

ARCHITECTURAL DESIGN ANALYSIS, HISTORICAL RECONSTRUCTION AND STRUCTURED ARCHIVAL USING 3D MODELS

Techniques, methodology and long term preservation of digital models

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Abstract: With the increased usage of 3D modeling, visualization, simulation and Building Information Modeling, architects produce 3D models, both for new designs and for historic reconstructions. However, these models are seldom shared to transfer structured information about the project. Even if they are exchanged, they are often not usable outside of their original design application. Additionally, digital archives with architectural content can not easily provide structured information about these 3D models, limiting their usefulness. This article discusses an approach to provide better structured models, using a combination of a sound methodology, the application of open file formats and additional metadata creation.

Keywords: *CAAD, Design Analysis, Reconstruction, Archival, Preservation*

Résumé : Avec l'utilisation croissant de la modélisation 3D, la visualisation, la simulation et la modélisation des données du bâtiment, les architectes créent des modèles 3D, pour les idées de conception nouvelles ou des rénovations historiques. Cependant, ces modèles ne sont pas souvent utilisés pour échanger l'information structurée, certainement pas dehors les logiciels de conception. En addition, les archives digitales avec le contenu architectural, n'ont pas assez de possibilités pour échanger des informations structurées. Cet article discute une approche qui combinera une méthodologie profonde, l'application des formats ouverts et la création additionnelle de méta data.

Mots-clé: *CAO, Analyse de design, Reconstruction, Archivistique, Préservation*

1. Introduction

In Architectural Design and Education, it is common to refer to prior design cases. This is apparent in a teaching context, where students often learn from examining existing projects, but also in a professional context, where reflection on existing buildings can inform the designer about possible solutions or as historic reference. With the increased usage of 3D techniques in modeling, visualization, simulation and Building Information Modeling (BIM), architects nowadays produce more and more designs as 3D models. These techniques can be used both in new design projects and in renovation

or reconstruction projects. Documenting historic buildings with 3D techniques is useful for many different reasons. They can be used as a digital replica of particular models, at any point in time, even when the building is not available, not accessible or even never realized as such.

In addition, since these models commonly are created in commercial design applications, they are usually stored in non-documented proprietary file formats. They are not always usable outside of the original design application and in many cases tied to a particular version of that application. While this might not immediately pose practical problems for the architect, the access to these models is at risk, in the near future. Sometimes fairly recent digital models can not always be reopened and accessed, unless the original design environment is reinstated.

Even when the problem of recreating the digital models could be solved, digital archives can not easily provide structured information about 3D models. It is, however, possible to improve and increase information about the design, by adding additional metadata to the 3D model, through “metadata enrichment”. This structured information can, in turn, facilitate the retrieval and recovery of such models, when searching or browsing for design information through online architectural repositories.

2. Methodology and Approach

This article discusses an approach to provide better structured models, using a combination of a sound methodology, the application of open file formats and additional metadata creation.

The methodology involves the creation of a “metafile” of project resources, relaying all historical resources to elements of the project, assisting the achievement of gradations of accuracy within the original source material. The metafile can be combined with 3D model visualization techniques to generate more legible reconstruction images, with an appropriate legend.

The application of open, documented file formats, together with the original design files, is part of the reconstruction methodology, allowing accessibility of the model, far beyond the regular lifecycle of the commercial design application that was used in the creation.

Finally, the proper description of the models with a suitable metadata scheme will ensure the availability of the material in online collections. Through metadata harvesting, models can be made accessible and retrievable for digital archives and repositories.

This will be illustrated with results from the 3D reconstruction of exemplary building projects and sites from recent history. The reconstructions used widely differing techniques, from regular 3D modeling using CAD and visualization software, to extensive measuring and surveying

techniques. The combination of these diverse techniques enables an increased accessibility of the inherent design information, which would not be established using each technique as such.

3. Digital 3D Reconstructions of historic buildings

During the previous years, several exemplary architectural designs have been reconstructed at the Department of Architecture, Urbanism and Planning from the K.U.Leuven, in Belgium ([url:www.asro.kuleuven.be](http://www.asro.kuleuven.be)). The projects comprise an interesting mixture of historic and modern buildings. They were elaborated by our research group, but also in the course of master theses projects, where the models served as a medium to perform an analysis of the architectural design and their historic context where appropriate.

