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IMPROVING ARCHITECTURAL DESIGN ANALYSIS USING 3D MODELING AND VISUALIZATION TECHNIQUES

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ABSTRACT:

In Architectural Design and Education, it is common to refer to prior design cases. This is apparent in a teaching context, where students study existing projects, but also in a professional context, where reflection on existing design examples can inform the designer about possible solutions or as historic reference. With the increased usage of 3D techniques in visualization, simulation and Building Information Modelling, architects nowadays produce more and more designs as 3D models. While these models provide new means to visualize and interrogate the design, much of this potential is left unused, as the models are seldom shared to exchange design information.

This article discusses results from the 3D reconstruction of exemplary building projects and sites from recent history. The reconstructions used widely differing techniques, from regular 3D modelling using CAD and visualization software, to extensive measuring and surveying techniques. These examples illustrate the added value 3D models enable, compared to traditional drawings or photographs. Even the structure and presentation of recent design projects can be improved using diagrams and overlays, capitalizing on the results of the 3D modelling efforts.

In parallel, it is possible to improve and increase information about the design, by adding additional metadata to the 3D model. The "enrichment" of the 3D models make better structured information available, which can in turn, facilitate the retrieval and recovery of such models, when searching or browsing for design information through online repositories.

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.

1. INTRODUCTION

1.1 Overview

This article discusses a series of digital reconstructions of architectural projects. The first section summarizes the case studies while the following sections describe conclusions and recommendations on the followed techniques and methodology.

1.2 Context

During the previous years, several exemplary architectural designs have been reconstructed at the Design & Building Methodology research group from the K.U.Leuven Department of Architecture, Urbanism and Planning (Leuven, Belgium). The projects comprise an interesting mixture of historic and modern buildings. They have been 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, where appropriate, their historic context.

Different applications and different techniques have been applied, from generic modelling 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.

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 modelling and presentation techniques provide increased interaction and embedded information, which benefits the learning experience.

Historic reconstructions allow the recreation of the architectural artefact for different time periods. Modern CAAD techniques present a new arsenal of techniques of modelling, representation and analysis, as described in (Alkhoven, 1991). Models of any chosen time period can be reconstructed and places 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.

1.3 Case Studies

The next section presents a summarized overview of conclusions that emerged from a series of case studies, which have been elaborated partly in collaboration with several master students, during the previous years. In most cases, the reconstruction model was used not only for visualization but also to assist an architectural analysis, e.g. on historic reconstruction, circulation patterns or the use of light and daylighting.

The case studies have different characteristics and have utilized different techniques. Information retrieval is often the result of a literature research, but if the project was accessible, on-site measurements have been taken, using a combination of traditional and photogrammetric techniques. In some cases 3D laser scanning techniques have been applied, as described in (Schueremans and Van Genechten, 2007) and (Santana Quintero and Van Genechten, 2007). The visualization outcome is also identified, ranging from 2D CAD drawings to rendered 3D models or even interactive scenes.

The case studies include historic reconstructions, but also 20th century modern buildings.

- Town Hall and Historic City Center (Leuven, Belgium) (Vandevyvere et al, 2007)
- Maison Du Peuple by Victor Horta (Brussels, Belgium)
- Indochina University by Ernest Hebrard (Hanoi, Vietnam)
- Ch. N.D. Du Haut by Le Corbusier (Ronchamp, France)
- Castle (Horst, Belgium)
- Palais Stoclet by Joseph Hoffmann (Brussels, Belgium)
- Vitra Pavillion by Tadao Ando (Wheil-Am-Rhein, Germany)
- National Assembly Hall by Louis I. Kahn (Dhaka, Bangladesh)
- Art Museum by Axel Schultes (Bonn, Germany)
- Castle Boussu by Jacques Du Broeucq (Mons, Belgium)
- Hunting Residence Mary of Hungary, (Mariemont, Belgium) (Vandevyvere et al, 2007)
- Rito Library by Henri Vandevelde (Leuven, Belgium)
- Béguinage Church and Site (Hasselt, Belgium)
- Broodhuys (Brussels, Belgium)
- Church of Saint-James (Leuven, Belgium) (Schueremans & Van Genechten, 2007)
- Palace of Justice by Joseph Poelaert (Brussels, Belgium) (currently in progress)

2. DIFFERENT APPROACHES TO MODEL AND VISUALIZE RECONSTRUCTED BUILDINGS

An important advantage of digital reconstructions and 3D models over regular drawings or photographs is the added information they can represent. Even fairly simple models can be used to create augmented diagrams, overlaying graphics and text on top of rendered images.

