Space and time scaling issues in data management: the virtual restitution of Cluniac heritage

Z. Petty · J. Landrieu · J. F. Coulais · C. Père · O. de Ganay

Abstract Recent research projects led in Cluny have focused on interoperability issues between computer-aided design (CAD) and geographic information system (GIS). In one of these projects, the Gunzo project went through a complete digital restitution of what was the largest church in the world during five centuries. In another project, a 3D GIS of the Cluny region was set up and led to the idea of designing an online historical and archaeological 3D database. This involves the development of time-based 3D data management functionalities in which both CAD and GIS could exchange information. Thanks to the close collaboration between interdisciplinary fields, the team managed to formulate the basis of a joint workflow. These steps are promising and could meet in the future this long-time dream of the scientific community: to be able to tie together CAD and GIS models with temporality on a single georeferenced collaborative platform, so closely that it will be possible to navigate through the history of a city in 3D.

Keywords Temporal GIS · CAD model · Georeferenced database · 2D–3D interoperability

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Introduction

The year 2010 celebrated the 1,100th anniversary of the settlement of the first Cluniac monastery which became head of a religious order that spread all through Europe, and locally has evolved throughout centuries in the current village. A multidisciplinary research team was created for the anniversary: the project, called "Gunzo", is constituted of multi-skilled members: engineers, art historians, project managers, an architect, a computer-aided drafting (CAD) designer, a geographer and a geomatician. Its members, part of a scientific laboratory called "Institut Image", are focused on heritage enhancement through the use of new technologies of image. Their topics of research deal with digital mock-up, virtual immersion, mixed and augmented reality… It is also part of the "Ecole Nationale Supérieure d'Arts et Métiers (ENSAM)", a graduate school of engineering. The main goal of Gunzo is to rebuild the grand abbatial church of Cluny (Landrieu et al. 2011)—reached in summer 2010—and also its spatial context, through the village of Cluny, its environment and its landscape. This goal is also handled with a historical perspective in order to perform a temporal journey and discover visually and virtually the evolution, the brutal transitions or the continuity of the whole.

In order to do so, several projects are pursued with various partners, private but also public administrations. A first and main step has been to focus on the reconstitution of the abbey. The second one changes the scale of study and takes into consideration the surroundings.

The goal is to create a dynamic model of the history of Cluny and its surrounding landscapes, from the Middle Ages to nowadays. To achieve this goal, we worked on new methodologies integrating geographic information system (GIS) and CAD tools, as well as a new time scale data management system. With the objective of providing a better understanding of changes in the urban pattern of the monastic village and its relation to the abbey, our first step was to digitize an important collection of eighteenth century ancient maps called “Plans Terriers”. Funded by the Ministry of Culture and the Departmental Archives of “Saone et Loire” (AD71), this project involved the digitizing of their collections of document (on the abbey of Cluny) and their disseminating through the internet.

The constant transformation of cities and landscapes implies a great number of different scales and fields of research and calls for new approaches to study and understand their evolution. In this article we review some 2D to 3D interoperability, space and time data scaling issues involved in the Gunzo project. We also introduce some key concepts for the design of a web-based 4D GIS collaborative platform dedicated to the history and archaeology of Cluny’s region, as well as related methods in designing web services for research communities.

Project context

According to the legend, Gunzo was the name of a monk who received a visit from St. Peters while dreaming: He was given the holy dimensions of Maior Ecclesia, the third abbatial church, also called Cluny III, or the “second Rome”. It was the greatest Christian building until the sixteenth century reconstruction of St. Peter of Rome by Michelangelo (see Fig. 1). Its length reached 187 m, its width up to 43 m (for the nave). The major transept peaked at 70 m. As a comparison, St. Peter is a few metres longer and more than twice higher.

The Cluniac order was very powerful and wealthy; it owned many lands in Burgundy and all through Europe. In order to manage these possessions, plans were drawn. About a thousand of these plans, made during the eighteenth century, are kept at the “Archives Départementales” and in the Museum of Cluny. These plans, related to what will later be the local cadastral register, form a heterogeneous corpus of documents, with different sizes (the widest is 4 m long), qualities and types of mapping representation but also various states of conservation (see examples in Fig. 2).