Different applications and different techniques have been used, from generic modeling with CAD software to visualization techniques and animation. In most studies, the models were not the final outcome, but they fully served as a basis to create presentations, diagrams and visual analysis drawings. Table 1 briefly summarizes some of the case studies, which include historic reconstructions, but also 20th century modern buildings.

TABLE 1. Overview of Case Studies

Case Study	Techniques
Maison Du Peuple by Victor Horta (Brussels, Belgium)	ArchiCAD, 3ds Max
Town Hall and Historic City Center (Leuven, Belgium) (Vandevyvere et al, 2007) National Assembly Hall by Louis I. Kahn (Dhaka, Bangladesh) Vitra Pavillion by Tadao Ando (Weil-Am-Rhein, Germany) Broodhuys (Brussels, Belgium) Castle Boussu by Jacques Du Broeucq (Mons, Belgium) Indochina University by Ernest Hebrard (Hanoi, Vietnam) Palace of Justice by Joseph Poelaert (Brussels, Belgium) Rito Library by Henri Vandevelde (Leuven, Belgium)	AutoCAD 3ds Max/VIZ
Castle (Horst, Belgium)	SketchUp, 3ds Max
Ch. N.D. Du Haut by Le Corbusier (Ronchamp, France)	3ds Max, STL
Art Museum by Axel Schultes (Bonn, Germany)	AutoCAD, 3ds Max Unreal Engine
Palais Stoclet by Joseph Hoffmann (Brussels, Belgium)	SketchUp, 3ds Max Quest3D
Church of Saint-James (Leuven, Belgium) (Schueremans & Van Genechten, 2007)	Laserscanning, AutoCAD, Custom
Béguinage Church and Site (Hasselt, Belgium)	SketchUp, VRML
Hunting Residence Mary of Hungary, (Mariemont, Belgium) (Vandevyvere et al, 2007)	AutoCAD, VIZ, Flash

An important motivation for these case studies lies in their educational value. Students commonly learn about architecture by looking at exemplary

architectural design projects. While drawings and photographs are still a very suitable method to present these cases, current modeling and presentation techniques provide increased interaction and embedded information, which benefits the learning experience.

Historic reconstructions allow the recreation of the architectural artifact for different time periods. Modern CAAD techniques present a new arsenal of techniques of modeling, representation and analysis, as described in (Alkhoven 1991). Models of any chosen time period can be reconstructed and placed inside their original context, using a hybrid of resources, from areal photography to historic manuscripts and custom models. Especially in cases where the building is currently demolished or largely renovated or altered, the reconstructed model can be used to provide insight into the evolution of the building or the site. Martens and Peter (2002) also provide a nice example, where they explain the methodology behind reconstructing Historic Synagogues using ArchiCAD.

Figure 1 displays the dining room in the Palais Stoclet, located in Brussels (Belgium), by architect Joseph Hoffmann. While this building is still largely intact, it is not open to the public. The reconstruction was based on available drawings, on-site reference measurements using a Total Station system and images available from literature.

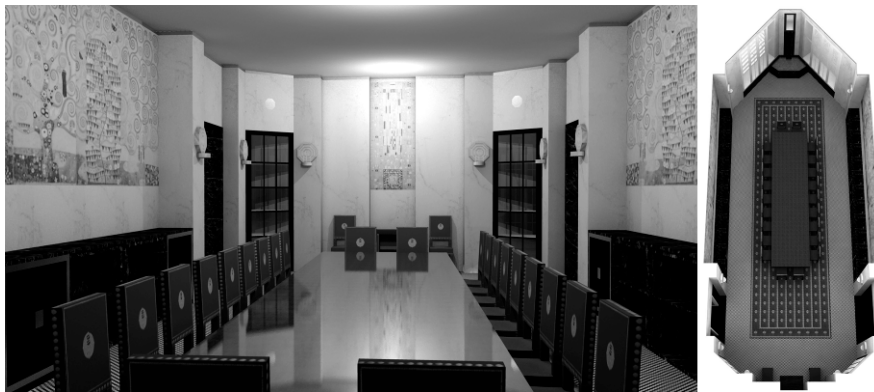


Figure 1: Palais Stoclet interior and open perspective

In this example, the added value of a digital reconstruction appeared not only in the different rendered images, but also in the possibility to derive and deconstruct the model, creating sections or see-through perspectives, which can not be obtained with other methods. It also allowed for export into a real-time navigation system (Quest3D).

