# INFORMATION AND KNOWLEDGE SYSTEMS FOR INTEGRATED MODELS IN CULTURAL HERITAGE

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## ABSTRACT:

The increasing availability of software tools for image- and range-based surveying and visualizing 3D objects has posed some issues relative to the need of integrating different contents (relative to data and metadata, structure and function) in a common Information System. In this work, we develop an integrated solution for a 3D GIS whose support is a global 3D model generated from the fusion of image and range information for interventions in Cultural Heritage buildings. The 3D GIS integrates different software tools for Information Processing, Management and Visualization, including a) the fusion of image and range information (UvaCad, e.g.), b) relational DB for data and metadata management, and c) navigation, inspection and reports generation from the information contained in different layers. The interoperability between software tools is a bottleneck for transferring and re-using digital information. Two key facts for solving interoperability issues are a) the development of a 3D vector support (extending the usual methodology of planar GIS) for referring information contained in different layers to a common framework; and b) the development of logical schemes for a hierarchised management of information following signification levels of increasing complexity involving geometric, structural and functional aspects issues appearing in semantic approaches. The geometry of objects provide a support for specifying logic schemata connecting the above levels. It allows a reuse of solutions, and makes easier the accessibility from the initial specification of contents (data and metadata) for on-line cooperative work and for remote assesment by experts, or for consultation by customers or simply citizens. The developed solution is being applied for conservation and restoration interventions in some monuments of the autonomous comunity of Castilla y Leon, Spain.
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## 1. INTRODUCTION

Information Society Technologies (IST, in the successive) are contributing to improve functionalities and performance of traditional approaches to interventions (surveying, conservation and restoration) in Cultural Heritage (CH). The increasing availability of software tools for accurate modelling three-dimensional objects has dramatically improved the performance of Cultural Heritage surveying. *Image-based approaches* are based in a combination of Digital Photogrammetry and Computer Vision tools with the common denominator of bundle adjustment [Triggs1999] in the framework of advanced Projective Geometry; their combination has allowed a robust method for 3D Reconstruction from multiple views, with spectacular renderings resulting in *continuous* models [Remondino et al, 2006]. *Range-based approaches* are mainly based on laser devices following different physical principles (triangulation, phase shift, time of flight); they provide dense clouds of 3D points with additional radiometric information (gray-level intensity function, colour) giving *discrete* high accuracy models. Resampling of clouds of points to different resolution, allows to patch together the information arising from different image- and range-based devices.

The need of performing *mixed approaches* has been acknowledged from several years ago (see [El-Hakim et al, 2002], e.g.). Some important issues for mixed approaches to Cultural Heritage surveying concern to accuracy, robustness, information transfer between discrete and continuous modelling, meaningfulness of details, etcetera. Geometric aspects concerning to multi-scale and semi-automatic recognition are explained in more detail in [Finat et al 2009a]. Several mixed approaches have been applied also to larger frameworks including archaeological sites [Fernandez-Martin 2005], [Godin et al, 2003], and urban environments [Finat et al 2006], [Fuentes et al, 06] with lower accuracy requirements. The software platform UvaCad (http://uvacad.no-ip.org) provides a support for the fusion of image- and range-based information arising from different non-calibrated views and any kind of scanners. It has been used for a large number of works involving Cultural Heritage, Civil Engineering and Construction activities (more details in http://www3.uva.es/davap/).

Advanced Visualization Frameworks (AVF) provide an interactive navigation, an on-line inspection and an extraction of (geo)metric information. The availability of an efficient AVF is relevant not only for architectural surveying of Cultural Heritage, but also for monitoring and updating intervention (conservation or restoration) policies. Thus, functionalities of AVF must be extended to interactive Cultural Heritage Information Systems (CHIS), allowing update different kinds of data and metadata. An important aspect of CHIS is the existence of thematic layers to different scales which are superimposed to geometric models for making easier the reference of any kind of information to vector data. Furthermore, text layers must allow reports generation from thematic layers, with on-line simultaneous access and modification by several users following specific protocols.