Moreover, starting from the French revolution, the abbatial church was destroyed over 30 years, leaving only 8 % of the building standing, and thousands of fragments. All this led to a tremendous loss of knowledge, related to both the information contained in the documentation and plans as well as our understanding of onsite remains.

Cluny and its surroundings attract a wide touristic flow and is a widely known site. The landscape has changed over the last century, and mapping methods have evolved over time as well as local names, places and roads. This impedes a proper understanding of the archaeological remains and accounts for a virtual restitution. Various skilled experts have been working on Cluny III remains, making available a substantial amount of documentary sources, which were unfortunately scattered and never aggregated. Furthermore, the continuous deterioration of the remains also advocated for an urgent digital backup, in order to create a numeric conservatory. Project Gunzo is now dedicated to this “virtual restitution”.

Rebuilding the abbey church

Gunzo actually began 20 years ago, with Christian Père’s (project coordinator of the Gunzo team) graduating internship. At that time, a first digital restitution was performed on

Fig. 1 A ghost model of the abbey church in today’s surroundings enables to get an idea of the volume occupied and its dominant situation in the town

Fig. 2 Eighteenth century plans owned by the Museum of Art and Archaeology. A whole corpus of such plans has been digitized. They conceal different types of mapping techniques, representations and land cover information

CATIA V3 thanks to a partnership between ENSAM and IBM. In 1992, this work led to a first movie named "Mémoires de pierres", followed in 2004 by a new restitution (partnership between ENSAM—J.M. Sanchez and Julien Roger—and the Centre des monuments nationaux) and a stereoscopic experience with pre-computed rendered images. It was named *Maior Ecclesia*. Lastly, 2 years of recent research was undertaken and led to new issues in the implementation of 3D reconstruction methods. The most noticeable added values of the new restitution were:

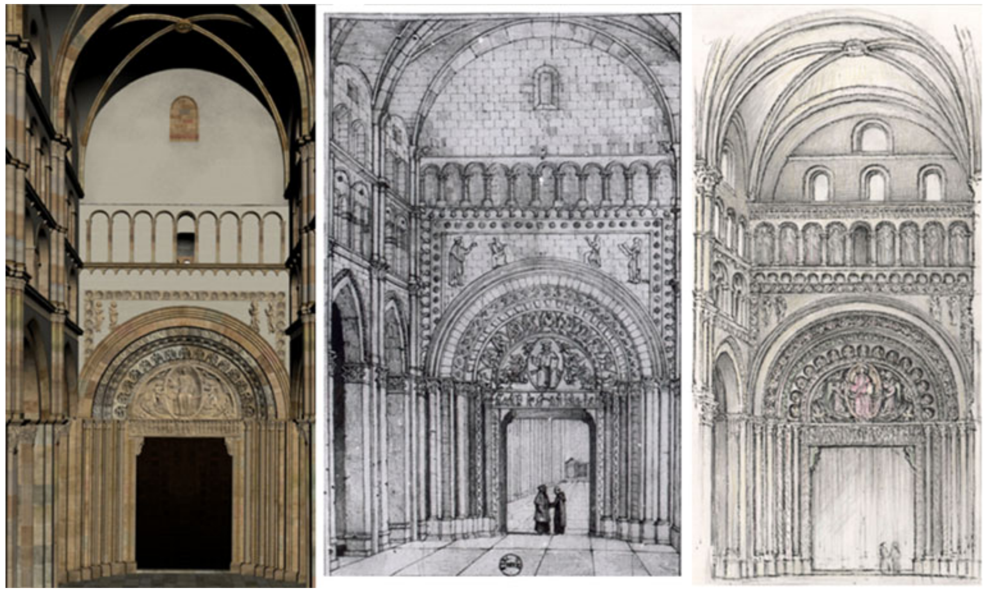
- To take into account the current remains, meaning that the digital version practically "sticks to" what can be seen onsite. The major lapidary elements are also part of the new release.
- To lead investigations on the abbatial polychromy, especially on two prominent facades and
- To offer a new stereoscopic experience, focusing on relevant textures.

This undertaking was enabled by a partnership between Arts et Metiers Paris Tech, on situ company and "le Centre des Monuments Nationaux" (CMN). Gunzo was responsible for the geometric modelling; on situ company achieved the texturing step and the post-production of the stereoscopic movie. The CMN was in charge of broadcasting these combined works to the tourists, with a deadline of July 2010.

