Advanced virtual reality visualization systems based on a meta-model dedicated to historical knowledge

Benjamin Hervy*†‡, Florent Laroche*, Jean-Louis Kerouanton† and Alain Bernard*

*LUNAM Université
École Centrale de Nantes
IRCCyN UMR CNRS 6597
1 rue de la Noë, 44321 Nantes, France

†LUNAM Université
Université de Nantes
CFV EA CNRS 1161
2 rue de la Houssinière, 44000 Nantes, France

‡Musée d'Histoire de Nantes
Château des ducs de Bretagne
4 place Marc Elder, 44000 Nantes, France

***Abstract*—In this paper, we illustrate how historical data can be capitalised for future virtual visualization applications. We will demonstrate our proposition thanks to a research and development project started in 2008 about a mock-up of Nantes (french city) harbour. This mock-up is an historic and geographic witness of the country it represents. The amount of available knowledge with such a historic witness is significant and can be useful for many experts and obviously for museum public. What we aim to do is to capitalise the whole knowledge related to this patrimonial object before designing any end user's application. Digital technologies such as 3D numerisation, virtual reality and cognitive infocommunications [1] will help us to achieve this goal.**

I. Introduction

Advanced visualization technologies have no need to prove their signification in the field of cultural heritage promotion [2]. With the rise of digital technologies, many applications (whatever the technology used) have been designed for museums in order to enhance collections. Even if they use multitouch, virtual-immersive worlds, or using augmented reality, those applications are designed for one-shot purpose. Most of the time, historical contents are hard-coded into the final software with no hope of reusing. What we aim to do with Nantes1900 project is to focus on information before designing any end-user's application. Some similar projects seem to emerge around the world, such as the project about a mock-up of Liege city, promoted by the geomatic laboratory of Liege university (Belgium) whose starting point is a 3D modelisation of the mock-up [3].

With Nantes1900 project, Nantes history museum wants to enhance a significant object from its collection which is a one hundred years old city mock-up [5]. Currently exposed in one of the thirty rooms of the museum, very few information are displayed about this mock-up. But as this mock-up represents about 4 square kilometres of Nantes city, we can imagine many applications, for many users, from historian expert to museum public. Nantes museum's main project is to develop a visually interactive, multitouch, database connected and content evolutive system, as shown on figure 2. Virtual visualization systems belong to the more modern interfaces in infocommunications and would allow us to provide high levels of interaction between information and users.

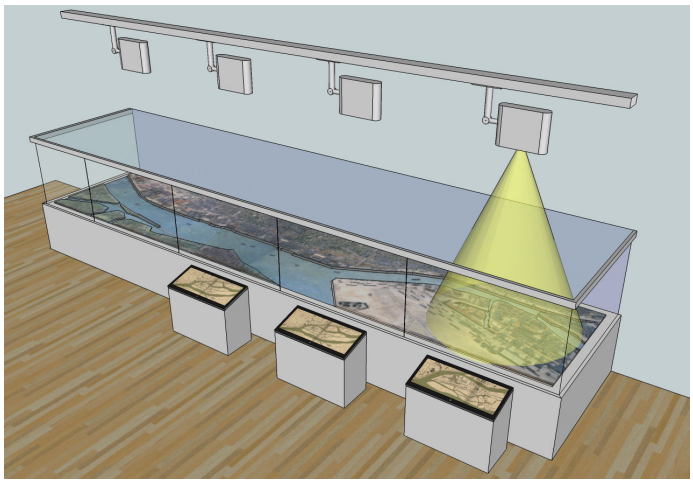

Fig. 2. Design view of the future museographic application

The project focuses not only on architectural data but also on social and economical aspects. This leads to a huge amount of knowledge (semantics merged with 3D data) and require automated or at least semi-automated system.

