAAD CHM learning objects*. The 'indexing' part complements the definitions of the individual *items* and *schemes* about a cultural site, cultural event or cultural resource. In this part, SQL tools should support queries for specific *logical questions* like: "*What is this Byzantine crypt? (nature)*", "*How old is this Ottoman bath? (age)*". Also, in this part, dialog boxes will support data-entry procedures using specific HCI forms, which guide the recording procedure for the *items* involved (like nature, age, etc.).

The main purpose of the proposed term is to support interoperability, i.e. to allow everyone (scientists from many disciplines, e-students, etc.), throughout the world, to access the CHM database and the virtual heritage site. Actually, the goals and objectives of the proposed *3D modeling metadata for CHM* structure are:

- to support interoperability and to facilitate and maximize data sharing, standards, and intergration;
- to incorporate imagery, metric and qualitative multimedia data in a Main (or Master) Application File (MAT) that is updated regularly;
- to support identification and documentation of any available incoherent trace evidences;
- to perform modeling splits, combines, and insertion of incoherent 3D traces;
- to improve CHM incoherent information quality and accuracy;
- to support archaeological analysis and architectural restitution;
- to help hypothesis formulation for archaeological and architectural digital reconstruction;
- to allow scientists from different disciplines to integrate different archaeological and architectural features and physical contexts for better documentation and understanding of the site area;
- to support structures with Web/Internet publication functionality(e.g. XML schemas).

The main outcome of the proposed *3D modeling metadata for CHM* issue is an FGDC (Federal Geospatial Data Committee) compatible and acceptable in modeling accuracy 3D model, in DXF (Digital Exchange Format) vector format, of the heritage site or the process (ruins' temporal position, structure pathology and pollution, geometry time-based estimation, etc.) being described. Actually, the benefits of the proposed issue are:

- the FGDC compliant 3D model;
- the flexibility in and the enhancement of 3D data delivery and services;
- the elimination of redundancy regarding trace evidence incoherency;
- the CHM data capturing at once and at the source (heritage site).

Conclusively, the proposed *3D modeling metadata for CHM* modeling approach includes both the traditional architectural (archaeology) documentation [6,7] and the digital one [2,3,19,37,48,49]. The cultural heritage sites are known as spatial-based artefacts, ruins, monuments and archaeological sites that involve time, morphogenetic 3D elements, processes and events that have been destroyed, exist or will occur [2]. Despite the fact that such "living" systems are too complicated, with significant 3D geometry-based complexity, they could be profit from *3D modeling metadata for CHM* based digital documentation procedures rich in e-learning functionality [29]; and this is the case of the proposed e-learning methodology in Section 3.

3. Cultural heritage digital documentation management: Database server implementation with e-learning functionality

After defining the *3D modeling metadata for CHM* term in Section 2, this Section is about the CHM database server implementation for synchronous, asynchronous and cooperative learning environments support. The operative basis of this implementation is the cultural site's 3D model; built according to the *3D modeling metadata for CHM* specifications.

The main streams of the proposed CHM database server implementation are defined as follows (in a client-server design framework with e-learning functionality):

- *The metadata stream (main server) & the media application sub-servers:* The metadata server is in charge with the XML files describing the CHM metadata. This is actually the main server stream; the heart of the e-learning sub-system responsible for metadata processing of the cultural objects. Also, two additional media application sub-servers are needed; an application sub-server for materials and structures typology metadata and an application sub-server for MPEG multimedia data. These application sub-servers must be able to provide metadata (i.e. historical reports, architectural records, ruins and modeling details, etc.) for learners and researchers on real-time. Also, these sub-servers must support materials archiving in repository (i.e. material palettes) which then can be searched by researchers or learners (e.g. students in archaeology or architecture, etc.);
- *The e-learning stream (application client server)*: This e-learning client stream provides the learner with additional information like explanations, proposals, hypotheses and conclusions about the monument or the historical site and its context. Also, it supports walk-through functionality, fly-through productions, as well as chatting and blogging on a learner-to-learner or learner-to-teacher basis. The community user profiles and the personalized learning scenarios are maintained in this application client server. Also, this e-learning stream includes the metadata interpretation, the system's operation manual and any teaching materials;
- *The visualization/VR stream (client server) & the CAAD application sub-server*: The visualization/VR client server gets requests from clients through the related CAAD application sub-server. Then, it accesses the 3D modeling data (stored in *dxf* format) and the related *dxf* metadata to handle the modeling requests. After that, it sents back to the clients the 3D modeling responses via the CAAD application sub-server as well. Actually, this is a client stream, which includes virtual reality and haptic rendering tools. It is related directly with the *e-learning stream*, as it includes virtual and resource classrooms, chat rooms, virtual museums, etc.;
- *The HCI-GUI stream (client server)*: This is also a client stream, which includes a graphical user interface (GUI) for metadata analysis, design knowledge and 3D modeling in an easy-to-use way [1,13,18,35]. So, after the learner's *logon* to the system, he can control the learning process on focusing on particular metadata and 3D modeling details of the ruins or the historical structure using the keyboard or the mouse. Evenmore, using this stream the learner can also communicate on-line with other learners (e-students);
- *The Web/Internet portal stream (client server)*: This is actually a Web application client stream, which supports the Web functionality of the proposed client-server framework communication schema and provides the Internet-based clients with the requested data about the cultural objects (requests & responses via Internet). Actually, this client server operates as an integration networking platform for the entire digital CHM documentation.