This project did not begin from scratch; it was widely inspired from available documentary sources among results from the works of Conant (1968): drawings, ground plans, sketches and description. As contradictory theses were often encountered (Fig. 3), a panel of experts guided the team's progression in order to ensure its consistence and the historical relevance of the model. We also took into account the latest researches such as the restitution of the Roman and Gothic facades, hypotheses on the chancel pavement. A few are still in progress, especially on polychromy topics; excavations are still being conducted in order to upgrade archaeologists', historians' and Gunzo's knowledge.

The modelling step began with an overview of the whole digital workflow. Then the digitalization of the remains followed: The building was digitally acquired. More than 200 fragments were also scanned. The meshes, once post treated, were used either for reverse engineering purposes (building remains) or for direct implementation in the mock-up (lapidary elements). One sub-element after the other, one assembly after the other, Gunzo achieved Cluny III's digital rebirth in CATIA V5 R18.

Fig. 3 Example of contradictory theses leading to frequent debates with the scientific group. From *left* to *right*: snapshot of the digital mock-up and of two drawings performed by Garnerey and Conant (from KJ Conant's funds)



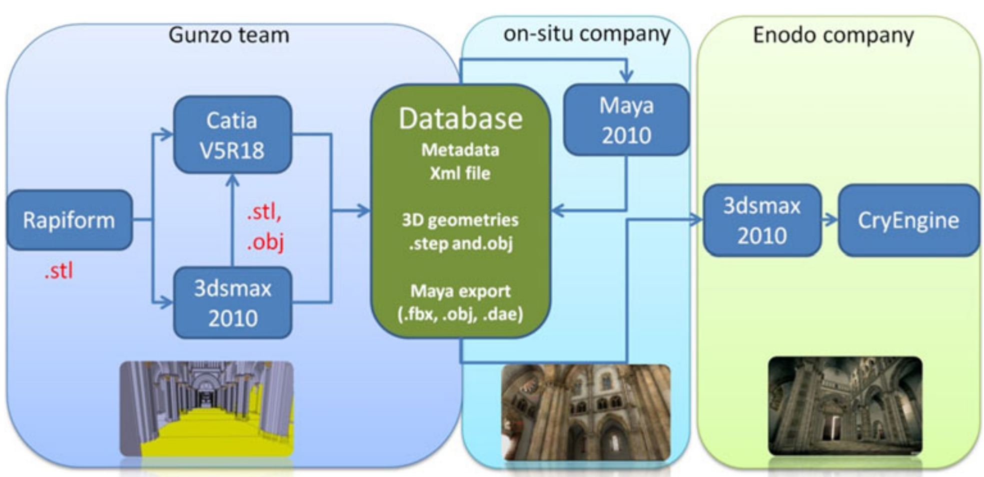
Secondly, each section was exported to Maya software in order to map the textures on polyhedric components. As outputs of this project, the weight of the abbatial church was estimated—considering its materials—to be 125,000 t. Twenty-nine percent of the building has been reverse engineered (which represent 460 components on the overall 1,600). Latest calculations estimate to one million euros the cost of such a project of digital restitution.

Beyond the abbey: getting to understand the evolution of Cluny and its environment

As part of the spatial and temporal restitution of the landscape, the 3D model of the abbey needed first to be inserted in the city and the eighteenth century plans were scanned and implemented into a GIS. For the former, the point cloud of the remains of Cluny III was georeferenced in order to be visualized through the TerraExplorer 3D GIS software enabling to work in real time (Fig. 4). Various methods were tested to estimate its coordinates (x, y, z) and its orientation. To settle its exact location, the geodesy point of the spire was used allowing a good accuracy (<10 cm). On the opposite, the accuracy for the height was lower (about 50 cm) so a surveyor measured on the field several points bringing back the z accuracy below 10 cm. The last aspect to find out was the orientation, which was solved with a high-resolution aerial photo (5 cm/pixel) by measuring the angle between the axis of the nave and the geographic north (78, 1°; Fig. 5).