The DAVAP research cluster of the University of Valladolid (Spain) has developed a software platform of Cultural Heritage Information Systems with several modules relative to Architecture (UvaCad), Urbanism (by referencing 2D to 3D information, cadastrial applications), Disperse Cultural Heritage (province of Valladolid), and Industrial Heritage (provinces of Valladolid and Salamanca). The methodology for the design and implementation of CHIS is very similar to the well-known GIS technology (Geographic Information Systems), but with a special emphasis on 3D aspects, visualization and interactive input of information (text, hyper-links to multimedia support, and metadata) which can be re-used with different proposals involving to professionals, firms (including SME focused towards services or leisure activities), CH entities and citizens in general.

Obviously, it is not possible to give an overview of all these applications, and we shall illustrate the performed approach with CHIS relative to the building scale for restoration purposes. Some additional applications planning and virtual insertion of simple geometric primitives on 3D range-based models have been developed, also, but not still integrated in the corresponding UvaCad module. In this work we paid attention to the design and implementation of CHIS, currently in development, which is being applied for restoration tasks in some complex monuments of the region Castilla y Leon (Spain). The integration of these modules following a semantic approach (under CityGML framework) is being accomplished in another work [Finat et al, 2009a].

This paper is organized as follows: Section 2 is focused to explain some aspects of CHIS for Architecture, following an increasing complexity modelling. We have adapted the same methodology of small scale GIS to a very restricted 3D environment (small urban zones or isolated building, e.g.). Next section is focused towards some structural aspects of Knowledge Systems for Conservation Tasks; a Knowledge System extends the ordinary functionalities of Information System for Architecture (ISA) by providing a support for assessment, advanced visualization and services linked to architectural surveying; such functionalities are illustrated with some examples of our ISA called PINTA (Processing INformation SysTem for Architecture), where some functionalities for collaborative and remote work are been developed. Some remarks about the achievements and the on-going work close this work.

## 2. INFORMATION SYSTEMS FOR ARCHITECTURE

### 2.1 GIS for architectural environments

A GIS can be seen as a system of hardware, software and procedures designed to support the capture, management, analysis, modelling and display of spatially-referenced data for solving complex planning and management problems [Goo89]. In particular, a GIS can be seen as 1) an *automated application* for generating maps or representations; 2) an *inventory* which allows a direct access to existing database with protocols for information processing and contents retrieval (fig2); 3) a support for *spatial analysis and decision taking*, which provides search and analysis tools to users from database; 4) a module for *information processing and analysis*, including the interactive generation of reports which can be adapted to the requirements of users; 5) a module for *advanced visualization* which allows to understand, analyse and explain the distribution of objects in the environment with increasing functionalities. Bottom-up strategy is the most commonly used for extracting information and reprojecting on a cartographic, planimetric or volumetric information. Usually, a GIS puts the accent on the management of planar representation of spatial information, involving raster and vector data in a *continuous space* which is already filled, and whose components must be identified.

In this framework, VR methods have been used for generating and navigating ordinary virtual or augmented environments, in order to provide a visualization of urban transformations along last centuries. In the next example, one can see an examples concerning to the destruction of some parts of the Renaissance style of the historic centre of Valladolid (Spain) along the sixties of the 20th century.