The CAAD CHM learning objects

An interaction between the described CHDDM method and an e-learning course in architecture, archaeology, computer modeling, etc. is conceivable and desirable. Furthermore, such a system could be supported by *CAAD CHM learning objects* embedded into the host CHM system.

These *CAAD CHM learning objects* include knowledge on architectural styles, materials and structure typology, construction techniques and methods, incoherent data, and material details of the historical structure. Even more, in an e-learning CHDDM environment, *3D modeling metadata* based routines -adapted accordingly to special features of the site- could be manually selected (online) by the Internet user. Then, the modeling of the discrete architectural elements could be used for the digital (virtual) 3D representation of the host historical structure throughout a CAAD software environment.

The Personalized e-learning CHM methodology framework

The CHM required personalized e-learning framework can be well supported by the proposed open client-server architecture and the *3D modeling metadata* based 3D model. Hence, diverse user communities from different disciplines could *login* with their own user profiles. Then, through the user management software they are assigned specific roles and access rights at different levels (privileges). For instance, managers might have the right to revise any wrong data-entry process, architects, archaeologists and e-students could create their own collections of *CAAD CHM learning objects* for various learning purposes and so on. Also, their interactive behaviors on CHM might be updated and recorded into their own user profiles.

The pedagogical strategy of the proposed CHDDM e-learning framework is based on encouraging and facilitating the communication and ideas exchange between the personnel involved in the metadata analysis and interpretation, design and restitution processes [29,30,31,32]. Finally, active role, interaction, group work, and design autonomy and portability are the main characteristics of any *personalized e-learning CHM scenario* implemented according to the proposed learning CHM schema [4,7,14,15,29].

The creative use of an e-learning platform strengthened students' capacity to work as a team and encouraged them to adopt a more active role in the learning and the professional processes as well. In this domain, a CAAD-oriented site should be used, where data storage, sharing of information, and students Web sites and blogs are placed and addressed. So, by using an e-learning operator agent, every student or tutor could create or visualize (either online or offline) the common CAAD model in a collaborative CAAD design environment.

4. A 3D modeling metadata based CHM case study: The Galerius Palace "Octagonon" in Thessaloniki

This Section is about an application case study regarding the e-learning documentation of the Galerius Palace "Octagonon" cultural heritage site (Thessaloniki, Greece). So, in sub-Section 4.1 the architectural recording (history, reasoning and relative photography) of the host environment (the Galerius Palace site) is presented. In sub-Sections 4.2 and 4.3 the 3D modeling metadata structure and the 3D (geometry) model-based digital documentation of the cultural heritage site ("Octagonon") are described respectively; and finally in sub-Section 4.4 the e-learning and the VR functionalities of the Galerius Palace complex (following a metadata based 3D modeling procedure rich in visualization) is documented.