Before designing such application, we propose a global route: to virtualize the physical mock-up [6], to gather historical sources related to identified points of interest

978-1-4673-5188-1/12/$31.00 ©2012 IEEE

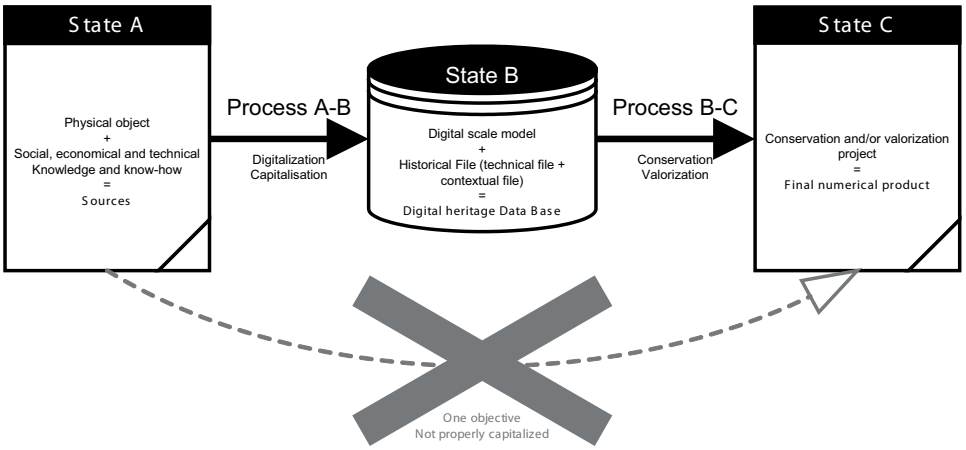

Fig. 1. General methodology to preserve and enhance the technical and industrial heritage [4]

(buildings, neighborood, historical thematics, etc.) and to link both of them into an enriched 3D model [7]. Thus, our methodology can be described as follow 1:

1) Modeling the system based on available information
2) Knowledge database for capitalising knowledge
3) Design end-user applications depending on purpose (museum, historians, architects, geomatic, etc.)

Finally, as far as infocommunications are concerned, there are many potentialities and issues due to the high level of user's cognitive capabilities. So many fields of competences are required. We will give further details on these points in the next sections of this communication.

II. Modeling the knowledge based system

What we have learnt from existing museographic projects is that we have to focus the whole system on information [8]. This way, the methodology can be re-used for other patrimonial objects. Several existing projects deal with the complexity of capitalising heterogeneous data [9], [10], [11], [12], but we have an additional step of complexity when dealing with historical content. As far as this research field is concerned, in an effort to efficiently capitalise historic knowledge, ontologies are often used such as CIDOC-CRM [13]. These are interesting ways for a formal structure, but we just try to make basic historic links for advanced visualization applications. Moreover, we don't know in advance what will be the future of an object. It can have several uses after its end of life (where "life" refers to its "initial" life : the purpose this object was made for), so we can't foresee what kind of data will be significant for future heritage promotion applications.

Based on previous works in the research field of ancient industrial archeology [14], our purpose is to capitalise both object's characteristics and external environments (that can evolve in a short, medium, or long term). Then, knowledge is naturally connected throughout a graph without any need of formalising the links as in semantic web. This step is obviously done in an interdisciplinary way with the help of historian experts 3.

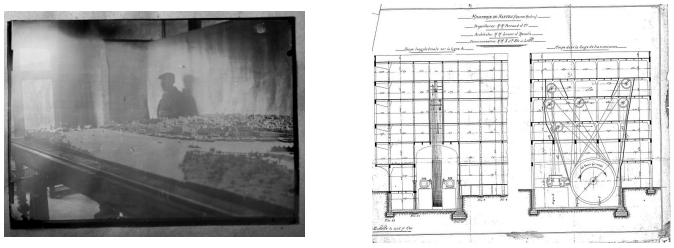

Fig. 4. Examples of heterogeneous historical sources — ©Archives municipales de Nantes

This methodology is part of other works related to cultural heritage objects for storing ancient knowledge (called Ancient industrial archeology, [15]). Challenge is due to the complexity of such patrimonial data. Capitalising the whole lifecycle of ancient objects raises several issues, such as the model of time (short, medium and long times), the connections between an object and its environment. To generalize our method, we propose to design a database that would store as much information as available on every object. It means we have to capitalise both internal structure (functional aspect, geometrical and temporal — often coupled — data) and external effects (multi-scale environments).

A. Historical information

As far as cultural heritage is concerned, an important part of the work is done by historian experts. This means a research campaign in available archives in order to gather a documentary corpus. These historical sources are heterogeneous (pictures, plans, text like shown on picture 4, which is an additional issue in terms of model.

