

# TOWARDS AN INTEGRATION OF DOCUMENTATION, INFORMATION AND MANAGEMENT SYSTEMS IN A COMMON FRAMEWORK

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**KEY WORDS:** Multidimensional GIS, Multi-resolution models, CityGML, Building Information Modelling, OGC Web Services

## ABSTRACT:

Three-dimensional modelling of urban environments is increasingly in a very fast way, and there is a diversifying demand of services and applications closed to virtual reality. The large diversity of formats, tools and products poses the need of developing software tools for sharing and exchanging information from context recognition. We propose an approach for system architecture composed by three subsystems to achieve this goal: Documentation, Information and Management System. CityGML provides a common framework for representing 3D urban object integrating different modules that involves extensions of traditional urban GIS. In this paper we introduces GIRAPIM, a software tool that implements these approach providing advance visualization, remote repository management and CityGML export features. We illustrate results with a case study applied to a small urban district of the city of Segovia (Spain), inside the framework of the PATRAC Project.

## 1 INTRODUCTION

The increasing demand of services from larger communities of users, including administration, enterprises and citizens linked to Urban environments poses new challenges for integrating modelling and software tools. There are a lot of standing problems related to access, interoperability and reinterpretation of data in different repositories containing heterogeneous information. In the absence of a common reference model, it is commonly acknowledged the need of specifying a vocabulary or an ontology [Gruber et al., 1993, Guarino, 1998]. However, each repository has its specific ontology in the Semantic Web framework, and we have not still good tools for reinterpreting an ontology in terms of another one in pure logical terms; it would be necessary to develop a wider ontology (see *Towntology* in [Keita et al., 2004]) able of translating and reinterpreting the implicit knowledge contained in different repositories. In view of this limitation and in the meantime, it seems convenient to develop a less conceptual approach, by taking a functional approach which is based on the different systems from which the knowledge can be managed and reinterpreted.

This work intends to contribute to the functional approach by specifying the most relevant aspects concerning the articulation between Documentation, Information and Management (DIM) Systems. In the same way as for GIS, all of them have a common reference to geodatabases, which provide a geometric support shared across DIM Systems. Instead of proposing a content exchange extracted from entity-relation diagrams involving the representation of embedded knowledge, we propose a development based in functional aspects extracted from a common reference. In other words, we propose a physical-centric approach instead of a logical-centric approach, where physical refers to the physical domain involving urban objects, including 'occupied' (buildings, e.g.) and 'empty' places (squares, streets, parks, rivers, etc). In this way, the physical domain becomes a 'living object' where exchange of information between different agents are holding in a continuous way.

We are not intending to formulate a general theory of such eour-

ban system (in terms of multi-agent systems, e.g.), because this goal requires more detailed studies and some developments from Adaptive or Evolving Complex Systems Theory [Holland and Miller, 1991]. Our real goal is more modest and it is focused towards to achieve better performance between tools for managing different systems as an intermediate stage for improving the quality of life of citizens. The integration of DIM systems is performed in the software application GIRAPIM which supports advanced functionalities linked to hybrid modelling (from image and range-based information), CAD export and advance visualization, between others.

The rest of the paper is organized as follows. The second section is devoted to expose some general ideas about the integration of Documentation, Information and Management Systems (DIMS), following a coarse functional approach. Next, in the third section, we develop some ideas about relational databases which seem the most appropriate solution, not only for traditional DIMS, but also for simulating the expected transformations holding in urban issues. CityGML [Kolbe and Groger, 2003, Kolbe et al., 2005, Kolbe, 2008] provides a general framework for Documentation and Information Systems; this framework can support additional functionalities in management systems, which are developed in the fourth section. The resulting structure needs the development of powerful visualization tools which is developed in the fifth section; here, advanced visualization is not only a way of interactive navigation, but a way of manage information, generate automatic reports, etc. We illustrate our approach with some urban districts in historic cities, which can be explored with Google Earth. Instead of providing answers, this paper proposes more challenges which are reported in the final notes as provisional conclusions and future research guidelines.