2.1 Modelling

Table 1 juxtaposes different modelling techniques. Not a single technique is best fit for both drawings and 3D models with full support for organic or freeform geometry and with included visualization. In all cases, some compromises have to be made, which leads to the need to translate models between different applications.

	Advantages	Disadvantages
Mesh Modelling (e.g. SketchUp)	Quick to model	No 2D drawings No visualization
Generic CAD (e.g. AutoCAD)	2D drawings 3D models Accuracy	Disconnect between drawings and model
Building Information Modelling (e.g. ArchiCAD)	2D/3D developed concurrently Integrated listing and visualization	Limited for freeform geometry External tools for advanced visualization
Digital Content Creation (e.g. 3ds Max)	Freeform models Visualization and animation	No drawings Difficult for accuracy and scale

Table 1: Comparison of Modelling Techniques

Regardless of the chosen application(s), architects, designers or researchers are faced with work flow problems. Data has to be translated between very different systems, often requiring partial remodelling or restructuring of the passed geometry. 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 modelling limitations of the BIM application.

In all cases, the translation process will also be unidirectional, where a model is translated, extended and then, possibly, translated into another tool. There is no way to synchronize these modifications between different applications. For a static reconstruction, this might seem less problematic than the modelling of a design-in-process, but nevertheless, new and updated information might and will become available during a reconstruction project and inserting it into the original model will start the translation process once again.

The choice of a modelling system directly reflects the potential outcome. E.g. the previous table clearly indicates that the need for 2D drawings leaves no choice but to apply CAD or BIM applications. Generic CAD software can use the 2D drawing to generate a 3D model, but consequent changes in the drawing are not reflected to this model. The only method where the 2D drawings can be elaborated alongside the 3D model is the use of BIM software. But the mediocre support for freeform geometry in these applications, make them unsuitable for highly organic architecture. In the reconstruction model of the Maison Du Peuple the ArchiCAD BIM application was applied to create a simplified model of the complete building layout, mainly to derive 2D drawings, while the highly ornamented façade details were recreated in Autodesk VIZ, using parametric lofting techniques. It would have been possible, in theory, to created parametric scripted GDL entities (Nicholson-Cole, 2000) in ArchiCAD as well, but this would have taken considerably more time, especially since there is little repetition in these entities.

A good example of the application of BIM methods can be found in a case study for historic reconstruction of synagogues (Martens et al, 2002). The study suggests that a structured approach can hugely improve the documentation and reconstruction process, which is important with the sometimes delicate nature of these projects.

2.2 Rendering and Visualization

With the potential of defining accurate simulations of materials and lighting, modern visualization applications provide means to create images that are of a similar quality as photographs. The term photo-realistic has been used for quite some time and visualization artists have produced images that can not be distinguished from reality for many years. An excellent example of the quality that can be achieved, even with currently outdated technology, are the reconstructions of unbuilt works of Louis I. Kahn (Kent Larson, 2000).

However, this aspect required extensive experience, which often means that these results were not obtainable by architects or designers, who need visualization as a by-product of the design process. Similarly, creation historic reconstructions up to a level of visual quality that seems to be expected with current technology, often demands the outsourcing of this tasks to artists, leading to results as collected in the books from Ballistic Publishing, such as Exposé (Snoswell, Teo, Eds., 2003) and Elemental (Wade, Snoswell, Eds., 2004).

The integration of improved lighting and material simulation, leading to applications such as Maxwell Render, by Next Limit (http://www.maxwellrender.com), has shown the potential to utilize algorithms which mimic the behavior of light in the real world, rather than using simplified methods to create nice looking images.