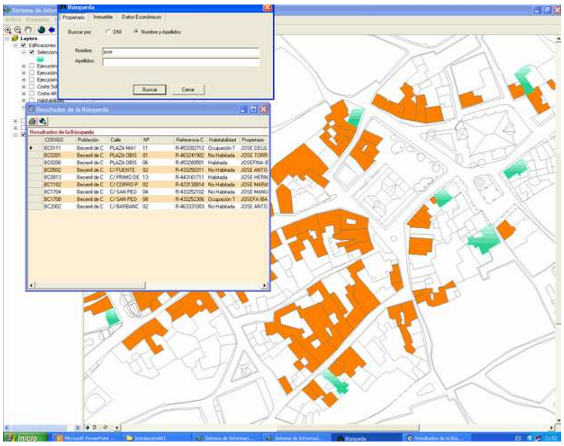
Fig.1. A virtual recovery of disappeared historic centre in the city of Valladolid (Spain)

From historical cartography and digitised views it has been possible to recover and visualize urban zones of Valladolid before their remodelling along the sixties of the 20th century. The above Fig.1 illustrates the visualization of an urban zone of Valladolid; it is only navigable by means of an exploration of a simplified model with reprojected textures. It gives an ideal representation extracted from drawings and non-calibrated views, because it is focused only to illustrate and not for surveying purposes. The main tool for design is a CAD system; these are applications for creating or synthesizing a drawings, analyzing it for design correctness, managing the storage and organization of the design data, and managing the process of design flow [Nakamura et al, 2003].

Nevertheless its interest for the recovery of the urban tissue memory and the understanding of functionalities almost lost, the above example has strong limitations, due to a limited graphical character. It is necessary to incorporate information systems to the graphical representation, and perform a multiscale approach which can be useful for different kinds of agents (citizens, administration, business, professionals) and different purposes (touristic, urban planning, commercial applications, services, respectively).

### 2.2 A traditional top-down approach

Due to the high complexity or urban tissue, first approaches for incorporating urban information are restricted to extremely simple geometric support, and follow a top-down approach. In other words, only a very restricted class of geometric primitives are allowed for supporting the information, and models are initially extracted from planar urban cartography. Traditional approach to Cadastral Applications is based on software GIS tools, where some additional information relative to particular interventions in buildings. Next, we display an example corresponding to the restoration and conservation interventions of the ARI (Area of Integral Rehabilitation) “Villas del Renacimiento” of four small villages of Palencia (Spain), which has been developed under ArcGIS due to a constraint arising from the local administration [Fuentes et al 2006]



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Nombre: jose

Apellidos:

Resultados de la Búsqueda

| CODIGO | Población | Calle | Nº | Referencia C | Habitabilidad | Propietario |
|---|---|---|---|---|---|---|
| BC0111 | Becerril de C | PLAZA MAY | 11 | R-453282712 | Ocupación T | JOSE DELG |
| BC0201 | Becerril de C | PLAZA OBIS | 01 | R-463241902 | No Habitada | JOSE TORR |
| BC0206 | Becerril de C | PLAZA OBIS | 06 | R-453280501 | Habitada | JOSEFINA IE |
| BC0502 | Becerril de C | C/ FUENTE | 02 | R-433250311 | No Habitada | JOSE ANTO |
| BC0813 | Becerril de C | C/ PRIMO DE | 13 | R-443161711 | Habitada | JOSE HERN |
| BC1102 | Becerril de C | C/ CORRO P | 02 | R-423138814 | No Habitada | JOSE MARIA |
| BC1704 | Becerril de C | C/ SAN PED | 04 | R-433252102 | No Habitada | JOSE MANU |
| BC1708 | Becerril de C | C/ SAN PED | 08 | R-433252306 | Ocupación T | JOSEFA IBA |
| BC2002 | Becerril de C | C/ BARBANC | 02 | R-463331003 | No Habitada | JOSE ANTO |

Fig.2. Cadastral Applications for urban GIS for the Area of Integral Rehabilitation in a small village of Palencia (Spain) with some buildings in Renaissance style

Each object has several links to images, local cartography, a relational database for observed incidence, a specific budget for recommended interventions, and a schedule for surveying and trakcing maintenance operations. Nevertheless, the interest of the above example for local administration and involved neighbors, the most important limitations concern to the lack of simulation tools, interoperability, automatic updating information, traceability and some troubles for navigating in an effective way the planned and performed interventions. It is necessary to improve some of them. From commercial or business viewpoint, the most important concern to design, planning and tracking intervention, and these activities concerns mainly to an extension of traditional design tools.