## 2 A FUNCTIONAL APPROACH TO DIM SYSTEMS

In this section, we give a general overview about the three main components of DIM system involving Documentation, Information and Management Systems, and their integration, with a special regard to urban cities. Figure 1 shows the conceptual archi-

ture of DIM Systems. We adapt the methodology developed in CityGML by Kolbe, T. et Al. where they do a basic distinction between five levels of detail (LoD) sharing a common geometric support (corresponding to the environment) and a common vocabulary.

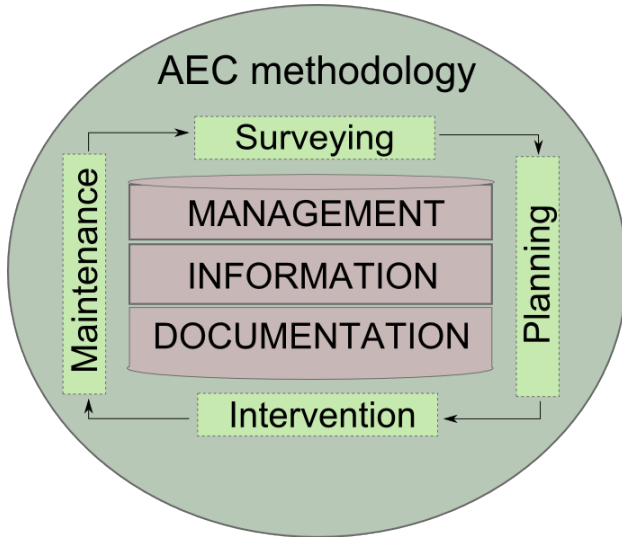


Figure 1: Conceptual organization of 3D DIM Systems

## 2.1 Documentation Systems

The main goal of Documentation Systems is to provide a common model for data repositories able of supporting more advanced functionalities linked to the Information and Management Systems. The model is usually provided by a 3D digital object which is modelled from image- and range-based data. Over the 3D model it is possible to overlay data captured with any kind of non-destructive techniques (NDT) involving acoustic, termographic, radar or another technologies. The protocols arising from photogrammetry for building surveying can be extended in a natural way to documentation extracted from application of NDT. Thus, this provides the geometric referenced support, basis for superimposing additional Information Systems or for planning interventions in the framework of Management Systems (see below).

There is an increasing amount of materials related with the application of this methodology to Architecture, Engineering and Construction (AEC [Khmlani, 2010]) environments. From a functional viewpoint, the most important aspect is the design and implementation of data repositories for identification of location of meaningful elements to make easier their updating and reuse along the entire life cycle of the whole building. Each data belonging to the repository has a collection of attributes (including metadata or corresponding to raster information, e.g.) or parameters (corresponding to vector information, e.g.) which are stored as an array. Restricted queries can be implemented by selecting an attribute or a specified value for a parameter, to generate a report which includes a low-level knowledge corresponding to the Documentation System.

Following the same functional approach and for making easier the visualization of knowledge discovery techniques, we adopt a matrix representation of the resources (basic cells as spaces, NDT and SDT as resources, e.g.) in the Documentation stage for 'similar objects' in AEC environments. Each non-null entry of the matrix includes a link to the referenced documents related with the surveyed object, including different multimedia documentation. The above notion of 'similarity' requires additional developments which are not still enough formalized.

## 2.2 Information Systems

Geographical Information Systems (GIS) provide a very useful methodology for Information Systems in AEC environments. Usual GIS methodology subordinates raster information to vector data; it has been applied to different scales or representation level, to improve the understanding of the environment (see [Emgard and Zlatanova, 2007]). The hierarchy between vector and raster data typical of GIS is translated in AEC environments to a representation of structural aspects involving the building before identifying materials. From a functional viewpoint, the integration between Documentation and Information systems involves verification of requirements (internal law), exchange (functional symmetries), sharing (possibility of composing between different components) and transformation methods (linked to processing and analysis tools).