4.1. The Galerius Palace "Octagonon": The architectural recording (history, reasoning and photography)

The Galerius Palace complex (archaeological site) lies at the down-town area of the City of Thessaloniki for more than 1,700 years. It was built during the Roman period by the Emperor Galerius circa the 4^{th} century AD and was named after him. Interested readers may find more details, in [11], from the work of F. Athanasiou and M. Karaberi in [33] (editor: the 16^{th} Greek Ephorate of Prehistoric and Classical Antiquities), and from the Web/Internet-Wikipedia (http://en.wikipedia.org/wiki/Arch_and_Tomb _of _Galerius). Actually, the ensemble of the Palace was built around 300 AD in the south east part of Thessaloniki

The Palace was a political and religious center and consisted of the Tomb of Galerius ("Rotunda"), the Arch of Galerious ("Kamara"), the "Octagonon", the Basilica, the Colonnades, the Roman Baths and the Hippodrome.

The restoration project of the Palace started in 1994, funded by the European Union and the Greek government and finished in 2007 [11]. Today, many ruins of the complex can be found in the area. The main excavations started in 1939 but were stopped shortly because of the 2nd World War; then they were carried on after almost a decade. The complex in the past covered an area of 18 hectares (180.000 m^2), however at present most of it is buried under the new building constructions at the Navarinou Square, Thessaloniki.

The Palace was erected on the outskirts of the City close to the Hippodrome and near the eastern walls. The excavations in the area of the Navarinou Square have brought to light a slightly asymmetrical central peristylar courtyard (colonnades), with rooms along three sides, being surrounded by corridors with mosaic floors [33]. There is a two storied barrel-vaulted building at the east of the central nucleus. Next to this building, an oblong-apsidal chamber (Basilica), facing northwards, shared a wall with the west side of the Hippodrome. The southeastern part of the site was occupied by the Roman Baths, where the imperial family would take their ease [11,33]. Next to the Baths was a monumental flight of marble steps which was the main entrance to the Palace at the sea end. At the west of the steps was the "Octagonon" which had a double-apsed elliptical antechamber.

As a throne-room serving various purposes (e.g. audiences, ceremonies and official banquets), the "Octagonon" reflected in its centrally-planned form the tetrarchical perception of the Emperor as ruler of the world. Recent excavations have shown that it was directly connected, via its monumental antechamber and two-columned propylon, with an oblong peristyle of a public nature and with the Emperor’s private harbour.

The "Octagonon" owes its name to the shape of its ground plan. It has an area of 875 m^2 and seven semicircular apses inside. The north apse, opposite the entrance, is larger than the others and its masonry has a brickwork ornament symbolizing the victory of the cross. The difference in size is due to the fact that the apse was reconstructed, probably in the first half of the 4^{th} century, when the "Octagonon" was converted into a church.

The chamber was roofed with a vault (i.e. a ceiling that is made of several arches joined together at the top) 23 m in diameter with two spiral staircases leading up to the base. The staircases were located on either side of the entrance to the vestibule. The keystone of the vault was 29 m above the floor. The chamber was splendidly decorated and its walls faced with slabs of coloured marble laid in horizontal rows of varying height.

The "Octagonon" was covered with coloured and white marble, which formed simple geometrical motifs. Oblong marble slabs in the central part formed panels symmetrically arranged on either side of the notional line between the entrance at the south and the north apse. The panels contained red and white tiles laid in a checkerboard pattern or large slabs of different sizes and colours. The apses were paved with large white and coloured slabs of marble.

4.2. The Galerius Palace "Octagonon": The 3D modeling metadata structure

In this sub-Section, first the data forming the basis of the "Octagonon" modeling study are examined as primary metadata, then the principles of both the archaeological analysis and the architectural restitution are presented (secondary and tertiary metadata), and finally the *archaeological hypothesis formulation* (fourth-level metadata) and following the *architectural reconstruction hypothesis formulation* (fifth-level metadata) are documented. Then, this *Architectural hypothesis formulation* is used as the basis for the enriched metadata-based 3D modeling procedure.

Metadata are very useful in documentation procedures regarding time-based structures like cultural heritage sites or historical monuments [1,2,3,9,34]. Obviously, the metadata approach is useful on 3D modeling projects of demolished or semi-demolished cultural heritage sites or monuments [18,19].

The primitive data (primary metadata)

For the discussing case study, the primitive data forming the basis of the 3D modeling study were: recent and historic photography; plans, cross-sections and drawings from the 16th Greek Ephorate of Prehistoric and Classical Antiquities; geometric clues (parallelism, orthogonality, perpendicularity, planarity and symmetry); topology (planar, space); and available text documents written before or after the recent restoration project.