Next step for developing Information Systems for Architecture (ISA) is try of combining CAD and GIS methodologies. Along the late nineties and the first years of the 21st century a first synthesis of CAD and GIS methodologies has been developed in the framework of Building Information Modelling (BIM). The BIM is a set of information generated and maintained throughout the life cycle of a building (including design, planning, construction and maintenance). Currently, there are different modules for BIM which cover design, geometry, spatial relationships, geographic information, quantities and properties of building components (including manufacturer’s details). A computer implementation of BIM in the OOP (Object-Oriented Programming) framework is developed by IFC (Industry Foundation Classes) and it has been applied to very large AEC (Architecture, Engineering, Construction) environments with meaningful performance in commercial applications. BIM was introduced for demonstrating the entire building life cycle including the processes of construction and facility operation [BIM2008]. Thus, a BIM puts the accent on 3D design and graphical aspects involving the whole life cycle of building in an *empty space* which is “filled” by the (re)construction of building. Hence, *top-down strategy* is the most commonly used for the management of primitives.

However, usual BIM are focused towards building scale interventions (it ignores small urban environments) and it requires a high degree of expertise from the user with a high degree of human interaction. It is necessary to develop a strategy which can applied to (at least small) urban environments, requiring less expertise from users (for cadastral or commercial applications, e.g.) and able of maintaining the accuracy requirements for professional applications (including surveying, planning, and controlling interventions). These constraints imply to solve non-trivial problems involving to multiscalability, the design and implementation of interfaces for interoperability between tools and remote repositories, the insertion of metric information involving urban objects (arising from image and range-based information), and the corresponding Advanced Visualization modules for navigating, exploring, superimposing and extracting information. We have developed software modules for all these topics by subordinating every information to geometric data provided by range-based devices

### 2.3 Some interoperability issues

An important difference involves to the database design, also. CAD systems follow a conceptual or top-down description (basic primitives, transformations, operations) with objects which are parametrically defined and with exact results relative to defined operations, and usually they do not manage alphanumeric data or non-spatial data. GIS systems follow a bottom-up strategy (image processing, automatic or interactive information extraction) with raster or vector data, which are usually defined as classes and with floating arithmetic, but they manage text and non-spatial data in a very efficient way. The methodology for contents (different kind of descriptors for data), manipulation (operations and transformations) and management are quite different. Hence, the data exchange between conventional CAD and GIS is a some difficult task. Nevertheless, both of them are managed to an upper level by means of trees with different kinds of hierarchies, obviously. Thus, it would suffice to specify the semantic of each one for exchanging data and functionalities. Again, we find a difficult problem because the semantics is never specified in generic CAD systems. Formal semantics of geometric operations are expected from academic research [Rap03], but nevertheless the design of some tools for Geometric Linguistic, it is not still available.

## 3. OPERATIONS INVOLVING SIMPLE SHAPES

The management of database in CAD systems is very complex; it concerns mainly to lists of 3D geometric objects which can be manipulated following similarity transformations and some arithmetical operations for assembling; unfortunately, they are not described as “classes” in an OOP (Object Oriented Programming) framework. On the other hand, raster and vector information can be described as classes, but separability between components or elementary transformations (assembling tasks, e.g.) are forbidden. Furthermore, the information contained in views is introduced by hand in CAD and GIS, usually. Thus, there is even a lack of interoperability not only for BIM and GIS, but also with Computer Vision techniques regarding both of them. However, situation is not as bad as one could think. Several key points for connecting top-down CAD and bottom-up GIS methodologies have been developed in Computer Vision framework and they can be extended to 3D environment. Two important issues for this extension are described in the following subsections

### 3.1 Volumetric segmentation

Objects living in 3D representations can be separated into parts by identifying geometric elements bounding them (dominant planes or quadrics, cells, e.g; more details in Finat et al, 2009a) or by grouping them by minimal volumetric elements (there are several available strategies based in elementary geometric properties, local curvatures or spherical harmonics, e.g.). The main problem for the first approach is the design and implementation of algorithms for decomposing and managing large amount of related information. The main problem for the second approach is to find efficient criteria for split-and-merge procedures, having in account a very irregular distribution of information (conditioned sampling, mathematical modelling of discrete information to be processed, 3D filtering, restoration, etc).