These methods are represented as 'resources' available in a digital representation of the physical space from Documentation System which are recombined through 'internal operations'; such operations are characteristic of the Information System. In other words, and from the functional viewpoint, we can represent such operations (involving 'elements' of the Documentation System) as an array with  $N$  inputs. A priori, these operations can be recombined in different ways to provide Information; if we introduce a  $N \times N$  information matrix  $MI$  representing all possible pairs of operations, the information is generated by a collection of connected boxes inside the matrix. In particular, the  $m_{ij}$  box represents the result of applying the  $j$ -th operation to the  $i$ -th operation. A system of weights superimposed to the entries  $m_{ij}$  allows to evaluate the generation of knowledge at Information System. This simple scheme allows to represent a sequential task in Information System as a row in the matrix  $MI$ , where the non-null entries represent components meaningful for the goals considered in the task. Similarly, more complex tasks requiring the combination of different operations at different temporal stages (including different feedback or feedforward procedures) are represented by means of connected paths inside the matrix.

## 2.3 Management Systems

The Management Systems intend to support an IST-based assistance for interventions, along the four stages which can be labelled as design, planning, execution and tracking. Each task is modelled as a 'path in a space of configurations' linked to functions acting on data; the path would must be given formally as the solution of a functional whose optimization involves the Management System. However, the large diversity of situations, the heterogeneity of techniques (NDT and SDT, with their corresponding protocols) and a very limited information of best practices in AEC environments, makes very difficult the formalization of this general approach. Thus, we shall content ourselves with a weighted approach which can be interpreted as 'affine coordinates of points' representing resources to be recombined. In the preliminary version, weights are variable and can be selected by user when initializing the analysis.

Nevertheless the recent advances, there is no a software platform providing the required functionalities in AEC environments. However, the advances performed along last years for integrating Documentation and Information Systems (hybrid systems), by one side, and the enlargement of functionalities linked to the application of IST-based monitoring and tracking the state of building, on the other side, are generating a convergence between different technologies and practices. A crucial aspect for warranting this convergence is the definition of standards which are being applied to business logic in industrial production for the construction sector. A paradigm for Management Systems in AEC is

given by Building Information Modeling (BIM [Eastman et al., 2008, Campbell, 2007]), early introduced in the seventies of the 20th century, and revitalised with the incorporation of the Industry Foundation Classes [Faraj et al., 2000] from the late nineties. The development of this methodology has provided a support of increasing use for generating and managing data concerning to AEC environments during its life cycle. A relevant challenge concerns to the design and implementation of Management Systems for interventions in Cultural Heritage architectural objects.

## 2.4 GIRAPIM software architecture

In our work we have developed a prototype software tool demonstrating the earlier introduced DIM scheme able to support and implement the features for each one of the systems. This tool, called GIRAPIM, has been designed with a modular architecture composed by three main components: a *Viewer*, a *Semantic Repository* and a *CityGML manager*. The conceptual representation of the modules in the architecture is showed in figure 2. The *Viewer* is a COLLADA-based graphic engine enabling visualization, navigation and interaction with the 3D model. The *CityGML manager* is the component responsible for adaptation of semantic of the model to CityGML standard vocabulary during import and export operations.

The *Semantic Repository* is composed by a database and a multimedia document repository that streams the files stored in the remote server. The application always uses open standards in order to improve interoperability and exchange of information with Web applications. Therefore, this architecture can provide services compatible with standard navigation tools based in Google Inc. applications such as Google Maps and Google Earth which gives a large support for the new Internet-based applications.

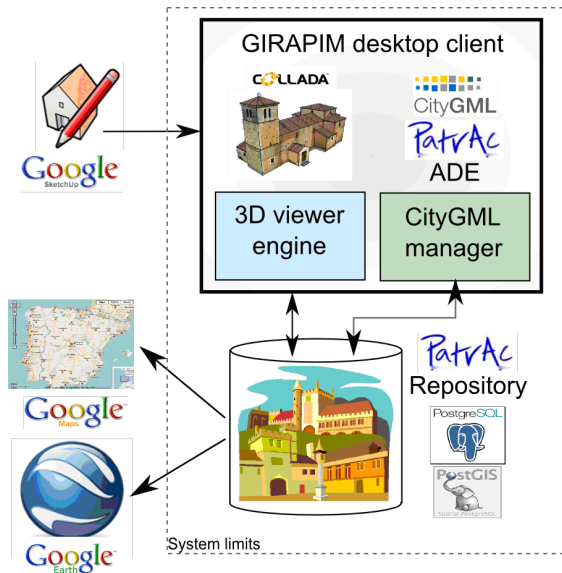


Figure 2: Overview of GIRAPIM software architecture

## 3 RELATIONAL DATABASE AS A COMMON SUPPORT

Relational databases are the traditional solution for data management due to its query engine efficiency, integrity checking, transaction control, extensibility through the PL/SQL language and large development experience. Although this databases provides support for traditional datatypes, they do not support complex data types such as images, videos, documents or geographical references and their implicit operations. For instance, PostgreSQL