When studying the historical mock-up, it appears that many points of interest have multiple connections. Those connections can be temporal, functional, geographical or structural. For both experts and general public, accessing and visualising such knowledge is a great challenge. So, based on historic sources, historian experts have written description sheets of every interesting point of interest. For each sheets, some given keywords are noticed and will allow us to create links 3. Then,

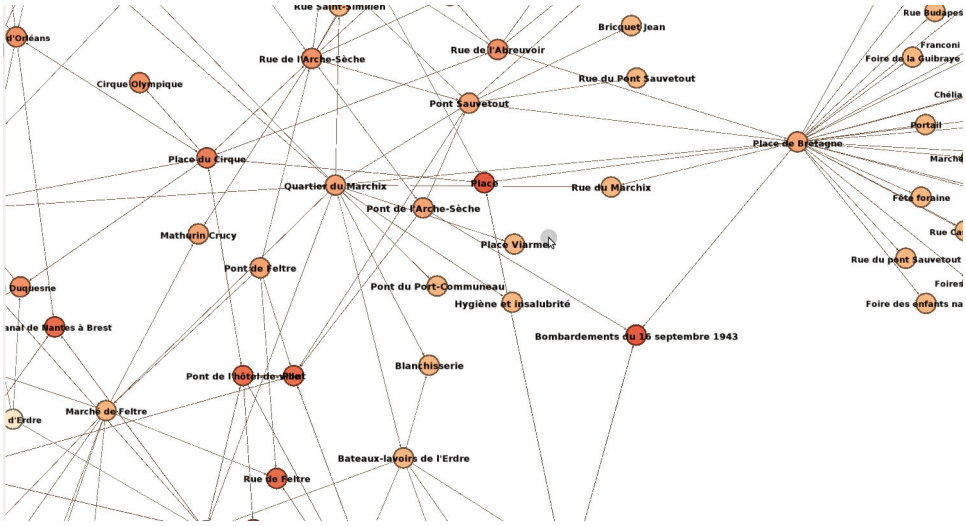

Fig. 3. A glimpse of our data structure

based on these informations, we capitalise the whole available knowledge (at this current step) for future access such as advanced visualization systems. In order to make automatic links between the semantic information and the geographic information on the physical mock-up, we decided to digitise the mock-up.

B. 3D digitization

In the litterature, few projects propose to digitize a large heritage object and to create a virtual model with many levels of details that are chosen by the users. Last experimentation known is the 3D digitalization of a physical mock-up of the city of Prague designed by Langweil. Data have been acquired by photographic systems [16]. Another experiment has been done by the Musée des Maquettes in France [17]. The physical mock-up representing the city of Toul has been digitalized in 3D and many photos have been taken. Then, the clouds of points have been combined in order to obtain a parametric virtual model. We can also quote the project named Rome Reborn whose purpose is to rebuild the city of Rome between the years 1000 BC to 500 AD. This project required numerous plans but also historical documents to understand the physical mock-up [18]. Every kind of digitization raised numerous problems. One of the most important of them is that it is impossible to visualize the enormous quantity of points acquired: files are so heavy. There are no software that can manipulate easily 200 millions of points. Consequently, digitized data were divided into several areas for being viewed independently and then simplified. We can find similar projects with art works digitization problem as The Digital Michelangelo Project [19].

The main idea developed in this communication is the use of cognitive infocommunications interfaces (e.g. virtual technologies) for cultural heritage enhancement. But, when we talk about heritage, there is not only architecture or castles as the architect Houdin and Dassault System have demonstrated using Catia V5 for understanding the Cheops pyramid [20]. Indeed, objects studied by our research teams belong to scientific and/or technical domains. Machines, industries and socio-economical context are also very important for a better understanding of our history. Our proposition consists in overturning the time axis of the design process generally used for developing contemporary technical products.

Contrary to examples presented in this state of the art, the specificity of all those projects is that the work is done manually; nothing is automatic. With Nantes1900 project, it would be impossible to do it manually due to the amount of data: neither the 3D cloud of points, nor the historical documents. Consequently, most of the process is semi-automated.

III. META-MODEL FOR HERITAGE KNOWLEDGE

In order to capitalise such heterogeneous data, we need to design a database that fits to the knowledge based system we introduced in section II. As far as object life-cycle is concerned, existing works in industrial research field can be used for our purpose. FBS-PPRE theory [21] gives us methodological advices for identifying key concepts to be taken into account.

Several dimensions have to be considered when dealing with heritage objects and lead to a complex lifecycle: product lifecycle (design and purposes, use, and promotion) but also a multidimensional space in which the heritage object is embraced (see “Scheme” definition in [15]).