For the latter, the first step consisted in georeferencing the plans in an actual frame of reference (ArcGIS). The difficult part in the georeferencing of these documents was to find similar control points (corners of houses, well, tours, crossroads, bridges,…) between the eighteenth century state and the recent frame of reference, namely aerial photos taken by IGN with a 50-cm resolution, and more recently by IGO/

Fig. 4 General workflow from digital scanning to full scale and real time (or pre-computed) visualization



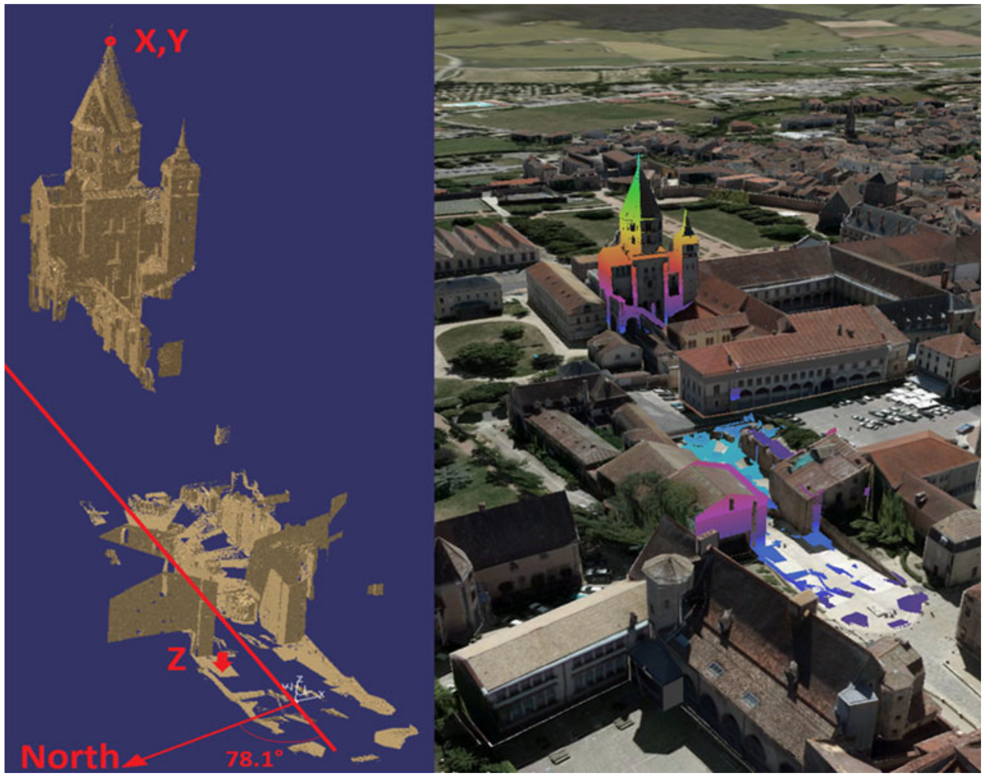


Fig. 5 The abbatial remains (point cloud after digitizing process) and plan mapping. On the right, each point of the point cloud is coloured according to its height (from *blue* to *green*)

Aerodata with 5 cm resolution, thanks to a specific flight mission commissioned by Gunzo. It was then necessary to go back in time and take an additional step in a historical regression method. The second step of the methodology was then to georeference the nineteenth century Napoleonian cadaster—which fitted perfectly—on the twentieth century frame, and then the eighteenth century plan on the whole (Grosso 2010). Finally the eighteenth century plans were geo-located on the twentieth century reference (see illustration, Fig. 6). In order to keep the shapes and spatial relations