[Momjian, 2001] is a Database Management System without support neither for geometric entities nor for multimedia documentation. The first limitation could be solved by PostGIS [Ramsey, 2005], a PL/SQL extension for PostgreSQL implementing the OpenGIS Simple Features Specification for SQL that includes operations and datatypes for geographical entities. The second limitation could be partially solved thanks to Universal Resource Identifier (URI) and metadata description frameworks like the Dublin Core Standards [Lawrence and Giles, 2000]. Thus, the database only stores metadata description of the multimedia resource, which is uniquely identified by the URI (see figure 3).

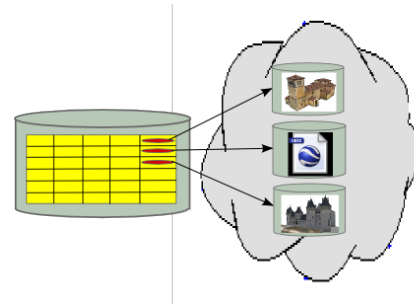


Figure 3: Database-repository conceptual scheme

In according to what explained in previous paragraph, the Documentation System can not be supported by traditional relational databases because of geometric data must be stored grouped by primitives such as points, lines, polygonal or polygons. In a similar way, the model appearance represented by textures must be saved with texture coordinates referencing the geometry. This approach introduces several issues. Firstly, it needs huge space requirements for storing vertices of the model and textures, which could be easily zipped into a file. Secondly, query performance retrieving the 3D model are bad, making very difficult a fluid visualization on the Web or on mobile devices. Thirdly, graphics engines usually load data from files but not directly from databases. These limitations make necessary to find another strategy for the efficient storage of documentation data, suitable to the client requirements.

Finally adopted solution is to store 3D model files distributed in several servers in the Web. The file is identified by its URL and the database stores information about the model in form of metadata, in the same way as multimedia resources. This is a more flexible solution since it allows loading the model and its information coming from different providers and repositories. For example, models from Google 3D Warehouse could be reused as documentation in DIM systems. Besides, the same models could be visualized in several devices able to run a COLLADA graphics engine connected to Internet. The main drawback is the loss of reliability due to URLs changes frequently and the model could be changed by the author without notice.

In order to provide data support for Information System the best solution undoubtedly are relational databases where semantic concept are efficiently managed. Then, a basic question arises, how could concepts of the Information Systems refer to the geometry of the model? The answer is not trivial. Since the geometry is encapsulated inside a file there is no way of referring to it, so we need a base support for both geometry and concepts. Geographic coordinate systems provides this support in the sense that it enables the specification of every location in the Earth with only three coordinates. Therefore, we position the model geometry and locate the concepts in a concrete point in the world. Moreover, this allows the integration of the contents from the Information System with another GIS tools for publishing the contents in the Web as figure 4 shows.

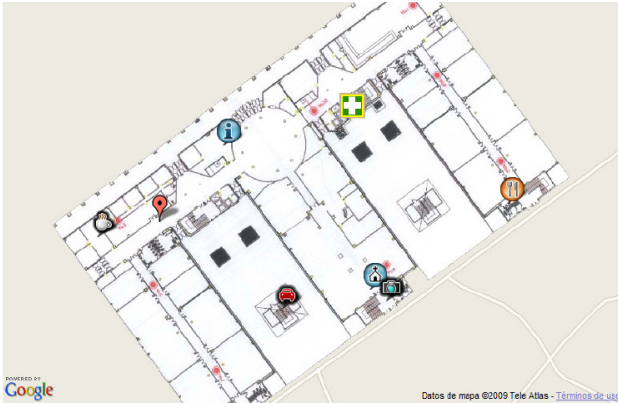


Figure 4: Example of information contents in Google Maps

The Management System overlay information about the business process over the Information System. This is translated into new entities in relational databases that refers to semantic concepts of the Information System. In this sense, there are different entity-relation schemas for each management process to be developed which can easily extend the Management System. In this work, for space limitation, we only present the schema for managing intervention processes and helping technicians to take decisions about which alternative is more suitable (see section 4).