In the Vitra Pavillion and Ronchamp Chapel case studies, attempts were made to juxtapose images of the 3D model alongside photographs taken on site. In both cases, the same software was used, in casu Autodesk VIZ, but the availability of more efficient and easier to use rendering engines has displayed great improvements over the last few years, as displayed in Figure 1, which was created in 2003 and Figure 2 which was rendered in 2007.

Figure 1: Vitra Pavillion, picture versus rendering

Figure 2: Picture versus Rendering of Ronchamp Chapel

The comparison mainly proves the achievable quality. The added value, however, is the possibility to create images that are not available with regular means, such as orthographic views, bird-view images or even disassembled sections. Figure 3 shows a rendered orthographic projection of the Indochine University reconstruction.

Figure 3: Orthographic Rendering of Indochine University

Figure 4 displays the dining room in the Palais Stoclet. While this building is still 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 4: Palais Stoclet interior and open perspective

In this particular example, the added value was not only the different rendered images, but the possibility to derive and deconstruct the model, creating sections or see-through perspectives, which can not be obtained with other methods.

Figure 5 displays a conceptual rendering of the dining room as an open perspective, locating this room in the whole of the building.

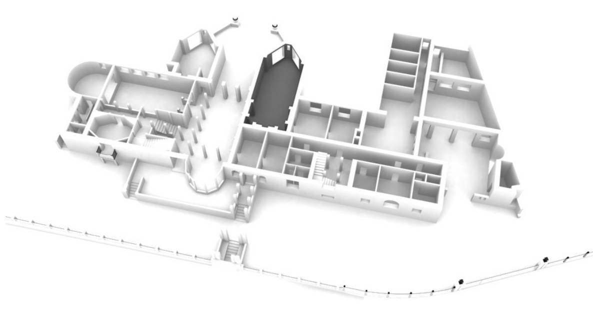

Figure 5: Locating the dining room in Palais Stoclet

2.3 Schemes and diagrams

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 6 displays the Horst Castle twice. The left image displays the different building phases, whereas the right image shows the degree of accuracy from the historic references.

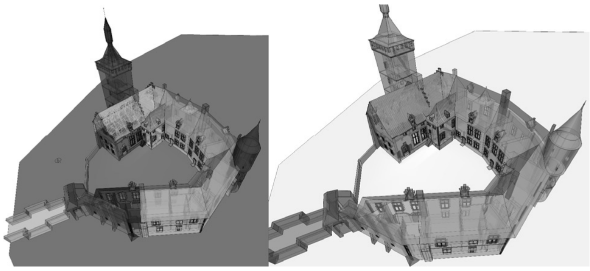

Figure 6: Color-coded model of Horst Castle

Figure 7 shows a similar approach to display the degrees of accuracy as witnessed in the reconstruction of the Hasselt Béguinage Church.

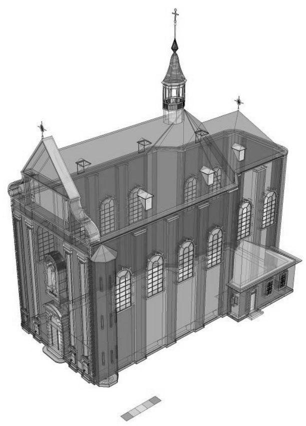

Figure 7: Color-coded model of Hasselt Béguinage Church

The same reconstruction also displayed the church in its environment, for different time periods. Figure 8 compares the 1842 context with the current situation, where only a ruin is left.

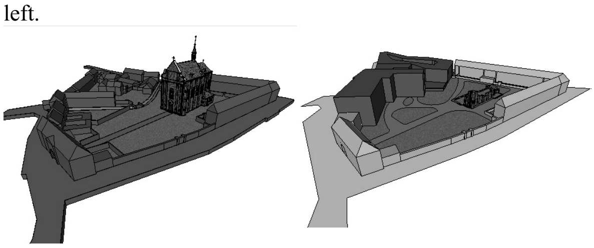

Figure 8: Comparing 1842 and 2007 context

The possibility to augment renderings with additional information is only partially achievable with regular drawings or photographs. Especially in an analysis and educational context, this proves to be very useful.