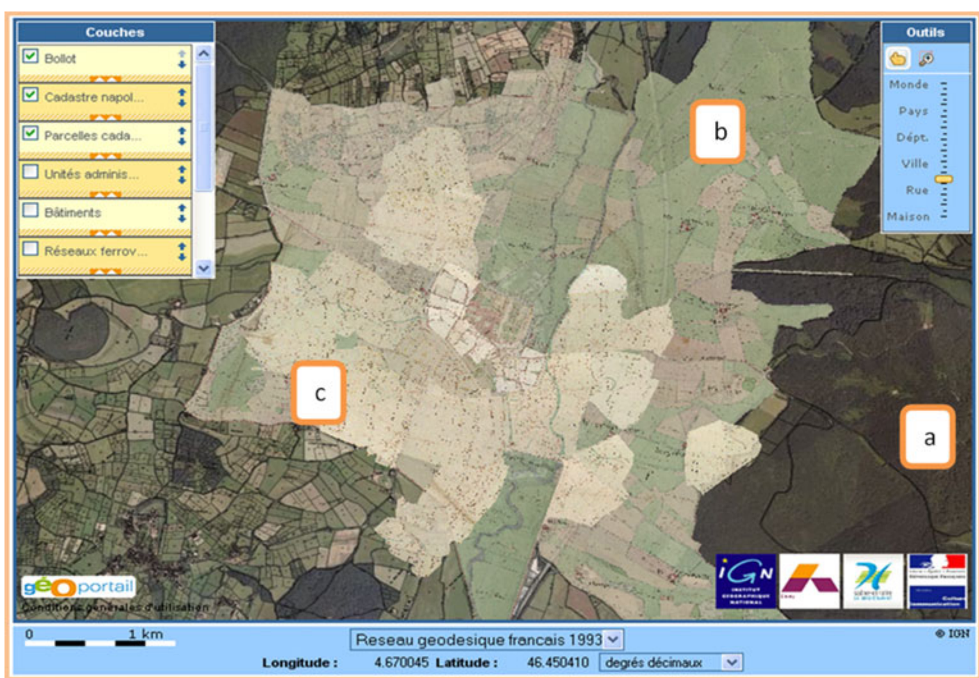


Fig. 6 Three historical records of Cluny's surroundings presented in the API developed by the IGN and implemented by the Gunzo team: **a** aerial photo of 1997 taken by IGN; **b** Napoleonian cadaster; c eighteenth century plans

Fig. 7 Mill Tower: today's city (3D CAD model) and the eighteenth century plan as under layer to understand the evolution of the city

between objects as similar as possible to the original paper plans, the georeferencing was done with an affine transformation (Boutoura and Livieratos 2006).

For every plan the coordinates of every control point as well as the interval between the plan and reality were filled in order to inform on the process level of accuracy. We do not know how these plans were produced, what cartographic criteria were used, what instruments and methods of measurement applied, but we do know that they were different as they induced many mistakes in the geometry

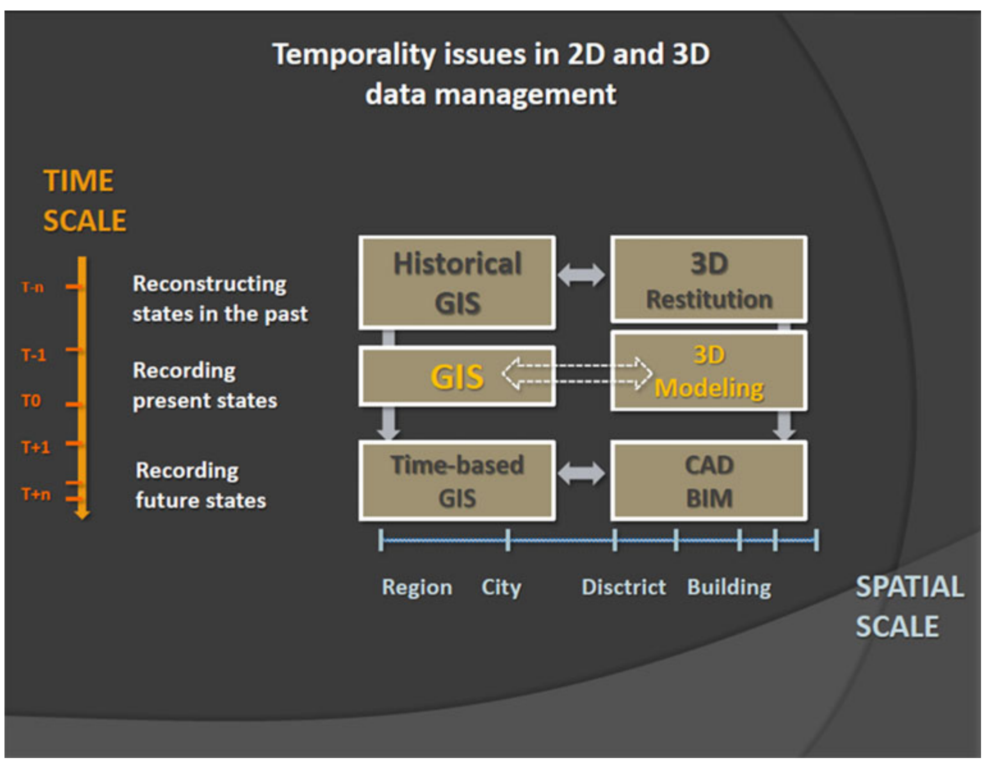


Fig. 8 2D–3D spatiotemporal database: theoretical workflow and scientific analysis of the link between 2D and 3D data in a spatiotemporal research