It is not possible to give here an overview of all of them, and we restrict ourselves to some comments about some contributions concerning to underline some results which have been obtained by analogy with similar techniques appearing in Computer Vision. Indeed, in a similar way to image processing and analysis, the search, identification and extraction can be performed by superimposing templates (top-down approaches) or by implementig segmentation procedures from grouping of mini-elements (bottom-up approach).

First tasks concern to 3D segmentation, grouping and separability of primitives. Following the classical dichotomy in terms of top-down and bottom-up methodologies, we have implemented two approaches which are based on: 1) *Cellular decomposition*: It arises from the superposition of a regular volumetric template (arising from an octree) which is superimposed to the building or the urban scene. The octree is recursively subdivided in smaller regular cells depending on finding some cells with the specified attributes or not. 2) *Adaptive decomposition* by means of the detection of meaningful geometric primitives (dominant or quadric planes, e.g.), and their grouping in larger entities corresponding to a block or a street, e.g.. More details of the semantic extension for the second approach under the CityGML framework is developed in [Finat et al, 2009b].

### 3.2 Symbolic respresentations

Any planar or volumetric representation of an object can be represented and managed as a tree, whose nodes represent planar regions or 3D components, and whose edges represent adjacency restrictions which can be automatically fulfilled. Seemingly, for the management of complex information to the lowest level it would suffice to specify the hierarchies between geometric primitives (as simplests objects), and design and implement software tools for interpreting such objects as an XML document.

Unfortunately, things are not so easy due to the limitations of semantic approaches for XML documents and relational databases for managing semantic information and interoperate in a remote way. It is necessary to have the possiibility of extracting information about components in a remote way. Hence, more advanced developments require the development of semi-automatic recognition tools in view- and range-based models.

A general roadmap for design and implementation of software tools for 3D Recognition involving the first block has been developed in the framework of the AIM&SHAPE NoE of the Sixth FP of EU (http://shapes.aim-at-shape.net/index.php). Some Labs participating in this NoE have obtained very good results in the development of recognition of components for efficient volumetric segmentation, development of open source software tools for estimating geometric properties or applications in VR domains for entertainment or biomedical approaches. However, it is restricted to small size objects and it requires more advanced developments for recognition of complex sculptures such those appearing in Cultural Heritage. It is necessary to develop an extension or to adapt their methodology to CH objects. From our side and by using the same semantical hierarchy (geometry, structure, function), we have designed methods and implemented algorithms for estimating simple (convexity vs concavity, e.g.) or more advanced (local estimation of curvatures along slabs, e.g.) geometric properties of complex objects.

### 3.3 PINTA

The software platform PINTA (Processing INformation SysTem for Architecture) is an ISA which combines functionalities of CAD and GIS systems. As an evolving system, an ISA is a combination of a BIM and a GIS which is always referenced to the range-based 3D model. In our case, PINTA intends to provide an integrated solution for conservation and restoration interventions in Cultural Heritage buildings, but it can be extended to simpler environments such those appearing in conventional AEC. The reference model is a discrete 3D cloud of points, on which we superimpose different kind of information following the usual hierarchy (geometry, structural, semantic) according to the AIM&SHAPE methodology .

