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Interpretation Management: How to make sustainable visualisations of the past

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Abstract

Current technology allows us to more and more easily create threedimensional models of landscapes and man-made structures and to visualise these models in several interactive and non-interactive ways. In the eighties, the idea arose at IBM to use this technology, which had been developed for designing and visualising structures that still had to be built, also for visualisation of structures that had existed but disappeared for one reason or another.

Although there is no fundamental technological difference between visualising structures that still need to be built and structures that have existed, there is a major conceptual difference because our knowledge of the past is partial and uncertain. In fact, we are not able to reconstruct the past at all. Even for the nearby past, we lack a lot of information to fully reconstruct structures that have disappeared.

We can try to puzzle together all information we have about a certain structure in a certain time period, and try to visualise this incomplete and uncertain information in the best possible way. This paper explains the methodology for doing this in a correct and reproducable way. In fact, archaeological and historical research have been using similar methods already for a long time, but this methodology hasn't been implemented yet for 3D visualisation, except for some pioneering efforts (see for example [NUME], [ROME]).

In this paper, we explain and illustrate methods such as source assessment, source correlation and hypothesis trees that help to structure and document the transformation process from source material to 3D visualisation. We will also discuss the different approaches of 3D visualisation in research and in public presentations, and present a tool to manage the interpretation process.

The key goal of this paper is to propose a methodology and tool to make open, sustainable 3D visualisations of the past and turn them into an instrument that is accepted in both the research and public presentation domain. This tool is part of the EPOCH Common Infrastructure that provides concrete tools and solutions for common problems in the cultural heritage domain.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Methodologies and Techniques]: Standards

1. Background

3D visualisation uses our current capabilities to create three-dimensional models of objects, and show them in different ways with varying degrees of realism and interactivity. 3D visualisation has proven to be able to recreate and visualise historical structures (buildings, cities, landscapes, man-made structures, ...) and is becoming more and more an accepted method for showing interpretation in historical and archaeological research.

3D visualisation however had and partially still has the connotation of lacking crediblity and documentation [RYAN96], which can lead to producing too optimistic and even false conclusions about the past and about the premises and possibilities of archaeology as a discipline [RYAN01]. Many cultural heritage specialists have voiced their concerns about the improper use of 3D visualisation and the lack of a proper methodology to produce recreations of the past [BOU00].

Although the term *interpretation* has other meanings and connotations in other domains, we use it here to indicate the intellectual process of turning source material into conclusions. In the context of 3D visualisation, these conclusions are of course focused on all visualisation aspects, but in fact the visualisation process is embedded in most cases in the wider interpretation process, and only helps to support research or transfer knowledge to the wider public.

We don't use the term *virtual reconstruction* because our main goal is not to reconstruct the past – this is something we simply can't do – but to bring together all available sources of information and visualise this with 3D technology. Visualisation can be very useful in a research context but also for public presentation. This means that we don't want to obtain always photorealistic, complete models of landscapes or man-made structures, sometimes we only want schematic or simplified representations. Therefore we use the general term *3D visualisation*.

Most of the technological issues in this field have reached a sufficient level of solution, and a variety of tools is available for most 3D visualisation tasks. The process of turning available sources into a 3D visualisation on the other hand is far less defined. This interpretation process not only takes most of the time within the visualisation process, it is also a complex, non-linear process that can profit significantly from tools that manage and organise this process. In other words, *interpretation management* is a key element of 3D visualisation of historical structures, as it records and manages how the available sources have led to the 3D visualisation, and supports and smoothes the interpretation process.

2. What purpose does interpretation management serve?

There are several reasons why interpretation management is necessary when visualising 3D models of historical structures.

First of all, it *records* the interpretation process and documents how all elements in the visualisation have been derived from the available sources. This is a necessary step, as practice shows that 80 to 90 percent of the work of 3D visualisation of historical structures goes into the assessment and interpretation of the sources, only 10 to 20 percent of the time is spent on building the 3D model. Practice learns that this interpretation process is complex and can extend over a long period, that the amount of source data can be overwhelmingly large, and that in many cases multiple people work simultaneous on the same project. Following well defined procedures, supported by a tool that records and manages this interpretation process, is therefore crucial in safeguarding the majority of the financial and intellectual investment of a visualisation effort.

A second reason for having interpretation management is the ability to *update* 3D visualisations with new results, coming from new excavations or recently discovered historical sources or from new scientific interpretations and insights. The influence of such new data is in most cases far from straight forward, hence having a well defined process how new results alter the interpretation process is necessary to properly manage existing 3D visualisations. In other words, 3D visualisations should remain “alive”, even many years after excavations or research efforts have ended.