compared to today's standards. Furthermore these plans were mostly used as work sheets and were handled over time. They were also cut out, re-assembled, which led to distortions. Bad conditions of preservation also caused distortions because of humidity, folds, rolling up, etc. All these distortions added to the original cartographic mistakes that explain several important intervals, which can be up to 4 m, and the fact that the plans do not perfectly "fit" the actual landscape.

The georeferencing tasks involved raster images only. In order to build the GIS and to start extracting the information and process it, the first step was to create a vector layer with every plans limit and its different name (at the archives, the museum, the computer files…) for each corpus (Fig. 6).

All through this workflow, the documents were analyzed and discovered in detail. Hence Gunzo has done a first appraisal of the plans as well as an elaborated and relevant georeferencing method for a heterogeneous corpus of ancient plans (De Boer 2010, Fig. 7).

Naming and data structuration for sustainable database

Beyond the historical restitution of the abbey and its environment, a whole aspect of the work was to organize the data and their associated attributes in order to perpetuate it through time and amongst different partners. Given the huge amount of data that would be generated and the probable study of other heritage sites, we aimed at establishing a good working method, transposable to any other building (Père and Faucher 2007). For the abbey church, the 3D database is ruled by naming conventions, according to the buildings structure. We aimed at elaborating a generic one, transposing a concept coming from the automotive and aeronautics industry to heritage field: the product structure (Hvam 1999). The overall church was cut into main architectural sets: Sections correspond to the nave, the chancel, apse, antechurch and its Romanesque and Gothic facades, great transept. Sections are also subdivided into subsections. Again, subsections were assembly of elements which are at the end, sets of subelements. For example, the antechurch is divided into a large central nave, and smaller north and south aisles. These are also organized in five bays with a group of imponent piers, overhung by capitals, blind arcading windows. Below, the subelements are for instance the floor, the walls, the roof, vaults and if necessary columns, piers, capitals and frieze. The breakup of the monument followed the principles used in architecture, as well as a scientific logic. This spatial cut consequently leads to denomination issues. We based our work on the Mérimée classification (Mérimée 2011). The naming strategy was also directly inspired from automotive methods: One code is assigned to each subset. One subset's name constituted of the list of the codes assigned to its structural parent plus its single individual code. In the end every component is deeply linked to its code which inform precisely on its location in the database. For example according to Mérimée's enriched classification, Cluny III's code is NC_FR-071_AA_AC. The antechurch is the sixth section of the church, beginning from the apse. Thus its assigned code is "*G*" (sixth letter in the alphabet). The antechurch contains three naves. The central nave's code is "A". The final central nave's name is NC_FR-071_AA_AC_*G*A. To perform this, and given the huge amount of data that would be generated, we aimed at establishing a good working method, transposable to any other building.

For the 2D work on the eighteenth century plans, the rules declared in the European directive INSPIRE were applied. In that perspective a metadata catalog was created (Geonetwork) following the ISO 1119-119115 standards, where the details on the georeferencing were specified. Since the ISO standard beholds around 400 different fields, in order to optimize the creation and management, a

Fig. 9 Onsite augmented reality device called ray on: This screen is adjustable (orientation) and displays what the user would see if the abbatial church had not been destroyed. Credits: ENSAM—in situ—Centre des monuments nationaux

template including the obligatory fields and several specific ones adapted to the project was created. These metadata were delivered with the data (xml) and will be available on the website along with the untreated data (Fig. 8).

Perspectives

From virtual to augmented reality

These two different projects focused on Cluny and its surroundings; they led to various results through original methodologies, but they all aim at seeing a state that once was and that has evolved. The perspective for the abbey is turned toward the temporal dimension of the buildings, so that users can navigate through time. The objective of the first experiments was to implement generic workflows ruling configuration management of any object, provided its organization follows product structure requirements. A demonstrator was settled with CATIA. Its scope targeted main changes that occurred for the abbatial church Cluny III—between 910 and 2010.

