In Proceedings Computer Graphics International, pages 36–43, Los Alamitos, CA, 1999. The Computer Graphics Society, IEEE Computer Society.

Visualizing Knowledge about Virtual Reconstructions of Ancient Architecture

Thomas Strothotte, Maic Masuch, Tobias Isenberg
Department of Simulation and Graphics, Otto-von-Guericke University of Magdeburg
{tstr|masuch|isenberg}@isg.cs.uni-magdeburg.de

Abstract

One of the assumptions of current software for visualizing architecture is that the underlying geometry is a correct, objective, and complete representation of the objects in question. However, we argue that such an ideal situation can hardly be met. Instead, there are a variety of situations in which there is considerable uncertainty associated with some features of a model. Furthermore, the model usually stems from design decisions which are not encoded in the model, but which may be important for users.

We argue that more information about geometric models should be representable and visualizable. In particular, we propose non-photorealistic rendering styles for encoding such additional information in a visualization of a 3D model which goes over and above the geometry. We then apply this concept to visualizations of virtual reconstructions of ancient architecture. Finally, we describe the prototypical system ANCIENTVIS *which represents an approach to visualizing models with uncertain features.*

Keywords: non-photorealistic rendering, rendering techniques, scientific visualization, visualizing ancient architecture

1. Introduction

Photorealistic images tend to leave their viewers with the impression that the objects depicted actually exist. In the case that the viewer knows that the objects do not really exist – either because they have not yet been built or because they were destroyed – a photorealistic image nonetheless suggests that detailed information has been amassed about the objects being shown. Such images also lead viewers to the conclusion that the information is correct and contains a high degree of certainty and accuracy. After all, a photorealistic image suggests that a camera could have taken the picture: “the medium is the message”.

However, there are many situations in which the geometric models from which rendered images stem are not as accurate or complete as the photorealistic rendition suggests. Indeed, in graphics drawn by hand, a great deal of effort is often spent on making sure that just the right amount of detail is given. Two examples will illustrate this point:

Example 1: Architectural sketches, an example of which is shown in Figure 1, are often drawn with relatively little detail. This typically has one of two reasons: the architect

- may not have worked out more details yet, or
- has more details but wants to focus on certain aspects of the design, so only these aspects are shown.

Such sketches are often used in an early design stage and have certain positive effects on viewers [1, 2].

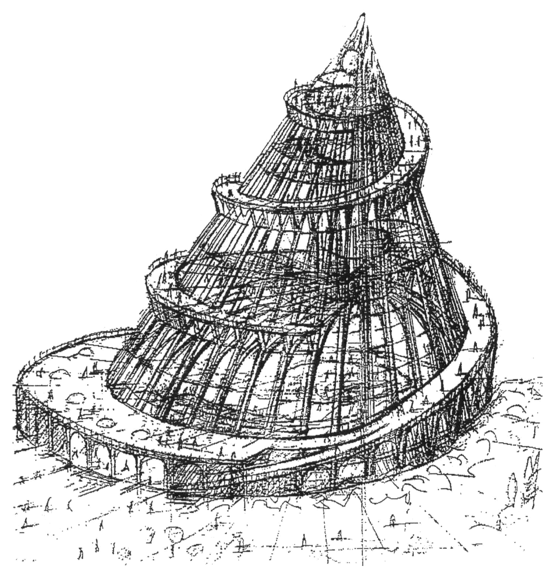

Figure 1. Example of an architectural sketch of an object in an early design phase (hand-drawn). Although the architectural structure is complex, the drawing lacks exact detail.

Example 2: Hand-drawn visualizations of reconstructions of ancient architecture (see Figure 2) are rarely visualized as photorealistic images. Instead, the visualizations attempt to convey information over and above the geometry, in particular such information as pertains to the certainty with which details are known.

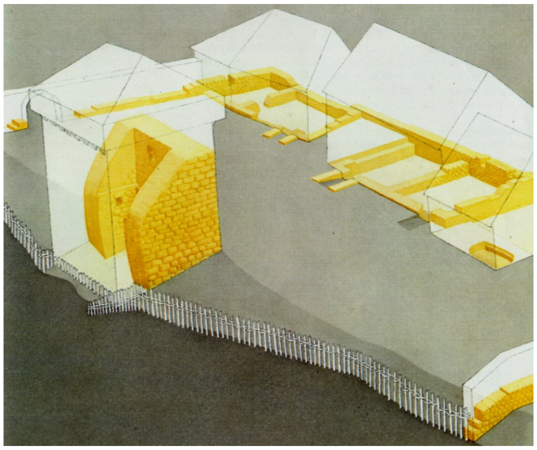

Figure 2. Example of a visualization of ancient architecture. Certain aspects of the model are based on archaeological finds, others are more speculative [3].

It is our goal to design and implement methods and tools for dealing with such models containing features with varying degrees of uncertainty, with which users are able to produce images which inform about these uncertainties in the models and about design decisions. In this regard, current software is lacking in two areas: First, methods and tools are needed to encode systematically more information about the model than just its geometry. Second, methods and tools are required which enable users to produce non-photorealistic images which encode this additional information.