This brings us to a third element which is *scholarly transparency*. When visualising historical buildings or landscapes, we need a lot of information to build complete 3D models. In most cases, we have insufficient and indirect sources to construct the 3D model, so coming from those available sources to a complete 3D model is a difficult process. We have to understand that the uncertainty of elements in a 3D visualisation can vary largely across the model, some elements are well defined while some elements are totally unclear. The process of how to fill in these uncertainties is undefined, and can yield several good solutions. Even more, when basic choices are unclear (e.g. is the excavated structure a small church or a large house ?), results can depend to a large extent on small details or even speculations or assumptions. This means that many 3D visualisations, or at least parts of it, can have large amount of uncertainty. For public presentations, it is not always useful to expose this uncertainty, hence a certain choice on what and how to show will be made, but for scientific purposes, a 3D visualisation needs to be transparent, and the uncertainty and choices made need to be well documented, and available for scientific critique and research. In other words, interpretation management is a way to “publish” 3D visualisation.

A fourth element is *data security*. Practice shows that most visualisation processes yield binders of unstructured documents from which outsiders cannot reconstruct the interpretation process. In other words, the intellectual efforts linked to creating a 3D visualisation cannot be passed onto the next generations. By providing a methodology and tool to record and manage the interpretation process of a 3D visualisation in a structured way, we also provide a way to store this data for the long term, giving access to the data and the interpretation process for future use and research.

A final element is *multidisciplinary cooperation*. We need to keep in mind that 3D visualisation brings together a wide range of skills (from history and archaeology to architecture and stability engineering, from pollen analysis and hydrography to 3D modelling and rendering) and that it is impossible that one person can master all the skills needed to do proper interpretation of all available sources. A tool that brings together all sources and all interpretations is in fact also a *collaboration platform* that allows all involved disciplines to contribute their part to the project, mainly in an iterative process.

3. Recording methodology

This tool wants to be practical and usable and helps supporting the 3D visualisation process. We need to be aware that this tool needs to be simple, create nearly no overhead and needs to adapt itself to a large range of situations.

We need to be aware that not many such tools have been introduced to the 3D visualisation community yet and that only practical use by a large number of experienced people will show how the tool needs to be further developed. Hence, we think that it is wrong to be too prescriptive and too restrictive by forcing people into a rigorous framework. The tool should rather be a container where information can be stored in a flexible way, gently guiding people through the interpretation process following the lines of a certain methodology.

The methodology for interpretation management presented here is based upon many years of experience in 3D visualisation. The main features of the methodology are:

- clear references to all sources used, no use of implicit knowledge
- in-depth source assessment, making the reliability and potential bias of each source clear
- correlation of all sources used for a certain visualisation in order to detect common ground as well as inconsistencies, outliers or dependencies
- structural analysis of the object to be visualised, and division of the object into logical sub-units
- list of all potential hypotheses, never “hiding” a discarded hypothesis

- records the interpretation process by making a clear link between the sources, the reasoning and the resulting hypothesis
- structures the potential hypotheses in a tree structure, with sub-hypotheses depending on main hypotheses
- keeps the recording process separate from the modelling and visualisation process, as the latter is far from linear

It's the rigorous implementation of this methodology in general and the use of correlation techniques for iconographic sources and a hypothesis tree in particular that makes it well suited to optimise the process of constructing a virtual model from related sources.

The methodology we propose here is basically a step-by-step process:

1. Creating a source database
2. Source assessment
3. Source correlation
4. Creating hypothesis trees with conclusions
5. Updating

We deal with issues such as the reliability of the hypotheses, multiple hypotheses with the same level of probability, ways to express uncertainties and visualising evolution. We explain the goal and approach of the London Charter, and demonstrate how the EPOCH tool implements these goals.

3.1. Creating a source database

It is a good practice to refer systematically to sources, and document these sources through references, images and text descriptions (many people forget that text is one of the most important sources in a 3D visualisation process). These sources are maintained in a *source database*. Practice shows that many errors in 3D visualisation are due to incorrect assumptions when using source material. Having a rigorous process to select and document sources helps avoiding this pitfall.

There is no standard way to structure the source database, as many different types of sources can be integrated (from iconography to pollen analysis, from unpublished excavation data to well-known historical sources, from historical analysis of existing buildings to oral history). The principle needs to be that *all sources are identified uniquely and can be traced easily when needed*. Basically, this does not differ from standard practice in archaeological and historical research (where footnotes are used in most cases) but more technically oriented people making 3D models need to adopt this too.

Each source is referenced on a source sheet that also contains digital images, details of those images or transcriptions of text where necessary. Having such key information copied in the interpretation management system is very useful to avoid physiscal search in documents, which can be available in libraries and archives only.

3.2. Source assessment

A key element in the interpretation process is *source assessment*. This assessment normally yields some understanding of the reliability of the source, and more specifically about the reasons why certain elements are not reliable.

This *assessment* can be a detailed study of the context of the source or the way the source depicts the reality. For example, iconography needs to be studied in terms of the creator of the iconography, the reason why the iconography was made or how the iconography needs to be interpreted. In fact, source assessment tries to know and understand the process how reality was represented in the source at hand.