In the proposed cultural heritage documentation methodology, all these data are characterized as primary (first level) metadata. For photography, the Nikon E3500 an amateur digital camera was used, whilst camera's focal length was kept unchanged for all the photography campaign [1,3]. Also, for documentation purposes, the weather conditions, hour and date information, and all the camera pose and orientation estimations are archived as first level (primary) metadata.

Following, on putting all these data on the table, the historic traces (e.g. incoherent traces in a masonry wall) and the geometric clues were verified by a constant comparison with the available plottings and historic text documents [3,8,40,41].

Archaeological analysis - The principles (secondary metadata)

For the discussing case study, the goal of the archaeological analysis was to identify those needs and principles which should guide: the initial conception and ideas, the architectural influences, the material characteristics and constraints, the experience of the architects, engineers and build-workers, and then the design rules and the construction procedure of "Octagonon" in the 4th century AD. Obviously, many of these needs and principles are hypothetical, whilst some others obey certain constraints and coherences.

Then, after analysing and documenting these needs and principles, the resulted archaeological analysis consistency provides the architectural restitution with a kind of "*local knowledge of construction rules and conditions*" coming from the past. These *local knowledge* data are the secondary metadata of the proposed cultural heritage documentation methodology.

Architectural restitution - The principles (tertiary metadata)

For the discussing case study, the architectural restitution approaches (tertiary metadata) rely on validating, formulating and composing the secondary metadata. So, the architectural restitution was actually a number of syntheses according to the "*local knowledge of construction rules and conditions*".

In the proposed methodology, the architectural restitution follows a number of principles from the history of architecture, as well as relative experience, in order to identify (or to approach), to validate, to formulate and finally to synthesize the structural and morphological characteristics of the cultural heritage object (e.g. "Octagonon"), the water and sewing sub-systems, the masonry walls, the roofing (domes), etc.

Archaeological hypothesis formulation (fourth-level metadata)

For the discussing case study and according to the selected architectural restitution synthetic approach, the archaeological hypothesis formulation was identified and this is the case of the fourth-level metadata (proposed methodology).

At this stage, by identifying in the amateur or architectural photography a number of incoherent, unclear and difficult to understand *traces* (but visible in photography, well accompanied by a tertiary metadata knowledge), the fourth-level metadata are documented as a "*list of the 3D modeling restrictions*".

Identifying incoherent trace evidences - An example

As an application example of the archaeological hypothesis formulation, let's consider some incoherent traces noticed on the masonry walls of the "Octagonon" (please see Fig. 1: Left images). These traces in companion with a tertiary metadata knowledge (obtained by validating, formulating and composing all the available data for the construction rules and conditions in the 4th Century AD) make any kind of planar roofing impossible for the "Octagonon". Hence, the roofing sub-system for the "Octagonon" was a dome-based one, and this formulation in the proposed cultural heritage documentation methodology is regarded as fourth-level metadata. This is actually a member of the "*list of the 3D modeling restrictions*".