Gunzo first focused on viewing a partially destroyed building (ray on devices, designed by in situ, see Fig. 9). Then, it pushed further the thought: What about enlarging the pipeline to complementary topics in architecture: viewing, inspecting, designing, maintaining, renewing. The perspectives supplied by augmented reality in this field are promising. As a consequence the team turned towards these topics: two engineers have been assigned to the development of new interacting methods with a 4D-model, in an augmented reality context.

Researches are still in progress, concerning in situ interactions on digital mock-ups in a context of renovation works, and also in situ visualization of thermal simulations. These are two main threads of two Ph.D. students' works. Moreover on this project, Gunzo aims at working on the modelled mock-up in real time, enabling collaborative work. It is leading experiments holding on several 3D engines (Virtools–Vizard–Cry Engine) in order to compare them. The purpose lies in a virtual realistic navigation in full scale into the church with a best rendering result. In the future the main goal is to virtually open the doors of the abbey and be able to navigate in the city and surroundings.

Web-based 4D SIG collaboration platform

In order to do so, Gunzo needs all the knowledge brought together on a single platform, thanks to the appropriate geodatabase and web mapping tools. A collaborative platform (Coulais and Père 2009) in good working order requires that the partners agree on basic principles of pooling, reciprocity, balance between partners and contributors (Coulais 2011). All of these are guaranteed by the membership in a common

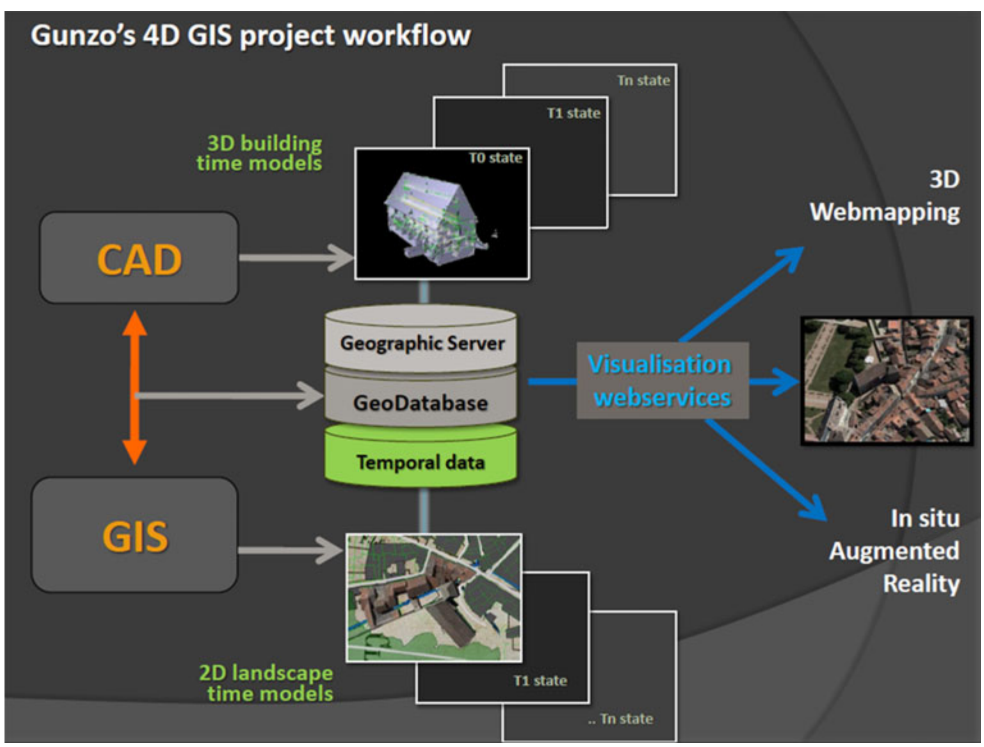


Fig. 10 Complete workflow of the Gunzo project, starting with CAD and GIS data inserted and managed through a 4D collaborative platform before being presented

policy chart. Such procedures have already been created for research programmes such as the ANR Alpage (2007–2010), which took the shape of a web GIS on the historical topography of Paris, with more than ten researches coming from diverse fields[1] (Noizet et al. 2010).