We need also to be aware that all sources, from text sources or iconography to archaeological sources or digitised buildings and objects, have been interpreted already during their creation, hence that mistakes, missing information, incorrect interpretations or deliberate alterations can occur, and that we need to understand the context of the creation of the source to try to get the maximum of correct information out of the source. By applying correlation with other independent sources (see next step) we can try to further remove the veil of error that is present in every source.

3.3. Source correlation

The *correlation method* compares the different sources and tries to draw conclusions from the corrspondences, differences and inconsistencies between the sources. Conclusions can be that a source is totally unreliable, contains certain deliberate errors or just mistakes, or is a correct and detailed representation of the item it depicts or describes.

The basic correlation method is *consistency checking* between sources that basically contain the same information. This can for example happen between different sources of iconography depicting the same scene, or archaeological sources versus iconography. Of course, it is important to keep the context in mind as a drawing from the middle ages for example cannot be expected to contain proper perspective. We also need to take the character and limitations of the sources (as recorded in the source assessment) into account.

A special case of this consistency checking is when *several versions* of a certain source exist. By analysing small differences between the different versions, and by historical study, in most cases the most reliable (often the oldest) source can be identified.

In most cases, we don't have the luck to find multiple sources such as drawings or paintings that basically depict the same. Normally we have different types of sources that depict the same environment at different points in time, made for different purposes. Correlation in that case consists of a *systematical comparison* of all available elements, record common elements and try to understand why some elements are different or absent. As the major hurdle to take here is understanding the evolution of the structure, we need to correlate all available sources on that structure at once (see chapter "Visualising evolution" below).

We have analysed several methodologies to formalise this correlation process, but as this is a very non-linear and complex process, finally it seems that only *description through text* can capture all the necessary nuances and be adopted easily. The short description of the tool below gives a good idea how this is done.

3.4. Making a hypothesis tree with conclusions

When visualising a building, a landscape or a city, we need to impose a certain top-down analysis of the object, decomposing it in *substructures*. These substructures do not always follow the normal, "structural" decomposition of the object but rather the logical decomposition, hence they are closely linked with the hypothesis tree we will introduce. Nevertheless, the object needs to remain well structured and plausible. Creating too much structure where no information is available generates only an additional burden for the person making the visualisation, we need to keep in mind that the methodology needs to support the visualisation process, not making it more complex.

The hypothesis tree is the *formalisation of the interpretation process*. It shows in a top-down fashion the potential alternatives, analyses each of the alternatives in relation to the available sources and draws a *conclusion* about which one of the alternatives has the highest probability, based upon the available sources.

In each hypothesis, *sub-hypotheses* are made, which again are evaluated and the most probable one is selected. The reasoning how the sources (indicated through hyperlinks) influence the hypothesis is done in written text, we do not believe a formal structure can be devised that is both flexible and user friendly enough to refrain from the normal written word, that everybody uses to express interpretation.

It is important though to stick to the branching hypothesis tree method, to avoid overlooking certain possibilities. Nevertheless, it is common sense that unlikely branches do not need to be expanded as this only creates additional overhead that is not useful, but the unlikely branch needs to be recorded anyway (see updating methodology).

A hypothesis tree implies at first sight that the analysis happens in a top-down fashion. For this, all information needs to be available, so related excavations and historical studies have to finalised. Archaeologists on the other hand want to work in a bottom-up fashion while they excavate and can only merge parts of structures to complete structures when excavations finish. Hence, the tool we will use to document the interpretation needs to be able to deal with this workflow in an elegant way.

Most historical structures show an *evolution through time*. When interpreting source data and proposing certain hypotheses, we need to think in fact in four dimensions, spatially and chronologically. In other words, every hypothesis needs also to check if it is consistent with the data of the phases before and after a specific 3D visualisation. Arriving at a consistent evolution is a major part of the interpretation to be done, and a major validation step when building or updating the virtual models.

Therefore it is important to entangle the different *phases* of a structure, in other words, interpretations should cover the full evolution of a building, landscape or site. Of course, when there is a discontinuous evolution (for example, a site is demolished and rebuilt in a totally different way), the interpretation can be divided in those discontinuous phases, and be treated separately.

3.5. Updating

One of the most important reasons to do interpretation management is *updating*. As new sources of information can appear, as new insights or correlations can be found during the study of the source material, we need to be able to record how this new material influences the existing 3D visualisations. We distinguish four different kinds of updating.

First of all, when a *new source* appears, we need to add this source to the database, find out what other sources it correlates to and assess this new source, both on its own and in comparison to all other related sources. The availability of new source material can influence the assessment of other sources, the reliability of the visualisations or even the hypotheses made (see below).

Another update action is the appearance of a *new assessment of an existing source* where new insights, new sources or new studies (which need to be added to the source list) render the current assessment of a source obsolete or at least incomplete. This new assessment can trigger changes in the hypotheses section and of the reliability of the visualisations.

New sources, changes in source assessment or new interpretations can yield an *additional or updated hypothesis* or can *change the probability of one or more hypotheses* or *the reliability of the visualisations*. This can yield in another conclusion (the hypothesis that has the highest probability) than before.