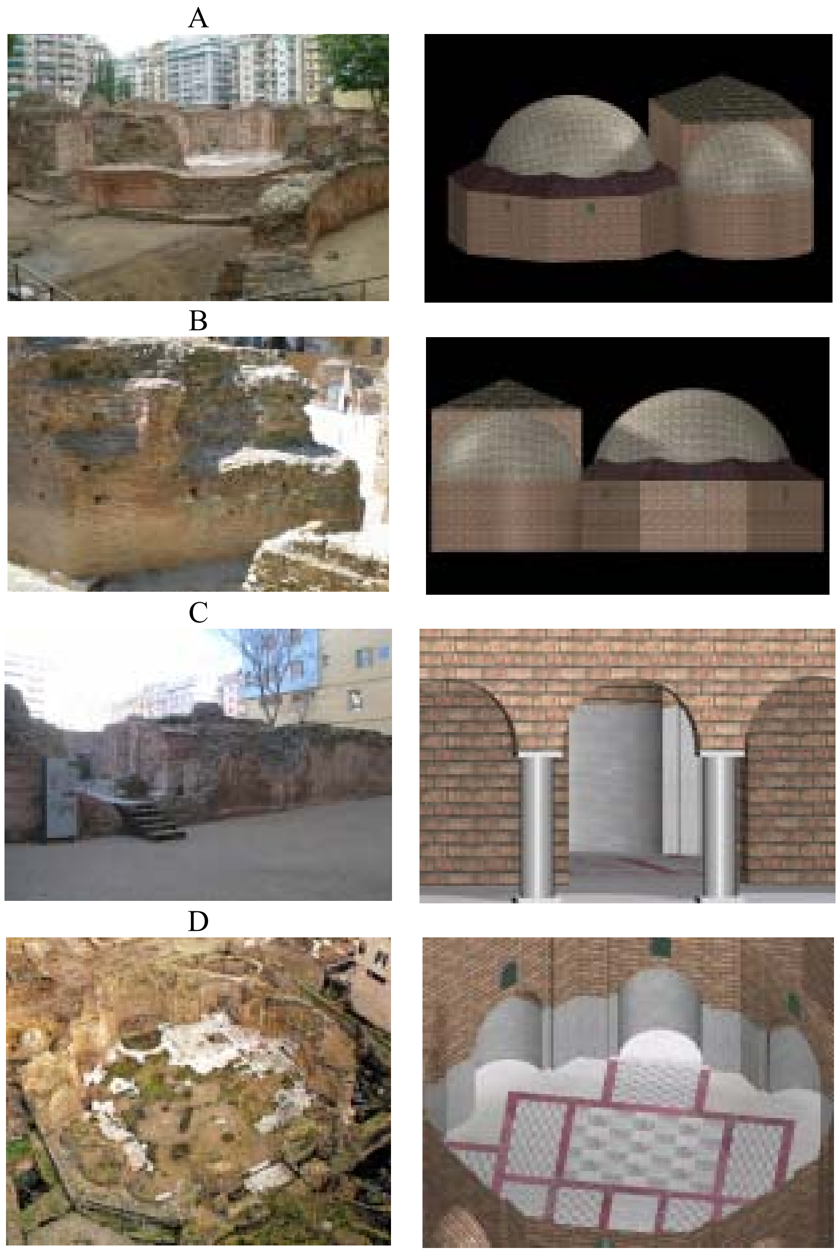


Fig. 1. Left images: Visible traces noticed at Octagonon photography; Right images: The relative 3D modeling (graphical) entities.

Architectural reconstruction hypothesis formulation (fifth-level metadata)

For the discussing case study, the architectural reconstruction hypothesis formulation was defined as a modeling interpreter of the "*list of the 3D modeling restrictions*". So, any interpretation according to this list is resulted to a fifth-level metadata element, which is actually a 3D graphical entity.

These 3D graphical entities are actually the fifth-level metadata of the proposed methodology and, obviously, they could be part of 3D modeling libraries as parametric design elements. These libraries are characterized as cell libraries in the proposed methodology.

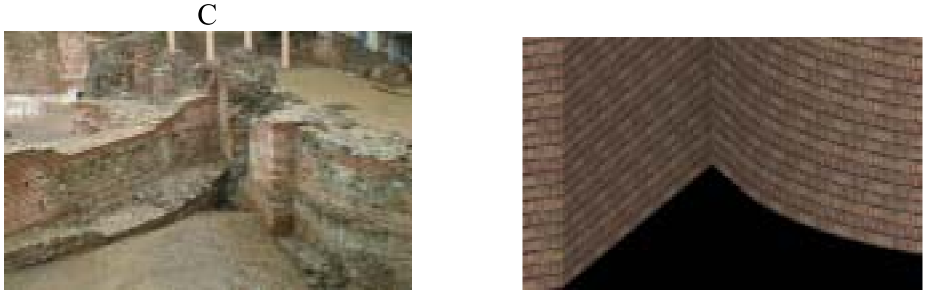
3D Modeling incoherent trace evidences - An example

As an application example of the architectural reconstruction hypothesis formulation, let's consider some 3D modeling (graphical) elements, relative to incoherent traces noticed on the masonry walls of the "Octagonon" (please see Figs. 1 and 2: Right images). Figure 2 presents in more detail the relation between the incoherent trace evidences (fourth-level metadata) and the relative 3D modeling elements (fifth-level metadata).