2.4 Realtime visualization

The Horst Castle and the Hasselt Béguinage models were converted to VRML files (http://www.web3d.org/x3d/vrml), as shown in Figure 9. This allows real-time exploration and gives the possibility to embed interactivity and hyperlinks. While the VRML technology is currently superseded with the X3D initiative, it is still widely supported by many modeling systems and still presents an accessible approach, despite its limitations, such as lack of streaming support.

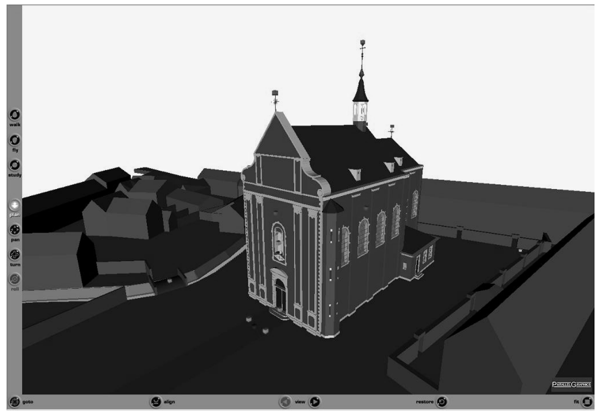

Figure 9: VRML model of Hasselt Béguinage Church

The model of the Art Museum in Bonn was translated to the Unreal game engine (http://www.unrealtechnology.com). 3ds Max was used to transfer the original AutoCAD model into ASE files for import as so-called “static meshes”. While the end result was an interactive model, complete with textures and partial shadows, the process was very involved.

The possible end result could ultimately lead to models such as the famous reconstruction of the F. L. Wright Kaufmann House (Falling Water) by 3D artist Kasperg (http://twhl.co.za/vault.php?map=3657) using the Half-Life 2 level editor. This particular model is rich in visual quality, utilizing lights, shadows, textures and even sound to convey an immersive end result. Yet, the process required a considerable amount of effort, bypassing traditional modeling tools and using the fairly primitive level editing software that was developed for the game. This was required to get to a playable and reasonably efficient model, which would not have been possible using common 3D modeling techniques.

In the Stoclet reconstruction, the model was translated into Quest3D (http://quest3d.com) as shown in Figure 10, which was used to generate a self-contained interactive model, allowing the user to walk through the building in realtime, exploring the structure and the different corners of the building.

Figure 10: Quest 3D interactive model of Palais Stoclet

The model was quite elaborate, but still was not a complete reconstruction, leaving several unfinished sections and gaps. They are not immediately noticeable, but can be discovered in the interactive model. There are some important limitations, however. The interactive model requires a Windows system and can only be run on a fairly well equipped machine with a decent graphics adaptor to be able to smoothly display the model.

In the case studies, mainly three different techniques have been studied, with different advantages and disadvantages. They are displayed in Table 2. All systems have decent support for hardware acceleration, using the graphics adapter.

	Advantages	Disadvantages
VRML models	Open Standard Widely supported Interactivity Hyperlinks Cross-platform	No shaders in current viewers No streaming
Game Engines (e.g. Half-Life 2 Source Engine, Unreal Engine)	Cheap application Free level editing Visual Quality (shaders)	Elaborate transfer “Weapons” visible Expensive licensing
Dedicated interactive systems (e.g. Quest 3D, VRContext)	Extensive interactivity Standalone viewer	Expensive Not always cross-platform Complex to use

Table 2: Comparison of realtime techniques

The potential of these systems is often diminished by the large effort it takes to translate an architectural model from a CAD or 3D application into a usable interactive model. The process is unidirectional and many steps take a considerable effort to turn the model into an efficient scene.

Some software firms try to solve this by providing direct exporting modules for a CAD or 3D system, but this usually limits the possibility to insert interactivity and the solutions are often expensive. Examples include Cult3D, TurnTool, EON Reality and VRContext.

3. STRUCTURING THE RECONSTRUCTION

3.1 Methodology

The methodological framework that was applied several times throughout the historic reconstruction case studies is described in (Vandevyvere et al, 2007). It involves surveying, historic investigation, the creation of a “Metafile”, the modelling of the 3D digital model and finally an enabling (multimedia) interface.

3.2 Metafile of resources and accuracies

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 3 displays a small mockup table, indicating the kind of information that can be noted in the 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. structure 1452-1460 Material oak … Carpenter selected 1452	V-M constr. Bill ... Internal note 1997	In site survey	
…				

Table 3: small fragment of Metafile

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.