In this process of updating, there needs to be a detailed *tracking* of the updates. This is not only a technical issue, there needs to be a *consensus* amongst the involved people on any changes to the 3D visualisation, and the changes need to be implemented and validated by 3D specialists. As pointed out before, this normally is an iterative process that needs involvement of several specialists, leading to a change to the virtual model by the 3D specialist. As in most cases these specialists do not share the same working space or meet each other daily, we need a tool that can act as an internet collaboration platform to allow these interactions to take place efficiently.

It can happen that specialists do no agree on a certain conclusion, or that too little evidence is present to favour one interpretation over another, or that the update is not endorsed by all involved specialists. In that case, there are *two or more solutions* that are treated *as equally probable*. This is in itself not problematic, but needs in-depth consultation and consideration before the decision can be taken that there is no most probable interpretation and 3D visualisation.

It is clear that a certain degree of skills is needed to make or change the interpretation and visualisation of a site. This is the same problem as Wikipedia is facing to maintain the quality of its online encyclopaedia and avoid "vandalism" of the content. Like Wikipedia, everybody needs to be able to contribute to the interpretation of the sources, following the typical discussion methodology and user authentication. Unlike Wikipedia, there should be an authorisation and accreditation process of people who want to change the conclusions and make or change the 3D visualisations, as these are complex tasks that require the appropriate skills. These accredited specialists can be seen as the “scientific committee” of the 3D visualisation programme. We think we can guarantee in this way the quality of a 3D visualisation while “publishing” this visualisation and creating full transparency about the interpretation.

All data that is stored as result of the creation and update process also needs a maintenance cycle that should not be longer than two years. The software of the implementation (see below) and its associated data (typically a database with all results) probably will need to be updated. Files integrated in the database (such as digital images) or in a digital repository (3D virtual models, derived results such as animations, interactive models, ...) need to be transferred to new file formats if the original file formats become obsolete (this is called “data migration”).

3.6. The reliability of the hypotheses

Besides what is most probable, we also need to care about the reliability of the visualisations that result from the most probable hypotheses. Although it is difficult to put a number on the reliability of each structural element of a visualisation, we can derive some estimation from the reliability of the sources (see source assessment and source correlation) and the number of sources that are available for that specific element (see source correlation). In most cases, an indication of high, medium and low reliability is sufficient. If we have only unreliable sources or if we only have one source, we will attribute the visualisation a low reliability. If we have multiple, reliable sources, we will consider the visualisation as highly reliable.

In the same way, if a hypothesis matches perfectly with all available sources, the visualisation can be considered as highly reliable, while if a hypothesis matches poorly with the available sources, but no better hypothesis can be found for the moment, the visualisation needs to be considered as unreliable (even if the hypothesis is considered most probable).

Unlike some other specialists in the field of 3D visualisation [HER05], we prefer not to quantify reliability in numbers but assess the reliability as *low, medium or high*. Other authors use a similar methodology. Peter Sterckx [STE07] uses the same system for the visualisation of the evolution of the Horst castle in Belgium, while Han Vandevyvere [VAN06] uses four catergories (low, medium, high and very high) for the Mariemont castle, as does Matt Jones [JON07] in his visualisation of Southampton in 1454.

The issue however is what to do with unreliable parts of the visualisation. Should we visualise them or not? When we start from a scholarly point of view, we rather will decide to not visualise unreliable parts. When we start from a presentation point of view, we try to show a *consistent* image of the visualised structure, so we rather will decide to show also the unreliable parts because they make the structure as a whole more consistent.

3.7. Dealing with multiple hypotheses with the same level of probability

If one hypothesis has clearly a higher probability than the others, the *conclusion* will put this hypothesis forward as the most probable interpretation of the available sources. However, if two or more hypotheses have more or less equal probabilities, the conclusion needs to reflect the undecided nature of the interpretation. In that case, all probable alternatives will be expanded, i.e. will have sub-hypotheses and developed virtual models.

Nevertheless, if the alternatives are not significantly different, one hypothesis can be chosen as the *representative conclusion* for public presentation, regarded that information is available in that presentation about the other equally probable alternatives.

3.8. Visualising evolution

When visualising evolution, we basically want to explore a 3D structure from all sides and see the evolution of (a part of) that structure from the most appropriate angle.

Several technical solutions have the potential to do that, but we want to present here a simple but very powerful techique: a QuickTime VR object. QuickTime VR [QTVR] is part of the QuickTime software that is able to visualise panoramical and spherical images and interactive objects.

Interactive objects basically consist of a matrix of images that can be visualised interactively by dragging horizontally or vertically in the viewer. If we put a 360-degree rotation of the object in the horizontal rows of the matrix, and an evolution through time in the vertical columns of the matrix, then we obtain a *4D visualisation tool* that shows interactively 3D plus time (evolution). Hence, if we drag our cursor horizontally or use the left/right arrow keys, we change our viewpoint, while if we drag vertically or use the up/down arrow keys, we visualise the evolution of the object from a particular point of view.