Obviously, recreating buildings that are not available anymore or that were never built is one of the biggest advantages of utilizing 3D techniques. Larson (2000) used the Lightscape software to visualize some un-built

designs from Louis I. Kahn. The results of the visualizations still stand up today, when compared with recent renderings, but the software used is no longer available from Autodesk.

4. Structured information and the “Metafile”

While photorealism is often a desired outcome of a 3D reconstruction, it is not always required to provide insight. Many of the case studies have used the 3D model to generate not necessarily realistic pictures, but attractive visual representations of the building structure. By overlaying the images with additional annotation, such as arrows, text or colors, it is possible to create visually attractive diagrams, which can provide more insight into the building, with a visual language that might appeal to a wider audience.

Figure 2 displays the historic castle of Horst (Belgium) twice. The left image displays the different building phases, whereas the right image shows the degree of accuracy from the historic references.

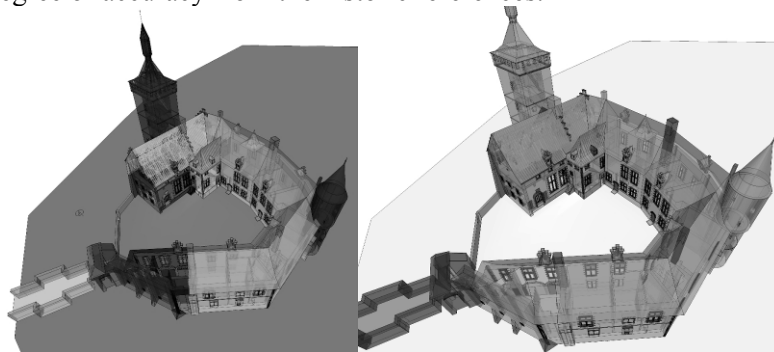


Figure 2: Color-coded model of Horst Castle

The methodological framework that was applied several times throughout the historic reconstruction case studies is described in (Vandevyvere et al 2006). It involves surveying, historic investigation, the creation of a “Metafile”, the modeling of the 3D digital model and commonly an enabling (multimedia) interface.

The Metafile is a tabular listing or a database of all retrieved and referenced resources, from documents, images, manuscripts and books. By summarizing all known historic facts or claimed construction steps, still referencing their source, they can be juxtaposed and compared. While the method of building such a table is quite straightforward, choosing categories or table rows is still investigated on a case-by-case basis. In some cases, this could follow the historic time line, whereas other cases have used different parts of the buildings to categorize the information.

Table 2 displays a small mockup table, indicating the kind of information that can be noted in the Metafile.

TABLE 2. Small fragment of Metafile

build/part	Facts	Sources	Iconography	...
Front House	First stone 1448 ... Restoration 1829	V-M constr. Bill ... Van Even Descr.	View on Market, 1610 ... Survey Plans In situ check 1997	
Roof Structure	Orig. struct. 1452-1460 Material oak ... Carpenter selected 1452	V-M constr. Bill ... Internal note 1997	In site survey	
...				

Even when the full table or database is created, it is not trivial to format it in a meaningful and readable layout. It would be helpful to create an interactive interface around the table, to be able to create ad-hoc filters and queries, while still being able to place related information side-by-side.

The example of the Horst Castle above relied on the Metafile to prepare and structure the color-coded visualization, indicating different aspects from the historic analysis. Vandevyvere et al (2006) describe the methodology in more detail.

5. Fast evolution of hardware and software

Reconstructing old stone inscriptions or paper documents from an archeological site can sometimes be easier than trying to reload a CAD model from nearly ten years ago.

As witnessed with the reconstruction of the digital model of the “BMW Bubble” as discussed in (Frank 2008), this is not trivial. The Bubble is an example of a fairly recent design project, which was created using digital techniques from within the conception stage. As it happened, to access the original CAD models, they had to recreate the complete hard- and software environment, which all had been superseded with newer technology. This involved the re-assembly of an old, broken SGI workstation, including the setup of the proprietary IRIX Operating System and the original design software from Alias|Wavefront.

There are several technical reasons that can be cited to explain the complexity and the difficulties involving the capability of accessing digital documents in the future. The combination of continuous hardware and software changes can make this process almost impossible.