The work tool allows a precise management of diffusion and online publishing, with a principle of data coproduction based on a close watch over the modifications and on a traceability of the contributors copyright. Inspired by the projects of Alpage and of the SITG of Geneva,[2] Gunzo's project of collaborative platform for Cluny is conceived as a work tool for researchers and not only a device to visualize different temporal states. Above all, the main aim is to find a common thread and language for all the actors. This project leads to an essential and permanent task: the readjustment of technologies and tools due to adaptations through time and uses (Fig. 10).

Another aspect is also to avoid the production of redundant data and data cemeteries, along with the isolation of the different fields of research. This mutualization impulse and continuum, with the aspect of benefiting to all, hold the heuristic potential of mapping for different corpus of social sciences.

To conclude, one of the main challenges for the Cluniac archaeology and history is to have a better knowledge of the initial conditions of settlement of the abbey. As well as the initial, tenth century state of the abbatial site, the city's beginning, its relation to the first abbey and its evolution are still quite unknown and are still not revealed by any text or archaeologic excavations. Gunzo works to rebuild this heritage, and including it in future building projects, through joint scientific efforts by combining different fields and researchers, with original methods, models and shared interoperable work tools such as a collaborative platform. Gunzo also turns towards knowledge popularization through the stereoscopic movie, as well as innovative mediation tools using onsite augmented reality.

Acknowledgments The project could not take place without the support and help of Cluny 2010 funders: the "Conseil Régional de Bourgogne", the European Union (FEDER), Arts et Métiers ParisTech engineering school and the "Conseil Général de Saône et Loire". We also thank the "Musée d'Art et d'Archéologie de Cluny", the"Centre d'Etudes Clunisiennes", the "Fédération Européenne des Sites Clunisiens", the French Ministry of Culture and communication, the "Mairie de Cluny", the "Centre des Monuments Nationaux (CMN)" and the "Direction Régionale des Affaires Culturelles".

References

Boutoura C, Livieratos E (2006) Some fundamentals for the study of the geometry of early maps by comparative methods. E-Perimetron 1(1):60–70

Conant KJ (1968) Cluny, les églises et la maison du chef d'ordre

Coulais JF (2011) La Clepsydre et la Groma vers une plateforme collaborative et ouverte pour l'Histoire et l'Archéologie des paysages clunisois. In: Actes du colloque Arch-I-tech. Cluny, France

Coulais JF, Père C (2009) Quand le tout n'égale pas la somme des parties: technologies et modèles de représentation pour l'archéologie des villes et des territoires. In: Actes du colloque Virtual Retrospect 2009, Ausonius éditions, collection Archéovision. Université de Bordeaux 3, Bordeaux

De Boer A (2010) Processing old maps and drawings to create virtual historic landscapes. Proceedings of the 5th International Workshop on Digital Approaches in Cartographic Heritage, Vienna, Austria, p. 22–24

Grosso E (2010) Integration of historical geographic data into current geo-referenced frameworks: a user-centered approach. Proceedings of the 5th International Workshop on Digital Approaches in Cartographic Heritage, Vienna, Austria, p. 22–24

Hvam L (1999) A procedure for building product models. Robot Comput Integr Manuf 15:77–87

Landrieu J, Père C, Rollier J, Castandet S, Schotte G (2011) Digital rebirth of the third church of Cluny *Maior ecclesia* from optronic surveys to real time use of the digital model. IAPRS&SIS, vol 38, ISPRS Commission V-WG 4

Mérimée (2011) The name of a classification established by French Ministry of Culture in the 19th century: it sorts buildings according to their nature and type of architecture (civil, religious…). http://www.culture.gouv.fr/culture/inventai/patrimoine/. Accessed Nov 2011

Noizet H, Bethe A-L, Bouju A, Chareille P (2010) Le géo-référencement des plans Vasserot: méthodes, déformations, interprétations. In: Paris, temps, surfaces et espaces: des plans Vasserot au SIG Alpage. Colloque ALPAGE, Paris

Père C, Faucher S (2007) Cluny : de la gestion de données à la réalité augmentée. Actes du colloque Virtual Retrospect, p 61–67

[1] For further information, visit this website: http://lamop.univ-paris1.fr/alpage

[2] For further details : http://etat.geneve.ch/sitg/