Simple software packages exist to turn a set of images, structured in such a matrix like 4D way, into such an interactive 4D object. The major advantage is that from the interactive object, *hyperlinks* can be made so that it can be integrated into hyperlink-based tools.

3.9. The London Charter

The London Charter [TLC] has been initiated at a meeting of 3D visualisation specialists in 2006 in London and aims to define the basic objectives and principles of the use of 3D visualisation methods in relation to intellectual integrity, reliability, transparency, documentation, standards, sustainability and access. It recognises that the range of available 3D visualisation methods is constantly increasing, and that these methods can be applied to address an equally expanding range of research aims.

The Charter therefore does not seek to prescribe specific aims or methods, but rather seeks to establish those broad principles for the use, in research and communication of cultural heritage, of 3D visualisation upon which the intellectual integrity of such methods and outcomes depend.

The Charter does seek to enhance the rigour with which 3D visualisation methods and outcomes are used and evaluated in the research and communication of cultural heritage, thereby promoting understanding of such methods and outcomes and enabling them to contribute more fully and authoritatively to this domain.

So the London Charter can be seen as the upcoming standard for 3D visualisation. The methodology we propose here is a way to implement the Charter (version 1.1) in practice, which is based on the following principles [TLC]:

- valid for 3D visualisation in all cultural heritage domains
- appropriate use of 3D visualisation
- identification and evaluation of relevant sources
- transparency of the 3D outcomes in relation to the sources
- documentation of the 3D visualisation process should allow repeatability of the interpretation process and reuse of the outcomes, and create a scientific dialogue and understanding
- use of standards and ontologies, approved by the community
- sustainability
- improve accessibility of cultural heritage

The London Charter wants to be valid for *all domains* in which 3D visualisation can be applied to cultural heritage. This tool is also very general and has a methodology that can be applied in a wide range of applications and for a wide range of goals. The concept of assessing sources before they are used in the interpretation process, and the method of correlating sources to reveal common thruth are generally applicable. The concept of building a tree of hypotheses allows to work both bottom-up and top-down, which makes it suitable for a wide range of cases. The methodology presented here can be used for research as well as for communication purposes.

The London Charter states that an evaluation of the goals to achieve should prove first of all if 3D visualisation is an *appropriate method*, and if so, which 3D visualisation method is the most adequate to reach the goals. The methodology used here is quite independent of the visualisation method of the results of the interpretation process, which could range from 2D maps over pencil sketches to 3D volume renderings and photorealistic 3D visualisation.

The London Charter states that *sources should be identified and evaluated in a structured way*. This is exactly one of the key elements of this methodology, and is explained and demonstrated in detail in this paper.

The London Charter states that the relation between the sources and the 3D visualisation outcomes, the reliability of those outcomes and the interpretation process should be *transparent* and well documented. This again is one of the key elements of this methodology, and is explained and demonstrated in detail in this paper.

The London Charter promotes the *scientific rigour of the interpretation process*, based upon documentation, reuse of results and scientific dialogue. These elements are also key elements of this methodology and its implementation through wiki-technology.

The London Charter promotes the development of *standards and ontologies* for documenting the interpretation and 3D visualisation process and enventual approval by the community that develops and uses these 3D visualisations. The proposed methodology in this text and its implementation through a wiki-based tool, together with possibly other implementations, can be considered as a first step and platform for the community to develop these standards and ontologies, as this is still a new and uncharted domain.

The London Charter promotes *long-term archival and sustainability* of the documentation of the interpretation process and its resulting 3D visualisations. This is also a major goal of the methodology proposed in this paper. The use of a standard wiki-tool and its inherent mechanisms of archival and versioning will help in realising this goal.

The London Charter states that the documentation of the interpretation process and 3D visualisation outcomes should provide a better *access* to cultural heritage assets in terms of study, interpretation and management. The approach of a wiki-based tool that is accessible for authorised specialists allows a high quality enviroment that can be used for further study, scientific discussion about interpretation and documentation for a wide range of uses.

5. Structure of the tool

EPOCH, as the Network of Excellence for the use of ICT in cultural heritage, has created tools for the cultural heritage community to support specific tasks [EPOCH]. For 3D visualisation, a tool based on the methodology explained in this paper, has been created and is freely available.

The tool has five major functionalities: the source database, source assessment, source correlation, the hypotheses tree with conclusions and the 4D visualisation page. It is based upon wiki technology that implements not only the hyperlinking, but also the discussion forum and the consensus process that is needed to communicate and discuss research results and update them when necessary. Resulting 3D models or derived products (still images, animations, ...) can be stored in a data repository and hyperlinked to the 4D visualisation page.

5.1. The source sheet

The *source database* needs to refer to the sources used in the interpretation. Strictly speaking, these sources need only to be traceable. In practice, storing enough data in a digital way makes the sources much more accessible, hence supports the interpretation process. For example, if iconographic sources are available as high-resolution images, this is of course more practical when doing interpretation than juggling with a lot of printouts and photographs. In other words, appropriate viewers, tools to find the right sources and good management of multiple windows are important. A functionality that is very powerful is the use of *annotated images*. In this way, text such as transscriptions or remarks can be added to certain areas of the images and appear when the cursor moves over the annotated area.