On the level of hardware, almost every single component of a computer is replaced with newer, incompatible systems, in only a few years. This

includes the data carrier. No current system has the possibility to load old tape cartridges, optical discs and most systems stopped supporting floppy discs a while ago. Even if external readers would still be around, they have been using different connection ports. Serial and parallel ports, SCSI interfaces and many other default interfaces, such as IEEE 1394 (FireWire) are being phased out in the latest generation of desktops and notebooks, which seemingly offer only USB ports anymore. Computer screens and graphical adapters also keep changing connections types, from VGA over DVI to DisplayPort. Analogue connections are quickly disappearing.

On the software level, the same fast evolution can be witnessed. The Operating System (OS) and the design software all evolve continuously. In many cases, it is not possible to run old applications in recent incarnations of the OS. The follow-up for Windows Vista is already available for testing and Mac OSX Leopard removed support for the “Classic” environment, which is an emulation of the old MacOS 9. As a consequence, design software from ten years ago can not be installed on recent computers anymore.

A partial solution is virtualization and emulation. Because of the fast processor speeds and large amounts of working memory (RAM), current machines can launch older Operating Systems as if they were simply an application. Typical examples include Microsoft Virtual PC, Parallels Desktop, VMWare WorkStation/Fusion and VirtualBox. There are also numerous other approaches to either emulation or virtualization available, such as PearPC (PowerPC), Obelisk (MacOS Classic), WINE (Windows in Linux) or ReactOS (Windows-compatible OS).

However, many design applications, as they were quite expensive, were protected with hardware dongles, which still require a physical connection, such as a parallel or SCSI port, which emulation alone will not solve. In practice, it is easier to use a non-protected or even an illegal copy of the software, to avoid this problem, but this is clearly not allowed by the software license.

1.1. Add-ons and connections between applications

Still another possible future problem lies in the increasing interconnections between design applications. The recent years have shown a growing number of add-ons, which connect applications directly. E.g. several structural analysis applications can be connected with the Structural version of Autodesk Revit and several visualization applications offer linkage with the models from CAD and BIM applications. The biggest risk lies in the asynchronous updating of different applications. These connections are usually launched for particular application versions and their future support largely depends on adoption by end users.

1.2. Proprietary File formats and applications

Regardless of the chosen application for modeling or visualization, architects, designers and researchers are faced with work flow problems. Data has to be translated between very different systems, often requiring partial remodeling or restructuring of the passed geometry.

Design applications are commonly proprietary and they apply custom, usually undocumented file formats. With the increased complexity of the models and increased embedded functionality, the problem of accessibility will also grow.

Opening 2D CAD drawings in the AutoCAD DWG format is fairly well supported, even when using non-Autodesk software. The Open Design Alliance has developed, independently from Autodesk, software libraries to read and write files in the DWG format ([url:www.opendwg.org/faq](http://www.opendwg.org/faq)). Most developers competing with Autodesk utilize them.

With 3D models, the problem increases. The AutoCAD software has supported different modeling systems, throughout the years and the old Advanced Modeling Extension (AME) was discontinued, being replaced with ACIS modeling. Similarly, the Architecture extension of AutoCAD also poses much more compatibility problems in transferring information between application versions.

Transferring more intelligent data, such as parametric assemblies or digital building models is even more problematic. The application of a format such as the Industry Foundation Classes (IFC) is only supported with BIM applications and even then, information gets lost in the translation process. As described in (Mitchell et al, 2007), where the exchange between a design tool and energy analysis was investigated, the IFC model proved to be useful, but still incomplete, while at the same time being hindered by the modeling limitations of the BIM application.

An application such as Graphisoft ArchiCAD defines library objects outside of the main project file. While newer releases of the ArchiCAD software are able to read files from at least the last two releases, the objects reference external library files, in the GDL format. There are basically three approaches to manage older projects. Projects can be archived, with the used part of the library. While the archive format is still version-specific, the project is at least completely embedded in the archive. This is a usable approach for finished projects. A second option is the migration library, which contains all discontinued or incompatible library objects, which are not included in the default library. This allows people to load a project into a newer version of the software, maintaining all old library objects. Currently, this is only offered for the previous version of the software. A third solution, which is often followed by users, is not migrating running projects into the new version of the software. This is possible as the license allows the older

version to stay installed and the hardware dongle will also work for older versions. Recently, Graphisoft offered free conversion tools, based on older ArchiCAD releases, to assist with the transfer of older files towards the newer formats, albeit without solving the library problems ([url:www.graphisoft.com/support/archicad/downloads/Fileconverter.html](http://www.graphisoft.com/support/archicad/downloads/Fileconverter.html)).