- Interaction with its environment (value analysis) at a fixed time t (including the relationship between human and object). Thus, we have to consider the different steps in the object life, and the situations in which the heritage object is used;

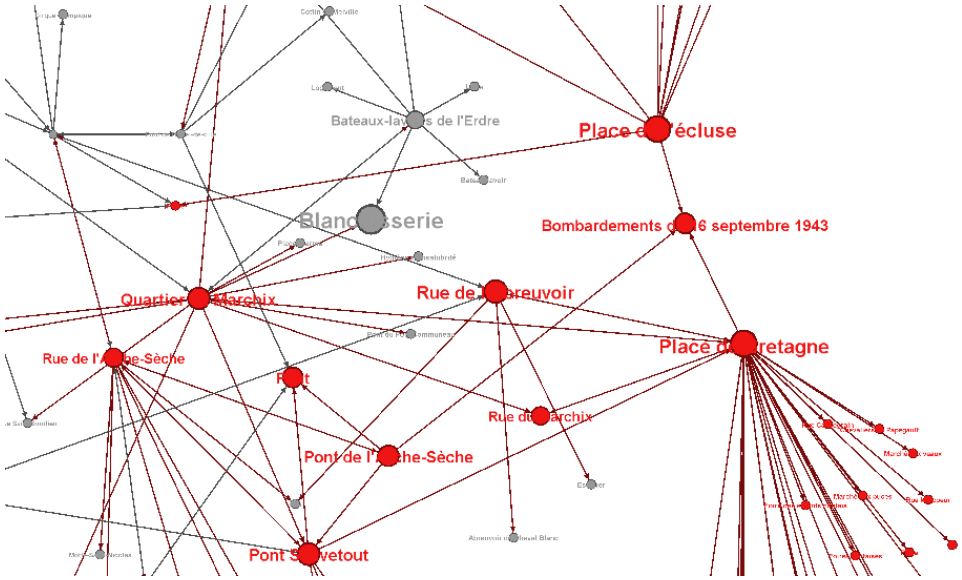

Fig. 5. Hypothetical historic paths

- Temporal links within the object (called internal view). Those links symbolize interactions between the different basic components that make up the object structure. Indeed, the function of the object itself evolves such as its characteristics;
- Temporal links between objects (called external view). It means that an ancient object will evolve in the context it is used for (in an organisational mean for example), but also in practises (human aspect).

Thus, the main objective is to gather every available information related to the object and to implement the links mentioned above. We will be able to create querying applications for each desired purpose:

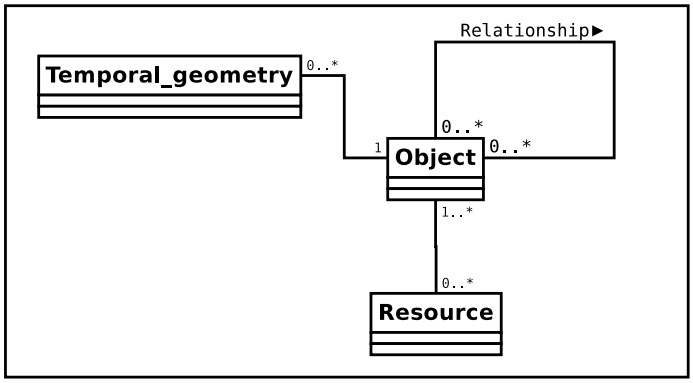

Fig. 6. Simplified glimpse of our database UML model

- Cultural promotion (*in situ*, immersive world, augmented reality) with possible evolutions (adaptative system);
- Historical research (by thematics, objects, or time);
- Urbanism, archeology, or even anthropology.

Many kinds of use can be identified for a heritage object during his lifecycle, especially for promotion stage, which can embrace various purposes : virtual reality, knowledge capitalization, teaching, and other unknown purposes. The complexity is mainly due to this step.

A. Knowledge database

Based on our meta-model proposal, we designed a relational database (see figure 6) with GIS support.

Thanks to this database, we can store both semantic data and geometrical data. It also allows us to store multi-dimensional levels of information for every point of interest. For example, we currently store districts, streets within a district, and building within a street (some ontologies already exist for such specific urban relationships such as MADS spatio-temporal model [22]. But we choose not to design formal ontology and to focus on global information). This way, we could produce a data model with infinite levels of detail such as a company, the factory owned by the company, and the different rooms within the factory. Consequently, the multi-level data and their links will be capitalised in our knwoledge database.