In this way, each source is recorded on a *source sheet* that also contains the *source assessment* that records the context, quality and interpretation of the source in itself.

We distinguish *primary and secondary sources*, the former are directly used in the interpretation process, the latter are only used in the source validation and don't need to have images, validation, ... (if there would be an issue with reliability of these secondary sources, a source assessment section can be added).

5.2. The source correlation sheet

On the *source correlation sheet*, we document the correlation process between sources that give us information about a certain topic. By numbering features in iconographic sources that match, we can extract elements with a higher reliability that can be used in the visualisation process.

A more elaborate version of this, that is used when there are significant differences between sources, is the technique where matching features are indicated in green while features that do not match are indicated in red. Features that have an uncertain matching can be indicated in yellow. Based on such an analysis, a detailed description will be recorded in the source correlation sheet that focuses not only on the matching features but also on the differences, and why they are different.

In this process, the secondary sources, that are referenced to provide the context of the source, simply go into the source database. The source correlation is captured in text with hyperlinks referring to the sources and annotations to the images recording remarks, transcriptions or interpretations.

5.3. The hypothesis sheet

The *hypothesis tree* provides a simple way to decompose the interpretation of a structure (building, landscape, ...) into a tree-like set of possibilities called hypotheses. Each hypothesis can be decomposed in other sub-hypotheses. At each level of the hypothesis tree, conclusions are made, based upon the probability of the possible hypotheses. If a hypothesis has little probability, one can choose not to generate sub-hypotheses for it.

We propose here to build this hypothesis tree as a set of hyperlinked pages called *hypothesis sheets*. This approach gives the freedom to change the structure of the tree easily. One common problem in historical interpretation is the assumption of certain conditions or elements. If we want to remove the assumption that is made at a certain level, we need to add an extra level of subhypotheses in the middle of the tree, which is very easy by changing a few hyperlinks.

As archaeologists like to work bottom-up instead of top-down (as they are dependent on what has been excavated already), they can make hypothesis sheets that deal with parts of structures and link them later on with overarching hypotheses once the excavations have progressed or finished. The flexibility of creating and modifying the hypothesis tree through creating or modifying hyperlinks makes the approach described here applicable in many different cases and contexts.

The structure of the hypothesis tree also reflects the logical structure of the object to visualise (see chapter 3.4). As Vatanen [VAT03] points out, only hyperlinked structures can provide the necessary flexibility and interlinking to represent three-dimensional structures (as they can show a complex evolution pattern, they can even be considered as four-dimensional).

If one hypothesis has clearly a higher probability than the others, the *conclusion* will put this hypothesis forward as the most probable interpretation of the available sources. Each conclusion is linked to the *visualisation of the resulting virtual model* and appropriate tools refer to parts of the virtual model, linked to each sub-hypothesis.

If two or more hypotheses have more or less equal probabilities, the conclusion will reflect the undecided nature of the interpretation. In that case, all probable alternatives will be expanded, i.e. will have sub-hypotheses and developed virtual models.

Nevertheless, one hypothesis can be chosen as the *representative conclusion* for public presentation, regarded that information is available in that presentation about the other equally probable alternatives.

Each conclusion should also make an estimation of the *reliability* of the most probable hypothesis. This depends on the number and quality of the involved sources and on the matching between the hypothesis and the sources.

Although parts of a structure can have a low reliability, we can choose to visualise those parts to maintain the consistency of the visualisation. The decision to visualise or not visualise depends very much on the purpose of the visualisation. When used in scientific research, it could better to not visualise unreliable parts.

5.4. The 3D/4D visualisation page

In most cases, the interpretation of a structure (building, landscape, city, ...) deals with the evolution of that structure through a certain period of time.

A potential user interface to show this evolution properly can be *4D visualisation* through for example QuickTime VR, where both time and 3D viewpoint can be changed. In this way, links can be made towards the pages of the interpretation, so that the 4D visualisation acts as a user interface to reach the appropriate parts of the interpretation. In other words, clicking on the reconstructed element refers to the exact place in the hypothesis tree, where the structure of that element is discussed.

If the visualisation contains no evolution, this page simply shows the reconstructed element from all sides, in 3D.

5.5. Advantages of a wiki implementation

As it is important to be able to work on a reconstruction as a full team, with the appropriate discussion and consensus mechanisms, we propose to use *wiki-technology* with predefined templates, revision control and consensus mechanisms to build the three components outlined above (source database, source correlation and hypothesis tree). 4D visualisation tools that can be embedded into a wiki provide the fourth component. User registration, authentication and authorization on different levels (edit, conclusions, 3D model creation and edit) can use the tools that most wikis provide. The update of 3D models is triggered by a change of the conclusions, therefore a change in conclusion and a change of the virtual models can only be decided by accredited people.