#### 4 EXTENDING CITYGML AS GENERAL FRAMEWORK FOR DIM

CityGML is a general modelling framework for 3D urban objects with five level of detail (LoD) built on top of geographically referenced vector data represented by the GML Geometry Markup Language (GML). CityGML is extensible thanks to its underlying XML support. The mechanism of extension is called ADE (Application Domain Extension), a way of importing CityGML vocabulary into another application schema that defines its own business entities, like in [Schulte and Coors, 2008]. The standard provides the required support for both Documentation and Information System but not for the Management System, which is delegated on ADEs. The main advantage of this approach is the achieved compatibility between data from Documentation and Information System and another CityGML compatible applications.

In this work, we have developed a CityGML extension for Cultural Heritage environments to manage concepts related to 1) a laser-based fine 3D modelling of small urban zones (see [L.M.Fuentes, 2006]); 2) an intelligent reduction from a semi-automatic selection of polygons of dominant planes; 3) the completion of details with modelling tools arising from common solutions (Google SketchUp, e.g.); 4) the insertion of services linked to an ubiquitous monitoring in small urban zones with corresponding support for communications; 5) the development of interactive Visualization tools navigable with mobile devices; 6) the management of web services (including additional Multimedia contents) linked to accessibility for disabled persons. Figure 5 shows the general overview of this extension, linked to the CityGML framework inside the DIM approach.

In this way, we extend the vocabulary base of CityGML to Cultural Heritage environments, expanding the Information System basic scope. But the management facilities are not yet achieved with this extension because the vocabulary does not include any business logic entities. In order to enable Management Systems we have to define the third layer with more ADE modules built on top of the CityGML modules. This strategy follows the same

philosophy that DIMS, where the management capabilities arise in the third layer.

The 'Intervention' module (see figure 6) of this extension includes entities for modelling the interventions, the techniques for its previous analysis and the assessment of alternatives. This last is intended to provide assistance to the user in decision making through a multicriterion optimization process. In order to achieve this goal, the module includes concepts such as 'criterion', 'constraint' or 'weight' linked to 'intervention'.

The optimization process can be briefly summarized as the selection of the most suitable intervention among all available alternatives. The fitness of each alternative is evaluated with a weighted sum of values for different criterions, which are estimated from a combination of model data and expert judgement. The system evaluates every alternative displaying an intervention ranking where results are the alternatives ordered from the fittest to the less suited. During the evaluation of criterion values, the system must check that the values fulfil the specified constraints and it alert the user if it does not occurs.

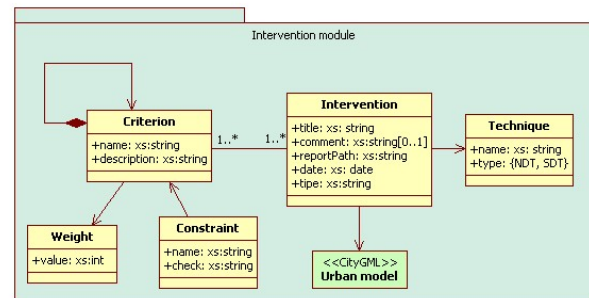


Figure 6: Intervention module in Management System

#### 5 ADVANCED VISUALIZATION TOOLS FOR DIM SYSTEMS

The visualization in three dimension of the models provides to users a natural representation of the geometric information, simplifying the human computer interaction with the urban environment. The model viewer is responsible for the visualization of data coming from the Documentation System in both vector and raster format. The vector data represents the geometry of the model, while the raster data exhibits model appearance usually documented with textures obtained from photographs.