This problem is far from unique in the architectural domain. Every sector will be confronted with the difficulties of proprietary systems and file formats in the upcoming years and decades. While there is the STEP standard, which is documented and open, there are still many reasons to rely on native file formats provided by the design software, as discussed in ([url:p-hamilton.blogspot.com/2008/12/cad-interoperability-native-files-vs.html](http://p-hamilton.blogspot.com/2008/12/cad-interoperability-native-files-vs.html)) to avoid the loss of intelligence and embedded design information. Similarly, Ken Fields discusses the pursuit of CAD File Compatibility ([url:www.caddigest.com/subjects/industry/select/010209_fields.htm](http://www.caddigest.com/subjects/industry/select/010209_fields.htm)).

(Patel et al 2008) describes the situation from the context of Product Lifecycle Management (PLM). The article suggests the combination of suitable lightweight formats, multi-layer annotation and the setup of a planning tool, containing a registry or repository of representation information, allowing for better informed choices for file format conversions.

Some firms offer their own approach to the problem. According to ([url:worldcadaccess.typepad.com/blog/2008/10/long-term-archiving-and-reuse-of-cad-data.html](http://worldcadaccess.typepad.com/blog/2008/10/long-term-archiving-and-reuse-of-cad-data.html)), the firm DataKit proposes a method for describing and classifying data using specific access and query methods. They call it the “ontological approach”, as existing formats, such as STEP do not seem to offer the full functionality with the data transfer of CAD documents.

Even outside of drawings or 3D models, such problems can occur. Many offices rely also on custom applications, developed within spreadsheet applications. Microsoft Excel has provided the Visual Basic for Applications (VBA) module for quite some time and many people develop custom solutions and application on this platform. However, this system is beginning to expose technical limitations and problems, which make its future uncertain. The latest release of the OSX version of MS Office did not offer support for VBA anymore, prompting users to migrate to the OSX-specific Applescript for custom developments. There were several reasons for this discontinuation, as explained in the Schwieb.com blog ([url:www.schwieb.com/blog/2006/08/08/saying-goodbye-to-visual-basic](http://www.schwieb.com/blog/2006/08/08/saying-goodbye-to-visual-basic)), citing platform differences, but also the old code base. It was also indicated that the porting to 64-bit systems will pose problems even for the Windows version of VBA. As a result, many offices re-evaluate their reliance on the software. Some firms decided not to upgrade for the time being. It also leads people to consider migration to other systems, such as OpenOffice, where

progress is made to offer compatibility with VBA ([url:vba.openoffice.org](http://vba.openoffice.org)), as a collaboration between Sun and Novell independent from Microsoft. However, recent announcements indicate the decision to continue the porting effort ([url:http://www.schwieb.com/blog/2008/05/13/saying-hello-again-to-visual-basic](http://www.schwieb.com/blog/2008/05/13/saying-hello-again-to-visual-basic)), probably pushed by the adverse reactions and negative comments from existing customers.

6. Metadata Description for digital archives

The creation and the presentation of reconstruction models poses some problems, which are mostly due to the large size of the 3D models, the different applied proprietary file formats and the commonly unstructured models. To make such models usable in content libraries thus presents a series of technical and logistic problems.

The authors are involved in MACE (Metadata for Architectural Content in Europe). This is a European *eContentplus* project ([url:mace-project.eu](http://mace-project.eu)), which investigates the usage of metadata to improve access to architectural content in online repositories (Heylighen et al, 2007). Within this project, an approach was set up to properly classify architectural content, by defining different taxonomies. The architectural domain taxonomy is a combination of common architectural classification systems, describing architectural features, such as function, performance and construction information. The media taxonomy, on the other hand, describes media objects, such as pictures, texts and other digital files. This taxonomy will have to be extended to properly cater for the description of 3D models. Common information about models could be collected, such as the kind of geometry, the amount of polygons, the availability of material and lighting information and so on. Searching through collected metadata, rather than looking at the actual models enables online retrieval of information. This does not directly solve the issues of large file sizes and proprietary formats, but it will facilitate the online recovery of models.

It was decided early on in the process of MACE to rely on Open Standards in the elaboration and the technical realization of the system.

1.3. Metadata description

All digital objects are seen as Learning Objects, which describe another entity, using metadata or information about data. In this project, it was decided to use the IEEE 1484.12.1 Standard for Learning Object Metadata (LOM, [url:http://ltsc.ieee.org/wg12](http://ltsc.ieee.org/wg12)).