Relative to extended CAD functionalities, PINTA is based on range-image models to which regular images (digital photographs) are referred. It allows the creation of thematic layers superimposed to the images, and relative to different sampling procedures for different resolutions, superposition of different kinds of PL- or PS-structures, basic projective operations (sections and projections) for boundaries extraction and export to different graphic formats, usual transformations, superposition of 2D or 3D regular templates, interactive extraction of meaningful elements contained in views and reprojections on 3D representations, between others.

Relative to GIS systems, and following the same basic distinction between raster and vector information, PINTA disposes several modules involving the treatment of properties and risk factors involving materials properties including degradation estimation due to natural (moisture, salt, e.g.), artificial (pollutants, graffiti, e.g.) or accidental (fire, earthquake, e.g.) risk factors.

Further aspects concerning to damages evaluation in structure (misalignement, lack of planarity or meaningful differences with respect to elementary quadrics) are being currently integrated as a module in UvaCad. Some aspects relative to recognition of simple curved elements are explained in [Finat et al 2009b].

## 4. A SEMANTIC FRAMEWORK FOR KNOWLEDGE SYSTEMS FOR CONSERVATION TASKS

A knowledge system for Conservation Tasks must facilitate the assessment, advanced visualization and provision of services linked to an Information System for Architecture. Main problems to be solved for assessing conservation and restoration tasks of Cultural Heritage concern the evaluation and modelling of critical factors influencing structural or material deterioration. A semi-automated solution requires the indexing, retrieving and visualising interventions to be performed on 3D digital models for facilitate operations. Different aggregation levels for elements contained in basic units (façades, buildings, urban environments) and infrastructures suggest a multilevel approach with different levels of detail which are organised in a hierarchical way. The support for knowledge system must be a knowledge space including annotated multimedia resources in formats which can be read by different applications. There is no hope for achieving a common standard; thus, the main issue concerns to the interoperabililty (including data exchange) in different repositories organized according to common criteria in the Semantic Web. Common criteria involve to the specification of lexicon, thessauri and taxonomies (following increasingly complex approaches), in order to an efficient management of domain, users and tasks ontologies. This is a long-term goal, and we expose here some general aspects relative to the components which are being developed by us in the framework of the PATRAC project.

Advanced visualization concerns to the design and implementation of software tools for simulating effects along the future or possible interventions. Thus, advanced visualization is typically linked to a Building Information System. A BIM covers design, geometry, spatial relationships, geographic information, quantities and properties of building components (including manufacturer's details). All of them are very useful for structural aspects involving the construction or maintenance interventions.

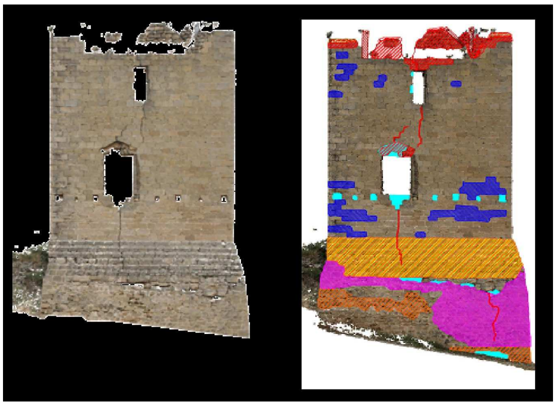
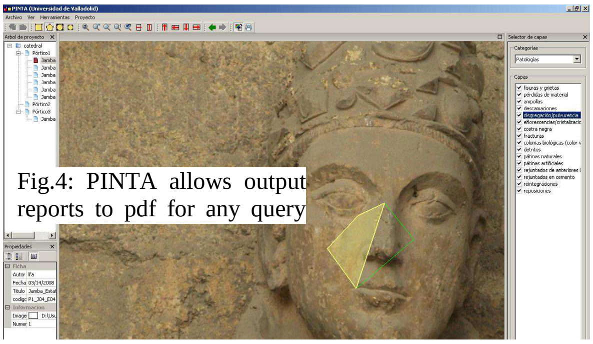