The Documentation System requires the creation of building models with traditional modelling CAD tools such as Maya, 3D Studio or Google SketchUp. Each one has its own proprietary formats, making difficult to share, exchange and interoperate with different tools through 3D models. In order to solve this compatibility issues, the Khronos Group defined COLLADA (COLLABorative Design Activity) for establishing an interchange file format for 3D models [Barnes, 2006, Arnaud and Barnes, 2006]. Basically, COLLADA is a XML schema for exchanging digital assets among different graphics applications such as modellers, renderers, editors, etc. GIRAPIM is able to display models from Documentation System thanks to its COLLADA-based graphic engine, like figure 7 shows.

Besides, COLLADA is the underlying 3D model file format for virtual globes like Google Earth, that links the model from its KML (Keyhole Markup Language) files [Wilson, 2008]. These two file formats are open standard largely supported by different



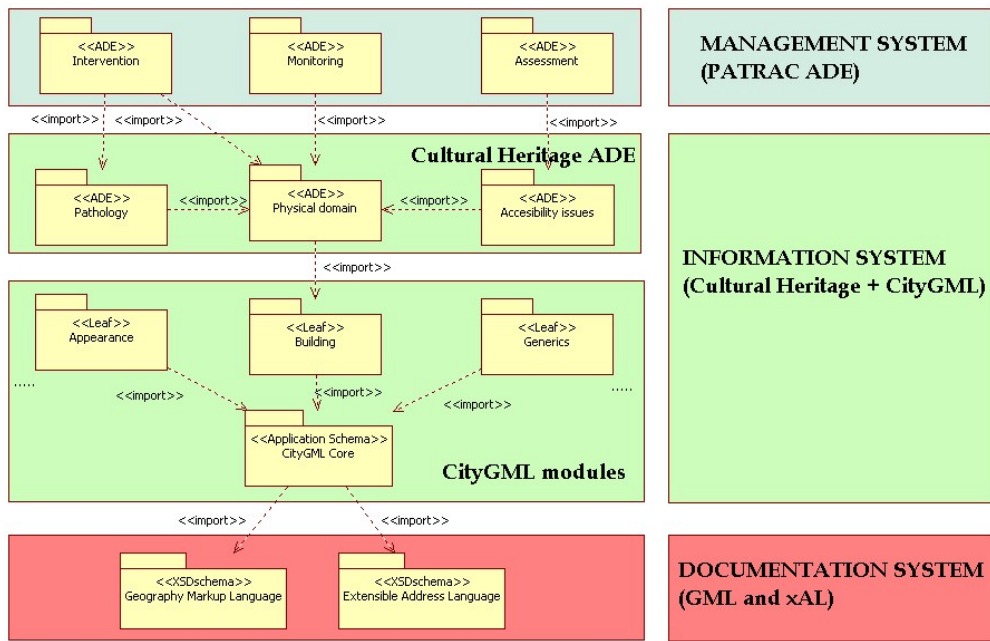


Figure 5: CityGML extensions for 3D DIM

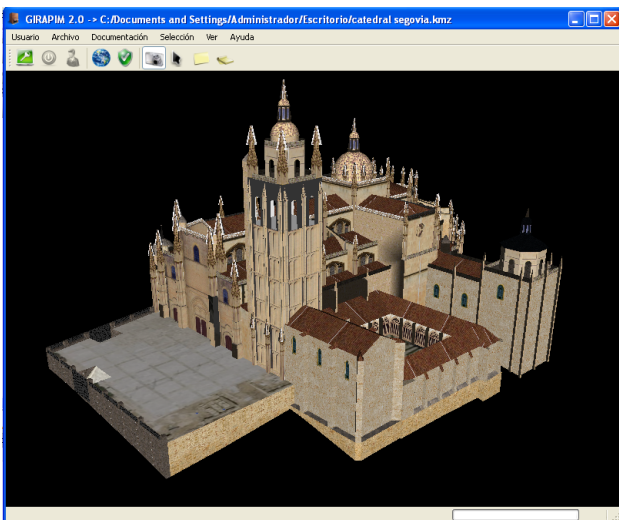


Figure 7: COLLADA graphic engine for Documentation System

tools which can be used without involving flexibility and extensibility of DIM systems, avoiding to entail Documentation System with proprietary vendor solutions. Moreover, KML is the key to enable interoperability with Google Earth and Google Maps from any (2D or 3D) GIS application, providing publication and visualisation support in the Web for traditional OGC Web Services [Honda et al., 2006] and for georeferenced databases contents [Stefanakis and Patroumpas, 2008] (see figure 8).