A

B

C



D

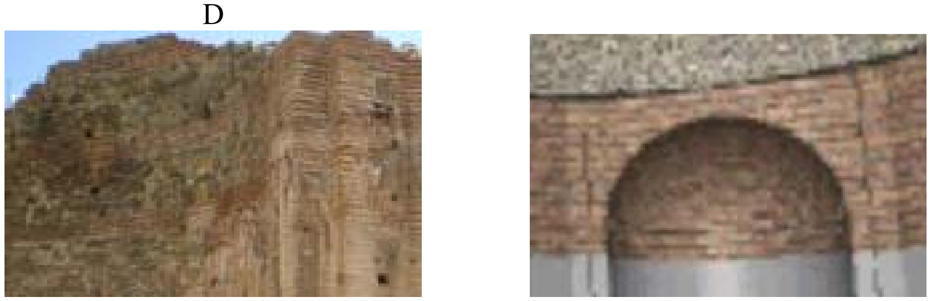


Fig. 2. An example of the incoherent trace evidences (forth level meta-data: Left images) and the relative 3D modeling elements (fifth level meta-data: Right images).

4.3. The Galerius Palace "Octagonon": The 3D model-based digital documentation (CAAD layering, 3D geometry & visualization)

CAAD layering (monument's logical segmentation)

In CAAD, the user should categorize the objects (i.e. the graphical entities in the design file) by drawing them in different levels or layers. So, at any time any number of levels can be visible or invisible depending on user's needs and considerations. Commercial CAAD software supports designing in a number of different levels [37,39,40]; whereas it is a good design practise to use different colours for each of them [13,20,21,39]. In the proposed digital documentation methodology the CAAD layering "Octagonon" logical segmentation is based on all the metadata knowledge followed by the documented principles, materials and structures typology, as well as the modeling restrictions.

In the discussed case study, the target cultural heritage object ("Octagonon") was segmented in one hundred (100) logically separated sub-structures. This segmentation schema enhances the 3D modeling procedure (by adding modeling functionality), resulting in a more flexible digital documentation and advancing any future e-learning requirement (by adding learning functionality).

3D modeling (geometry) & visualization (materials, texturing, lighting and rendering)

3D computer modeling extends traditional techniques for archaeological recording, documenting and analysing. Also, computer-based visualization, as a common design language connecting art and science, increases archaeological data and metadata functionality by displaying them in a rendered 3D design session in order to simulate better the original appearance of the site [13,14,30,32].

In the proposed methodology for the discussing case study, the fifth-level available metadata and a pre-defined level of accuracy were used for the 3D modeling and visualization procedures. Also, for modeling the "Octagonon" a 3D vector CAAD environment and the relative 3D cell libraries were used. These 3D cell libraries are actually the graphical elements of the fifth-level metadata list.

In order to increase visualization of the virtual reconstructed 3D model, a number of materials with or without texturing were used. These materials were obtained either from suitable prepared ortho-photography of relative to "Octagonon" historical structures (i.e. the "Kamara" and "Rotunda" historical monuments for the discussed case study), or alternatively from the Web/Internet.

4.4. The Galerius Palace "Octagonon": The e-learning & Virtual Reality functionalities

Galerius Palace complex: The e-learning functionality

In the discussing case study, the application e-learning client server is dealing with the user profiles metadata which include administration attributes (user name, password, role), as well as user behaviors and user content selection alternatives, in which *multimedia data* or *personalized (CAAD) CHM learning objects* may be collected according to the particular group interests. In this way, diverse and personalized learning queries (submitted by e-students) are supported by the learning behaviors and a number of content selection alternatives already developed.

The photography of the monument ("Octagonon") and its surrounding were acquired practically with a digital camera. They were required to make the modeling process with e-learning functionality easier and faster in a digital environment. The e-learning documentation is controlled by the addition of graphical, haptic and semantic information. In this case, the resolutions and the qualities of digital images are important facts for the e-learning functionality to work properly.

An interaction between the described CHM e-learning framework and an e-learning course in architecture, archaeology, computer modeling, etc. is conceivable and desirable for the future. Furthermore, such a system could be supported by the *CAAD CHM learning objects* embedded into the host CAD system. These *learning objects* should include knowledge on architectural styles, construction techniques and materials of the historical structures. Even more, a number of CHM analysis routines -adapted to special site features- could be manually selected by the e-student for parametric modeling, multimedia authoring presentations, etc.