Fig.3: Vector thematic features layered over range data

The software platform UvaCad provides tools for architectural surveying, structural analysis, identification of pathologies, and simulation of effects corresponding to interventions, with the incorporation of different layers for illustrating all of them. All layers are managed following a geometrical hierarchy for preserving the local consistency of layers and the global coherence of the whole object. This methodology has been also applied for surveying and ideal reconstruction of archaecological sites [Fernandez-Martin et al, 2005]

However, conservation and restoration tasks require identify, annotate and track along several years some aspects concerning different manifestations involving properties of materials which can provide a measure (porosity, permeability, biological attacks, mineralogical changes, etc) of risk factors. Furthermore, often it is necessary to apply non-destructive techniques (radar, ultrasonic) or partially destructive techniques (including archaeological trials, e.g.) for evaluating critical zones or samples which are irregularly distributed.

All of them suggest their incorporation on the Information System as attributes supported by 3D mini-regions which must be geometrically refered. Intuitively, 3D miniregions they play a role similar to raster data in 2D GIS with attributes supported on (families of neighbour) pixels and they are referenced to the vector information of range-based model. This goal has been achieved by developing a Software Oriented Architecture (SOA) for PINTA as a framework with three modules corresponding to internal manager, applications server and communications. The implemented software architecture allows the services provision to entities (public or private) or citizens in general which can be interested in the development of services or simple information about the cultural goods. The development of services is a key issue for sustainability of activities linked to Cultural Heritage. The development of a SOA for Cultural Heritage applications is an on-going research which is being developed with applications to different kinds of users or entities.



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Categorías: Patologías

Capas:
- ☑ fisuras y grietas
- ☑ pérdidas de material
- ☑ ampollas
- ☑ descamaciones
- ☑ disgregación/pulvurencia
- ☑ eflorescencias/cristalizacic
- ☑ costra negra
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- ☑ pátinas naturales
- ☑ pátinas artificiales
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- ☑ rejuntados en cemento
- ☑ reintegraciones
- ☑ reposiciones

Fig.4: PINTA allows output reports to pdf for any query

Fig.4: Vector thematic features layered over images

Some technical aspects that have been enabled to the early versions of PINTA are the selection of regions for adding vector marks or inserting annotations, interactive semi-automatic segmentation of images and their re-projection onto the 3D model as thematic layers (fig4) with the corresponding access protocols, interoperability between 2D and 3D information supported on the range-based model. All of them under specific access protocols fixed by the system's administrator according to the customer (usually, an official entity). From the viewpoint of communications, it is allowed a simultaneous access from different users, information updating in a local (intranet) and remote way (internet), and automated generation of reports involving thematic layers or key words used in annotations.

## 5. CONCLUSIONS AND FUTURE WORK

In this work we explain a hierarchy of software architectures arising as a natural extension of hybrid methodologies for architectural surveying. A general goal is to provide a multi-purpose support to experts, (public or private) entities and citizens interested in Cultural Heritage which can improve the sustainability of Cultural Heritage resources. To achieve it, it is necessary to integrate different viewpoints arising from professional design, information systems and advanced visualization software tools. Thus, we are developing a Knowledge System able of integrating some functionalities of CAD, GIS and hybrid surveying methodologies (integrating Computer Vision, Photogrammetry and Computer Graphics), which is being developed within the software platform UvaCad.

Knowledge systems emerge as the next step to be done. However, to achieve the ambitious scheduled program and to satisfy requirements of distinct agents, it is necessary to solve some problems concerning to aspects such as the transformation to a common data model of heterogeneous multimedia database, matching of semantically related objects which sometimes are not well specified (CAD), schema integration with their corresponding query, retrieval and labelling procedures, transformation of data and metadata in commonly accepted frameworks (requiring an additional effort in standarization) and matching of semantically equivalent data. These tasks must be performed in a collaborative way in the Semantic Web and require a collective effort which must be coordinated by ad-hoc committees of international societies

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