Another aspect that we try to realise is data security. We try not only to provide a safe, long term storage of the interpretation process, but also long term storage of the virtual models themselves. As the interpretation process and its updating is linked to a specific 3D model, this model can also be stored (together with all related files, such as textures and animation scripts, and derived files, such as images, animations, interactive applications). In this way, a *central, public storage* is implemented so that the investment of making the virtual model is secured. As 3D model files can have a variety of file types, it is important to provide long term maintenance of those files by translating them into open file formats and provide a further translation of those file if the chosen open file format becomes obsolete in the future.

As nearly all virtual reconstructions are made with public money, it is conceivable to request that 3D models are published and maintained in such a way. In this way, there is not only a much better safeguarding of the financial and intellectual effort that goes into the virtual reconstruction project, but also a public availability of the results (as they have been made with public money). The Network of Expertise, that has been created in the EPOCH project, and that hopes to continue under 7FP, will provide training to have these concepts widely accepted and do lobbying to turn this approach into national policies.

6. Other approaches

The Architectural History and Conservation Research group and the CAAD research group at the University of Leuven have defined a metafile approach for documenting 3D visualisations of historical buildings [VAN06]. This metafile has the form of a spreadsheet and distinguishes the logical structures in the object to visualise (rows) and contains the facts, the written and iconographical sources, the onsite inspection reports, reliability and remarks (columns). This metafile also decomposes the different major elements into a tree structure through a numbering system of the rows.

Practical application to complex structures such as the Horst castle in Belgium [STE07] shows however that this approach has unsufficient flexibility to represent the large amount of links between the elements and the large amount of description and interpretation needed for each of those elements. There is no entry for hypotheses which results in the fact that the interpretation gets scattered over the facts column (where it definitely does not belong) and the remarks column. Especially the interlinking between the different hypotheses get somewhat lost in the limited area that each facts or remarks cell provides. The assessment of the sources is not systematic as it ends up in the remarks column, separated from the different source columns. Most sources don't get any source assessment and there is nearly no source correlation. There is only a text link to the sources, which results in a lot of manual browsing and searching.

Most projects where the metafile approach has been applied are standing buildings for which resolution of interpretation issues at the detail level are the most important. The metafile approach works quite well for this kind of projects but is less optimal for other projects where there are only ruins or archaeological remains left, or when significant rebuilding has take place as in that case, significantly different hypotheses need to be compared to each other.

Another approach has been used by Joyce Wittur [WIT08] in studying the methodology for the Lorsch Abbey Reconstruction and Information System [LARIS]. The Lorsch abbey is a major 8th century abbey and UNESCO World Heritage Site nearby Mannheim in Germany, which has a few standing buildings but also major archaeological remains. This approach uses argumentation networks that link sources with interpretations and is very similar to the approach we take in this paper. These networks are built of interlinked primary data, comparisons, observations and interpretations. The major difference however is that there are no phases in the interpretation process such as source assessment, source correlation and hypothesis building, and that the hypothesis building doesn't need to have a tree structure.

Each of the elements in the argumentation network can be linked to data such as images, texts, etc. This is very similar to the hyperlink approach we use in this paper and produces an efficient way to link and structure the data.

Although there are no formal phases of source assessment, source correlation or hypothesis construction, all these elements are present in these argumentation networks. The network approach allows on one hand the flexibility needed to describe all kinds of different interpretation processes, but lacks on the other hand the rigour and guiding of the step by step approach that we promote here.

At this moment, the argumentation networks do not care about reliability of sources, the probability of hypotheses or the update process, although we think that these elements are crucial in good interpretation management.

This argumentation network approach has also been promoted by Vatanen [VAT03], who does take care about the history of the interpretation process and updating.

Argumentation networks do represent very well the way we are thinking, but look somewhat complex and scary at first sight. This could influence negatively the take-up by the 3D visualisation community, so we promote in a first phase the use of plain text to describe the arguments. As Vatanen [VAT03] points out, the first goal of documenting interpretation should be communication within the involved community. Nevertheless, they are a good basis for structured storage of the interpretation process in the near future.

7. Wiki template

This section provides a detailed proposal of the structure of the different types of wiki pages (sources with their assessment, source correlation, hypothesis tree, 4D visualisation, overview).

The source database is implemented as a set of *source pages*, which provide the right reference to the physical source, useful tools such as images that are helpful in the interpretation process and a validation of the source itself.

The goal of source assessment is to define if the source is has a certain degree of reliability and therefore is eligible to be used in the interpretation process, and to reveal the interpretation processes that have already taken place in the creation of the source, so that we can define which elements of the source can be trusted and which elements should be discarded.

A source page contains:

- a short description of the source
- a conclusion (of the validation/assessment process) at the top of the page
- a correct and complete reference to the source, and a URL if online
- images (plus details if necessary) related to the source, for practical reference and for supporting the reconstruction process
- a detailed description of the source
- a detailed description of the context of the source (who made it, why, ...), this can require links to other sources (both primary and secondary sources)
- a validation and assessment of the source itself concerning its context and reliability (both through primary and secondary sources)

A source correlation page groups a number of sources that have something in common, and records the correlation process between all these sources, yielding conclusions that can be made from that group of sources. In this way, archaeological sources are correlated with iconographic sources, or similar iconographic sources are compared amongst themselves.