We obtain a data structure that can be represented like a graph (see figure 3) where nodes are historical points of interest and edges are links identified by historian experts as significants.

B. Exploring data

Our proof-of-concept (based on a similar wooden model than the Nantes harbour mock-up) starts with 30 historical sheets (dedicated to a particular point of interest, for example a building). We create 150 nodes (based on keywords), that automatically create links between existant information. From all this information, our goal is to create additional knowledge by identifying potential historic paths through this graph. This is one of our current research field because many parameters have to be taken into account. Most of the time, those

parameters are related to semantics or are manually identified by historian experts so that graph theory will have to be deeply analysed if this step need to be automated. But this is an interesting hypothesis for knowledge visualization (in both scientific and general purposes). End user's could be able to visualise people flows, raw material flows, etc.

In addition to these semantic and historic links, our data model allow us to store objects structure. But even if the studied object is a 1900's contemporary witness, we want to be able to capitalise the evolution of any point of interest during history. We then store a geometrical state on a given historic period so that any future or past situation can be stored depending on availability of such information. Ultimate goal should be an multi-agent expert system [23], that would create those thematic links automatically.

Virtual reality tools would then allow end-users to explore the different levels. Historian experts will finally be able to explore knowledge through different ways, and also to generate new knowledge that can be capitalised. These iterative steps represent a new way of analysing and visualising history and so can be a great tool for historian research works.

IV. Virtual Reality Applications and Discussion

Based on this data model, we are now able to design advanced querying systems depending on end-user's perspective. For a cultural promotion as introduced at the beginning of this paper, for research experts or any possible use case of all the knowledge stored. Those infocommunication interfaces provide a link between 3D representation(s) of the object and semantics.

We have two main categories of visualization application 7:

1) 3D mock-up based systems such as virtual world (see figure 8)
2) Semantic data based systems (such as web applications, search engines)

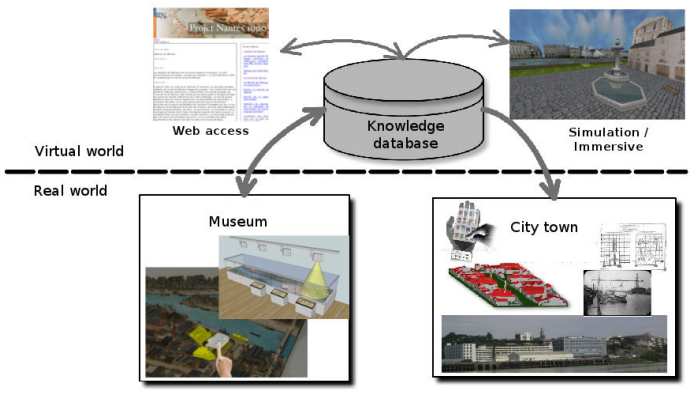

Fig. 7. Project applications in virtual and real worlds

- As explained in section II-B, many research works have been made related to our 3D cloud of points. Developed algorithms allowed us to extract basic semantic information (roofs, walls, ground), so that we hope to link the content in our database to specified elements in the 3D model. Then, we can imagine that a visitor would virtually and visually select geometrical elements inside the virtual world and get back some information.
- As far as the Nantes museum project is concerned, the final system will be operational at the spring of year 2014. The project is in progress and we chose to first design a prototype in order to validate some hypotheses, mainly towards ergonomy and use cases. Dealing with historical heterogeneous data visualization for general public raises many questions, such as "what should we show, and how? What is the best way to access such information?". Graphical design and cognitive aspects are also important and need significant work.
- Recently, mobile devices have raise and allow interesting applications using augmented reality, geographical information system. This is particularly interesting in the domain of cultural heritage promotion. General public could access data stored in knowledge database directly from portable device, depending on their geographical position.