4. AVAILABILITY FOR A WIDER AUDIENCE

Even though the case studies indicated the different techniques that can be applied for modelling and visualization, there is often the need to disseminate and communicate these results to a wider audience, such as students or visitors of an exhibition portal or website.

While it is easy to present rendered images in a text or on a website, it is beneficial to provide some form of interactivity. The case studies have also investigated some possible approaches to enable this.

4.1 Presentation Techniques

The Mariemont reconstruction was used in an art exhibition, in the form of an interactive Flash gallery, on a CD-ROM. A series of rendered images was used to allow visitors to interactively turn around the reconstructed model, without the requirement of a real-time system or loading full 3D models. Most computers have the Flash player installed, which makes the result potentially compatible towards a larger audience.

The Hasselt Béguinage case study presented the result as a website, with hyperlinks to the VRML model. This model in its turn contained several links, embedded inside the interactive scene towards additional references, such as manuscript excerpts, pictures or PDF documents. The model became the interface. This was possible since the model itself had only a low level of detail. The end user has to install a VRML browser plug-in, however, to be able to load the interactive model in a web browser.

While the Bonn Art Museum and the Stoclet Palace have utilized more advanced real-time animation systems, they suffered from a very labor intensive translation effort and high system requirements, making the interactive model only suitable for powerful Windows-based CAD or gaming workstations. The interactivity was also limited to exploring the scene, using gravity and collision detection. The programming of additional interactivity proved to be difficult and would ad an additional level of complexity in the reconstruction. Ironically, the study using the aged VRML format realized better interactivity, using the helper objects in 3ds max, to embed actions such as following an external hyperlink.

The Leuven Town Hall and the Ronchamp Chapel have been translated into STL files and were used to generate physical models, using Stereo Litographic techniques, as shown in Figure 11.

Figure 11: Stereo Lithographic model of Leuven Town Hall

However, the end results took several hours of preparation by an expert, to optimize the model for a faultless output. Moreover, the final model, while intricately beautiful and visible for a non-specialist audience, is very brittle. Touching the model is not feasible in an exhibition context, as the small details can easily be broken.

A potential further exploration is the inclusion of external reference information inside an interactive system. Examples such as Google Earth or Second Life illustrate that there are means to interact between a virtual world and an online community, by connecting content from external sites into the system. With Google Earth, users can create 3D models of sites or buildings and allow users to load them into this world. There are several users investigating means to embed dynamic information into otherwise static environments, e.g. embedding real-time weather or mapping information into Second Life, as presented on the Digital Urban blog (Batty, Smith, 2005).

4.2 Towards retrievable information in an online repository

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 Contents in Europe). This is a European eContentsPlus project (http://www.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. Online retrieval of information is enabled by searching through collected metadata, rather than looking at the actual models. This does not directly solve the issues of large file sizes and proprietary formats, but it will facilitate the online recovery of models.

In addition, it is envisaged to make more extensive use of Open Standard formats, such as VRML or IFC, which enables models to become accessible in the future. Through these case studies, the problem of recovering models in proprietary formats is already apparent, even for models which have been created only a few years ago, because of changes in applications and formats. A long-term strategy has to cater for their conversion into open and documented formats, to ensure their availability in the following years. With most design applications evolving into yearly updates, this problem might increase even more in the future. It is important to keep digital reconstructions accessible for the following generations.

CONCLUSIONS

While these case studies have shown the added value of digital reconstructions, for models from any time period, their outcome is still limited by several factors.

The models often become very large and cumbersome to handle. They are also not directly usable for exposition towards a larger audience. And finally, much of the potential of structured information is lost, because the end results were often created in non-architectural applications, such as game engines and visualization applications.

To combine interactive models with embedded architectural information requires the combination of different techniques, such as transferring models to open standards and the addition of metadata to facilitate online retrieval.

Future research could explore these possibilities.

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Figure 6: Peter Sterckx
Figure 7, 8, 9: Peter Savenay
Figure 11: Model: Han Vandevyvere, Manufacturing: PMA at K.U.Leuven University

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