The Information System annotates the Documentation System contents with semantic information about concepts represented in 3D models. In order to visualize this information, GIRAPIM shows the hierarchy of concepts in a tree at the left side of the window, easing the navigation to the user. Figure 9 shows an example of this conceptual tree. When user select a concept in the tree, its position and geometric reference are highlighted in the viewer, displaying concrete location and graphical representation of the abstract concept. Although this distinction could be naive for a human, it is very valuable for a machine because the geom-



Figure 8: Advance visualization in Google Earth

etry and topology information about the concept allows providing complex services and advanced reasoning tasks. Below the concept tree, there is a property browser showing the metadata, properties or attributes linked to each concept when user clicks on it.

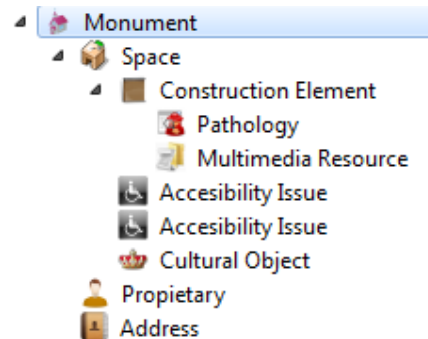


Figure 9: Hierarchy of concepts of the Information System

Finally, the Management System overlays the Information System with data about building processes (including task and activities) like monitoring activity from sensors, intervention project management, equipment organization, etc. There are different solutions to display these information attending device capabilities,

user experience and task to be developed. For instance, if the user is monitoring the building, then the value of the data would be showed in the viewer near of the geometry of the concept, highlighted in a different color according to its intensity or hazard. But if the user is managing the intervention process the previous solution is unsatisfactory; a tabular view for project management is more suitable to this task, highlighting the geometry of the managed concepts for each activity. This solution is the typical approach in four dimension systems: 3D information systems which manages space and time dimensions at the same time, in which DIM systems can be included.

## 6 CONCLUSIONS AND FUTURE WORK

Nowadays, there is a growing effort to achieve that building processes in AEC environments follow the BIM methodology which integrates information and provide support to enterprise and organization involved in the process. According to this methodology, this work propose a layered system composed by three subsystem: Documentation, Information and Management. The assembly of these systems is inspired by the CityGML modelling framework that represents semantic information linked to its geometry and appearance. The addition of a management layer in form of CityGML extension enables the integration BIM requires. Meanwhile, the first two systems provides the needed support to manage building process throughout the entire building life cycle.

GIRAPIM is a software tool showing the viability of this conceptual approach. It introduces some required features such as import of 3D models, support for CityGML standard model, management of documentation repository in a relational database and 3D advanced visualization. Currently, it has been applied in cultural heritage environments for the management and evaluation of intervention processes but it can be adapted to different urban environments and different management processes. The extension of Management System capabilities is our most important pendant challenge and the main limitation of GIRAPIM. However, the flexibility achieved by DIM Systems enables the rapid development of extensions for the required capabilities.

In the next future, we incorporate different business logic capabilities to the Management System since this is the broadest system. Moreover, we are developing Semantic Web Services to provide remote access to the information from mobile devices such as the new SmartPhones. This facilitates the monitoring of the work processes in different places, allowing sending data directly from the place of work and sharing the information between enterprises to increase throughput of workers and reduce job deadlines. Besides, recent advances in Web 3D technologies eases the provision of the information through a Web interface in a service portal allowing universal access to the contents in every place.

## ACKNOWLEDGEMENTS

This work is mainly supported by the "Proyecto Singular Estratégico PATRAC (Patrimonio Accesible: I+D+i para una cultura sin barreras)", PS-380000-2009-2 of the Spanish Ministry of Science and Innovation which has been co-funded with FEDER grants. The authors acknowledge also to the ADISPA (CICYT) Project with reference BIA2009-14254-C02-01 for their partial financial support.

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