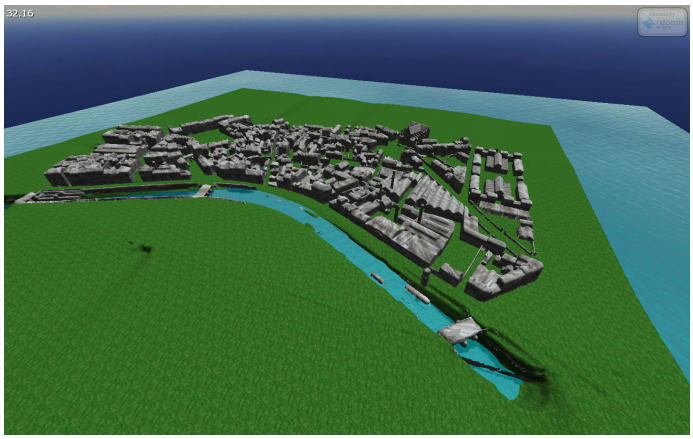

Fig. 8. Automatic generated virtual world

All those cognitive infocommunication applications would allow us to connect the virtual world to real world and to make links between past and present! Similar projects are already in progress such as the Chapelle des Ursulines development project lead by the LAMIC laboratory [1].

V. Conclusion

Dealing with digital technologies and historic heritage means wide interdisciplinary and interoperability between specialists and between tools. With this collaboration between engineering and human sciences, we achieved a methodology for capitalising ancient knowledge. Thanks to the focus on information and created knowledge, we are able to gather most of historic sources related to heritage objects. Based on these

[1] http://www.lamic.ulaval.ca/accueil/

data, we plan to design various cognitive infocommunication interfaces such as interactive multitouch application, virtual and immersive worlds, or augmented reality. This process may carry us to expert systems theory for better cognitive interfaces. We make the hypothesis that thanks to our meta-model, we will be able to design any future application so that we stay free from technology evolutions.

ACKNOWLEDGMENT

This project is supported by the European project called Visionair (http://www.infra-visionair.eu/) which the authors would like to thank.

REFERENCES

[1] P. Baranyi and Ádám Csapó, "Definition and Synergies of Cognitive Infocommunications," *Acta Polytechnica Hungarica*, vol. 9, no. 1, pp. 67–83, 2012. [Online]. Available: http://www.uni-obuda.hu/journal/Baranyi_Csapo_33.pdf

[2] B. Flynn, "Augmented visualisation: Designing experience for an interpretative cultural heritage," in *Information Visualisation, 2008. IV'08. 12th International Conference*. IEEE, 2008, pp. 447 – 452. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4577986

[3] R. Billen, P. Blain, O. Donneau, S. Habraken, Y. Renotte, and M. Van Ruymbeke, "Virtual model of the city of Liège in the eighteen century - " Virtual Leodium"," in *Proceedings of 3D Stereo MEDIA 2009, International 3D Stereo Film and Technology Festival (3D Stereo MEDIA), Liège, Belgium, 1-3 Dec. 2009.*, J. Verly, Ed., Liège, 2009. [Online]. Available: http://orbi.ulg.ac.be/handle/2268/34167

[4] F. Laroche, J.-L. Kerouanton, and A. Bernard, "A case study of capitalisation and valorisation of our technical heritage," in *CIRP Design Conference*, Apr. 2010. [Online]. Available: http://hal.archives-ouvertes.fr/hal-00473004

[5] Guillet B, Huron L, and Kerouanton J.-L, "La maquette du port de Nantes," in *"Des villes, des ports : la mer, les hommes" : 124e congrès des sociétés historiques et scientifiques*, Manneville P, Ed. Nantes: Éditions du CTHS, 2001, 1999.

[6] F. LAROCHE, D. Lefèvre, M. Servières, and A. Bernard, "Intelligent reverse engineering: AUTOMATIC SEMANTIC RECOGNITION OF 3D DIGITALIZED CLOUD OF POINTS," in *11th Biennial Conference on Engineering systems design and analysis*, Nantes, 2012, pp. 1–7.

[7] R. Billen, C. Carré, V. Delfosse, B. Hervy, F. Laroche, D. Lefèvre, M. Servières, and M. Van Ruymbeke, "3D historical models: the case studies of Liege and Nantes." in *COST Action TU801 workshop on Semantic Enrichment of 3D city models for sustainable urban development*, Madrid, 2012.