A source correlation page contains:

- a conclusion at the top of the page
- a list of related sources that document a certain structure, area or period, each source is identified through a hyperlink to its own source page (a source can appear in more than one list)
- a comparison of the listed sources, using correlation techniques and based upon the source assessment, trying to assess similarities (are they really similar?), differences (why is there a difference?), omissions (why is a certain structure missing in a certain source?) or interpretations from other authors in relation to the full set of available sources, each source is hyperlinked for easy reference
- drawing conclusions from the correlation process: if all sources depict the same feature in the same way, the conclusion is that the sources show a reliable feature, if the sources show different and non-consistent depictions of a certain feature, we can conclude that we have little to no evidence for that feature

The *hypothesis tree* is implemented by a set of hyperlinked hypothesis pages and each page covers one branch of the hypothesis tree. All hypothesis pages are linked with each other through hyperlinks to form a tree.

A hypothesis page contains:

- one or more conclusions at the top of the page, linked to the 3D/4D visualisation page if available
- all hypotheses concerning a certain structure or part of a structure, each hypothesis links to its sub-hypotheses
- a written description of the argumentation, pros and cons of a certain hypothesis, linked to the appropriate source and source correlation pages

A *4D reconstruction* page that shows the resulting virtual reconstruction in an interactive way, with links to the related hypothesis pages. If an evolution in time is available, the model can be 4D. Techniques such as Flash of QuickTime VR can visualise such 4D models.

Finally, access to all this pages are provided through one or more *overview pages* that give access to the hypotheses for the object to visualise. An overview page can contain multiple objects (for example a list of buildings) and overview pages can be organised in a tree like structure for large and complex sites. As primary and secondary source pages, source correlation pages and 3D/4D visualisation pages are referenced from hypothesis pages, we don't list them explicitly on the overview page.

8. Benefits

This methodology has several benefits for the different stakeholders involved in a 3D visualisation process.

First of all, as there is very little standardisation in how to conduct and document 3D visualisation research, this methodology helps to *structure and rationalise the interpretation process.* Currently, the interpretation process behind a 3D visualisation project is in most cases a black box with certain inputs and outputs but very little transparency concerning the process itself. Using some commonly accepted methodology will be beneficial for mastering the process and its quality.

Secondly, by recording the interpretation process through an online tool, other scholars or 3D visualisation specialists can understand the process and contribute their knowledge, through the known wiki mechanisms of discussion and consensus. This creates not only *scientific transparency* but stimulates also *multidisciplinary cooperation* as specialists in certain domains (for example stability analysis or building historians, specialised in a certain era) can be invited easily to contribute.

In other words, the proposed tool provides a *collaboration platform* to bring together all necessary specialists around the research and/or public presentation through 3D visualisation of historical manmade structures or landscapes.

By hosting this tool on some central server, managed by a central cultural heritage organisation in every country or region, all 3D visualisation processes can be *recorded and stored*, while the organisation itself can take care of all backup and long term storage, including all software updating and data migration in a user transparant way.

As most 3D visualisation projects are funded by public money, a supplementary requirement to record the corresponding interpretation process through such a centralised tool would yield not only a *long term storage* of knowledge that would otherwise disappear, a better safeguarding of the financial and intellectual effort that went into 3D visualisation projects, but also *general availability of 3D visualisation results* for the related community and for resuse in other projects.

Whenever new or updated information becomes available, the underlining database of the tool can be searched and all projects that use that specific information can be earmarked for update. Specialists can be invited to work on such an update or simply a list of projects that need update could invite specialists to donate time to integrate these new or updated results into the 3D visualisations. In the same way, results that would be reused will be earmarked for update, so no outdated 3D visualisations will be used or distributed.

9. Conclusion

The focus of 3D visualisation of historical structures is not 3D modelling or creating stunning images but conducting an indepth, systematic study of the sources, correlate and assess them, derive the most probable hypotheses, document this interpretation process in a well structured way and finally visualise them according the requirements of the context in which these visualisation results are used.

This paper provides a methodology that is on one hand flexible and capable of dealing with a wide range of subjects and goals, but on the other hand provides a standardised workflow which tries to turn 3D visualisation of historical structures into a repeatable, documented process that is transparent and publicly available.

In other words, this methodology for interpretation management establishes a sound framework for creating and publishing 3D visualisation results, improve their quality and preserve the investments and intellectual effort that has been spent to create them.

A specific EPOCH tool, based on wiki technology, has been realised to support this process and guarantee the safeguarding of the resulting data [EPOCH].

This paper is also available as an illustrated knowhow booklet for cultural heritage specialists [KHB08] and as a technical paper [PLE08], with many examples and a case study, on the EPOCH website [EPOCH].

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