Galerius Palace complex: The Virtual CAAD camera (Virtual Reality functionality)

The 3D CAAD model is by default a source of a number of functionalities, included VR applications, Web/Internet authoring and multimedia presentations, digital video, fly-through productions, augmented reality projects, etc. [43,44]. So, in the discussing case study, a 3D model-based animation sequence for a VR video-on-demand application was used [16,20,39]. At the heart of this sequence is the digital virtual camera of the so-called fly-through producer.

In cultural heritage digital documentation applications the VR functionality enhances the 3D model visualization and the related promotion prospects of the historical site or the monument despite the various ambiguities and inconsistencies involved in the raw site data, historic documents, multimedia data and drawings provided or the archiving metadata of the cultural heritage sites, monuments or objects [32,35,36,37]. So, for the "Octagonon" case study, a digital CAAD video function was developed and is used for e-learning applications regarding computer-based digital photography and video, as well as for video-on-demand-based animation sequences and products [30,31,35].

5. Conclusions

Historically, in cultural heritage management (CHM), the collection, analysis and management of the various textual, multimedia, spatial and 3D modeling datasets was a complex and time consuming procedure. This article reasoned out that the incorporation of the proposed *3D modeling metadata* structure in CHM, should: (i) improve the quality in access and query procedures; (ii) enhance CHM performance, and (iii) support e-learning functionality.

The article also claimed that such a CHM methodology could be supported by *CAAD CHM learning objects* embedded into the host CAAD system. These *CAAD CHM learning objects* include knowledge on architectural styles, incoherence, materials and structure typology, construction techniques and methods, and material details of the historical structure. Even more, in an e-learning cultural heritage digital documentation, metadata based 3D modeling routines adapted accordingly to special features of the site could be manually selected by the Internet user. Then, the modeling of the discrete architectural elements could be used for the digital 3D representation of the host historical structure throughout a CAAD software environment.

The main contributions of this paper are: the presentation and documentation of a metadata-based CHM case study with e-learning functionality; the introduction and the formal definition of the new term *3D modeling metadata for CHM*; the discussion of both, the *e-learning scenarios* and the *personalized e-learning methodology frameworks* suitable for CHM; the presentation of a particular five levels 3D modeling metadata schema for a CHM case study; the merging of both, the 3D modeling and the learning technologies in a personalized e-learning CHM schema; and the development of a specific to cultural heritage applications HCI (Human-Computer Interface) dialog environment for virtual CAAD camera and fly-through productions (e.g. video-on-demand animation sequences, augmented and virtual reality walk-throughs, etc.).

The advantages of the proposed method are: the metadata schema and hence the 3D model future portability [18]; the e-learning, haptic rendering and virtual reality easy-to-implement extensions; and the 10^{-2} modeling accuracy (i.e. a 1% relative error or inaccuracy) which make it suitable for promotion-oriented applications in archaeology, architecture, virtual reality, e-learning and virtual tourism. On the other hand, the main limitation of the proposed methodology is the relatively large level of the modeling inaccuracy in case of site geometry accurate reconstruction and renovation projects.

Possible extensions of the proposed method include: the cultural landscape functionality [19,20,50]; the collaborative Web/Internet-based CAAD environments [1,14,15]; the memetic engineering e-learning technology [38]; the automated procedures in close-range architectural photogrammetry [39,40,41]; and the related GIS applications (cultural heritage digital documentation with spatial functionality, Community Cultural Information Systems) [2,42,45,46]. Also, an interaction between the described digital documentation method and an e-learning course in architecture, archaeology, computer modeling, etc. is conceivable and desirable for the future.

Finally, for future research in CHM: the *historic incoherent evidence data enrichment* for architectural reconstruction hypothesis formulation [8]; the relation between the Web collaborative engineering modeling (*Web-based concurrent CHM*); the new haptic rendering equipment and software [14,15]; the *spatio-temporal CHM databases* [2,42] and the *e-learning functionality in Community Cultural (Heritage) Information Systems* [45,46], must be examined, formulated and documented.

Conclusively, a personalized e-learning CHM methodology framework, within a metadata-based 3D virtual environment, is proposed to give active roles to many different users (scientists, archaeologists, architects, history researchers, e-students, etc.) by integrating metadata and 3D modeling with synchronous, asynchronous and cooperative learning environments.

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