In addition, this standard was extended to be better suitable for the description of architectural content. This involved mainly the extension of the classification, which is located in table 9 within the LOM standard.

This extension creates the MACE Application Profile (AP), which contains different types of metadata, being domain, context, competence and usage. A short extract from the MACE AP is displayed in Table 3.

TABLE 3. Small fragment of classification from MACE AP

MACE Application Profile	Explanation
LOM Category 9 classification	This fragment is lifted from a complete hierarchic thesaurus. It is structured in six main groups and further divided.
Conceptual Design Functional Typology commercial banking, financial facility Supermarket ... recreational facilities urban park exposition pavilion ... Form Typology tower ...	
Context Geographic Context landforms valleys mesas ...	Each term has an internal ID and can have multiple translations and synonyms.
Identification Project Type sculpture design urban design Intervention Type demolition new construction ...	
Theories and Concepts Theoretical Concepts creative process un-built projects ...	The thesaurus is managed dynamically, online, through the Protégé client and webservices by an expert panel from MACE.
	The internal IDs are used for all metadata enrichment.
	When harvesting external repositories, a mapping needs to be made between their classification (if any) and the MACE AP.

Domain metadata contains all classification information, for which a combination was made from several existing architectural classification systems, such as Uniclass, CI/SfB and parts of the Getty Art and Architecture Thesaurus. Context metadata deals with geographic locations, allowing content such as buildings, architectural offices or sites to be positioned on a map. Competence metadata is primarily meant to attach learning context information to digital resources, while Usage metadata is mostly generated through the system, from user activities.

1.4. Metadata Harvesting

To collect information from repositories with architectural content, the MACE project applies the Open Archives protocol for Metadata Harvesting (OAI-PMH, [url:www.openarchives.org/OAI/openarchivesprotocol.html](http://www.openarchives.org/OAI/openarchivesprotocol.html)).

This defines a unified communication protocol, which allows the system to collect or harvest metadata from the repositories, into a central metadata store. The protocol allows for incremental harvesting and updating, which is important to keep the collected information up to date.

It is suggested that the content providers give access to their metadata under a Creative Commons (CC) license, allowing for further adaption, but with attribution to the original content.

No actual content is collected with this approach, so original documents, full texts, images or models stay with the repository. This allows repository owners to keep their own policy on access and registration, if needed.

The sharing and collecting of information from an archive with digital models becomes possible, allowing for further reuse in other context, without losing the connection with the original model, as this will still be located in its original repository.

1.5. Metadata enrichment

Several services have been set up to extend the collected metadata. This extension is called “enrichment”. This is one of the main reasons for such a project, within the context of the EU *eContentplus* programme. Through the addition of metadata, contents will be better described and their retrieval and usage will improve.

An interesting aspect is the possibility of enriching content with information for which they were not initially set up. A database of architectural projects could receive geo-positions for all projects, even when the database was not structured that way. Similarly, new classification information could be attached to an item, regardless of the internal structure. Tutorials could be enriched with competence data, making their reuse and retrieval for course material easier and better structured.

Archives with digital reconstructions could thus be improved and better described, without any modifications to the archive itself.

1.6. Portal, Tools and services

Figure 3 gives an overview of the concept of the project, displaying the content from the repositories, the collected and enriched metadata and the services layer, which is used in the public portal. It also illustrates the connections between these components.