[8] H. Quisbert, M. Korenkova, and A. Hägerfors, "Towards a Definition of Digital Information Preservation Object," *Preservation*, pp. 11–22, 2009. [Online]. Available: http://www.springerlink.com/index/j5u68311w2k223q5.pdf

[9] M. Adiba, R. Lozano, H. Martin, and F. Mocellin, "Management of multimedia data using an object-oriented database system," in *Database and Expert Systems Applications, 1997. Proceedings., Eighth International Workshop*. Toulous: IEEE, 1997, pp. 106–111. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=617245

[10] S. Mecca, C. Cirinnà, and M. Masera, "A Semantic Web Portal for Supporting Knowledge Contribution, Sharing, and Management in the Earthen Architectural Heritage Domain," in *Terra 2008: The 10th International Conference on the Study and Conservation of Earthen Architectural Heritage*. Getty Conservation Institute, 2008, pp. 114–119. [Online]. Available: http://craterre.org/diffusion:ouvrages-telechargeables/view/id/31889df9c3ba804068290047b242185a

[11] Y. Keraron, "Le document numérique entre préservation et usage," pp. 105–128, Jan. 2008. [Online]. Available: http://www.cairn.info/article.php?ID_ARTICLE=DN_102_0105

[12] B. Bachimont, A. Isaac, and R. Troncy, "Semantic commitment for designing ontologies: A proposal," *Lecture notes in computer science*, pp. 114–121. [Online]. Available: http://cat.inist.fr/?aModele=afficheN&cpsidt=14800740

[13] M. Doerr, C. Ore, and S. Stead, "The CIDOC Conceptual Reference Model-A New Standard for Knowledge Sharing ER2007 Tutorial," in *Tutorials, posters, panels and industrial contributions at the 26th International Conference on Conceptual Modeling - ER 2007*, vol. 83, no. Er. ACS, 2007, pp. 51–56. [Online]. Available: http://crpit.com/confpapers/CRPITV83Doerr.pdf

[14] F. Laroche, "Une nouvelle forme de capitalisation des connaissances grâce à larchéologie industrielle avancée," *Documents pour lhistoire des techniques*, vol. 18, pp. 51–60, 2009. [Online]. Available: http://dht.revues.org/186

[15] ——, "Contribution à la sauvegarde des Objets techniques anciens par l'Archéologie industrielle avancée. Proposition d'un Modèle d'information de référence muséologique et d'une Méthode inter-disciplinaire pour la Capitalisation des connaissances du Patrimoine ," Ph.D. dissertation, École Centrale de Nantes, Dec. 2007. [Online]. Available: http://tel.archives-ouvertes.fr/tel-00382703/

[16] J. Burinek, "Digital langweil model of prague," 2008. [Online]. Available: http://www.langweil.cz/

[17] C. Chevrier, K. Jacquot, and J. Perrin, "3D modelling of a town scale model," in *Digital Heritage. Third International Conference EuroMed 2010 dedicated on Digital Heritage. Short Papers. Limassol, Cyprus, November 8-13, 2010*. Limassol: Marinos Ioannides, Dieter Fellner, Andreas Georgopoulos, Diofantos G. Hadjimitsis (eds.), 2010, pp. 99–107. [Online]. Available: http://amezule.crai.archi.fr/media/pdf/Chevier.pdf

[18] B. Frischer, "The Rome Reborn Project." *How technology is helping us to study history. . . .*, 2008. [Online]. Available: http://www.romereborn.virginia.edu/rome_reborn_2_documents/papers/Frischer_OpE

[19] "The digital michelangelo project." [Online]. Available: http://graphics.stanford.edu/projects/mich/

[20] "3d unveils the mystery of the great pyramid." [Online]. Available: http://www.3ds.com/fr/company/passion-for-innovation/the-projects/khufu-reborn/khufu-reborn

[21] M. Labrousse, N. Perry, and A. Bernard, "Modèle FBS-PPR : des objets d'entreprise à la gestion dynamique des connaissances industrielles," *Gestion Dynamique des Connaissances Industrielles*, Oct. 2004. [Online]. Available: http://hal.archives-ouvertes.fr/hal-00540012

[22] C. Parent, S. Spaccapietra, and E. Zimányi, *Conceptual Modeling for Traditional and Spatio-Temporal Applications: The MADS Approach*. Springer, 2006. [Online]. Available: http://www.lavoisier.fr/livre/notice.asp?id=2AKWO2AORA2OWY

[23] P. Sajja, "Multi-agent system for knowledge-based access to distributed databases," *Journal of Information, Knowledge, and Management*, 2008. [Online]. Available: http://pdf.aminer.org/000/262/313/trends_in_distributed_and_cooperative_database_n