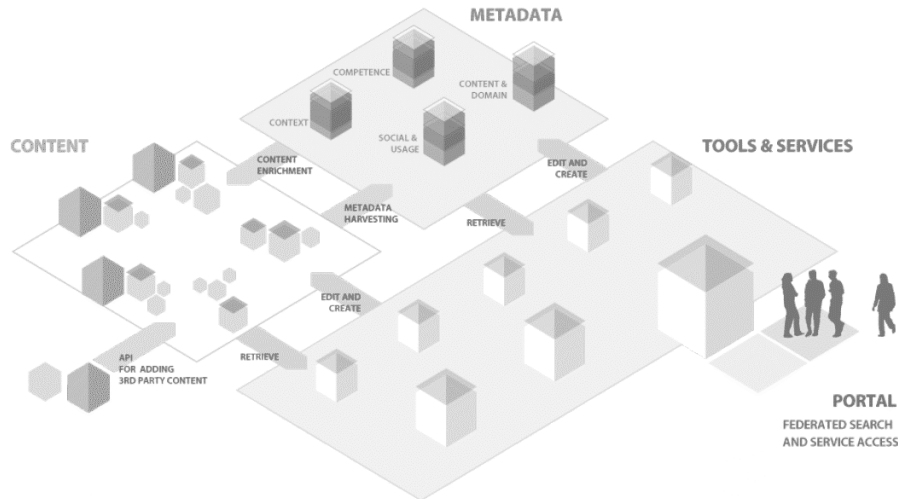


Figure 3. Schematic overview of the MACE system

The MACE portal offers search facilities, tagging of content and community features. The process is ongoing to include more content repositories by the end of the project, to improve its usefulness. Moreover, the EU funding specifically demands further availability after the granting period for at least three years. The project partners are currently evaluating several approaches for long-term sustainability of the system.

7. Conclusions and future work

Through case studies of historical reconstructions using 3D, several inherent problems with 3D reconstructions are revealed. The models often become very large and cumbersome to handle and they are not directly usable for exposition towards a larger audience, without access to the design software.

The problem of recovering models in proprietary formats is illustrated, even for models which have been created only a few years ago, because of changes in hardware, operating systems, design applications and file formats. Much of the potential of structured information is also lost because the end results of these reconstructions were often created in non-architectural applications, such as game engines and visualization applications.

A long-term strategy has to cater for different aspects, to improve the chance for models to stay accessible in the future. This strategy consisted of better structuring and describing of models using a Metafile of resources, conversion into open and documented formats, such as VRML, Collada or IFC and making models accessible and retrievable in online repositories.

Future work has to be performed to ensure the continuity of accessibility to the reconstructed models, which involves migrating files, converting them into Open Formats and properly describing them. This is not a one-time effort, but a continuous maintenance task.

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References

- Alkhoven, P: 1991, The Reconstruction of the Past: The Application of New Techniques for Visualization and Research in Architectural History, in: *Computer Aided Architectural Design Futures: Education, Research, Applications* (CAAD Futures '91 Conference Proceedings) Zürich (Switzerland), July 1991, pp. 549-566.
- Frank, B; Scharrer, B; Vogel, S: 2008, Save the bubble: The Architectural Archive in the Digital Age, in: *Browsing Architecture, Metadata and Beyond. EAAE Transactions on Architectural Education no. 40. Online repositories in Architecture*, Fraunhofer IRB Verlag, pp. 224-236.
- Heylighen, A; Neuckermans, H; Wolpers, M; Casaer, M; Duval, E: 2007, Sharing and Enriching Metadata in Architectural Repositories, in: *Predicting the Future [25th eCAADe Conference Proceedings]*, Frankfurt am Main (Germany), Sep 2007, pp. 401-408.
- Larson, K: 2000, *Louis I. Kahn: Unbuilt Masterworks*. The Monacelli Press, Inc., New York, USA, 2000.
- Martens, B; Peter, H: 2002, Developing Systematics Regarding Virtual Reconstruction of Synagogues, in: *Thresholds—Design, Research, Education and Practice, in the Space Between the Physical and the Virtual, Proceedings of the 2002 Annual Conference of the Association for Computer Aided Design In Architecture*, Pomona (California) USA, Oct 2002. ACADIA, pp. 349-356.
- Mitchell, J; Wong, J; Plume, J: 2007, Design Collaboration Using IFC, in: *Proceedings of the 12th International Conference on Computer Aided Architectural Design Futures*, Sydney (Australia), pp. 317-329.
- Patel, M; Balla, A; Ding, L: 2008, Curation and Preservation of CAD Engineering Models in Product Lifecycle Management, in: Ioannides, M; Addison, A; Georgopoulos, A; Kalisperis, L (eds): *Digital Heritage – Proceedings of the 14th International Conference on Virtual Systems and Multimedia (VSMM 2008)*, October 2008, Limassol (Cyprus), pp. 59-66.
- Schueremans, L; Van Genechten, B: 2007, The use of 3D-scanning in structural restoration projects – a case study on the Church of Saint-James illustrating the possibilities and limitations, in: *International Journal Optics and Lasers, special issue related to 3rd Workshop on Optical Measurement Techniques for Structures and Systems, Optimes 2007*, May 2007, Leuven (Belgium)
- Vandevyvere H; Neuckermans H; De Jonge K: 2006, Digital historical reconstruction; Case studies of an interdisciplinary task, in: *International Journal of Design Sciences & Technology*, 13(1), pp. 51-65.