In this paper we address these two points as they pertain to ancient architecture. The paper is organized as follows. Section 2 describes previous research related to visualization of uncertainty and ancient architecture. In Section 3, we lay the conceptual foundations for methods and tools for flexible rendering. An overview of the ANCIENTVIS system can be found in Section 4. We illustrate the capabilities of our system on an exemplary virtual reconstruction in Section 5. Some final remarks and a preview of future work will conclude the article in Section 6.

2. Related work

In recent years, considerable attention has been paid to virtual reconstructions of ancient architecture. Many museums are expressing interest in using modern multimedia technology to make presentations augmenting traditional displays. A very comprehensive survey of current work in this area has been compiled by Forte and Siliotti [4]. However, practically all computer visualizations of virtual reconstructions in their collection were rendered in a photorealistic style, whereas the images constructed without the use of computers are line drawings. The same is true, for example, for the volume describing the virtual reconstruction of the Monastery of Cluny [5].

Visualizations of ancient architecture are part of the larger area referred to as *scientific illustration*. Books on this topic emphasize in particular methods of illustration using traditional drawing materials like pencils of varying hardness [3]. Spectacular results are achieved by highly gifted and trained specialists. In both their beauty and communicative power, such illustrations cannot be matched in quality yet by methods and tools on computers [6].

In contrast to most objects drawn by scientific illustrators, geometric models of ancient architecture are characterized by the fact that little is known for sure about the details of their design. Within computer science, the area of *fuzzy systems* studies uncertainty in computer models. For example, Kruse et al. work with definitions of the terms uncertainty, imprecision, incompleteness, and vagueness [7]. It must be added, however, that the computer models of interest in this area have largely dealt with numerical data as well as logical expressions, rather than geometric models. Hence the methods and tools for visualization developed have concentrated on graph-like presentations, rather than on renditions of 3D geometry. Nonetheless, some lessons can be learnt for use in rendering 3D models, so we will come back to these terms later on in Section 3.

Recent interest has been expressed within the computer graphics community in *visualizing uncertainty*. In particular, Gershon [8] called for methods and tools for visualizing different kinds of imperfection in computer models. Work to date has concentrated on uncertainty and errors in numerical data (see for example Lodha et al. [9]); the authors propose new methods of visualization of these phenomena. Pang et al. [10] also present new results for visualizing uncertain data, defining uncertainty as "to include statistical variations or spread, errors and differences, minimum-maximum range values, noisy, or missing data".

A recent trend in research on rendering has been toward *non-photorealistic visualization*. Work by Landsdown and Schofield [11] emphasizes user interaction with rendered images to modify them to suit the needs of end-users.[1] Strothotte et al. [12] emphasize a communicative model for generating images which look like line drawings. Salesin [13, 14] presents algorithms for rendering images which also imitate pencil and pen drawings. The research to date shows that it is indeed possible to generate non-photorealistic images in various styles, for instance using cross-hatching as demonstrated by Deussen et al. [15].

[1] This research has led to the development of a product called PIRANESI, see `www.informatix.co.uk/pir_intro.htm`

Table 1. Design decisions

Type of reason	Explanation
excavation	artifacts that have been actually found
physical constraints	assuming that the buildings in question stood for a long time without falling apart, one can draw conclusions about their structural properties
period features	certain data may be concluded by knowing how objects were constructed in certain periods of history, like the Romanesque or Baroque periods
analogies	elements that can be concluded logically from other buildings of this period
deductions	information derived from other data within this model

However, a difficult algorithmic problem is to decide when to use which style. Furthermore, work on systematically mixing non-photorealistic rendering styles in a single image is just beginning [16].

3. Information to visualize

Based on our work with historians and archaeologists, we have found that the information on the grounds of which such researchers decide on attributes of a virtual reconstruction can be classified into two categories: uncertainty and design decisions. We shall treat these two facets in turn and then discuss their visualization.

3.1. Uncertainty and design decisions

Uncertainty describes the absence of information due to some reason. One simply does not know what something was like in the past or (for that matter) what it will be like in the future. In our context, uncertainty can arise for two reasons as defined – in general – by Kruse et al. [7]:

imprecision: this describes the fact that "one cannot measure or observe with an arbitrary degree of accuracy", this means that the existence of a certain feature can be safely assumed, but not its dimensions.

incompleteness: this refers to the fact that certain information is unavailable, for example the answer to the question, "Did a given tower have windows, or not"?

When historians, archaeologists, and others develop reconstructions of ancient architecture, they are basically forced to decide on precise details which they often would prefer to keep rather vague in traditional linguistic accounts. Whereas it is possible to speak of a tower without knowing or having to be precise about what it looks like, visualization technology forces clear-cut decisions. Once committed, however, no support is generally made available to confirm or even check the consistency of such design decisions. In the absence of the possibility to express linguistic vagueness by computer graphical means, some historians and archaeologists are hesitant to commit themselves to specific design alternatives, especially in a computer-based visualization.

There are several different types of reasons for design decisions in a virtual reconstruction. Table 1 describes a number of these types of reasons. These types define the basic correlation between design decisions and their visualization.

Of particular interest are deductions and analogies. We have found it sufficient to enable users to specify two features: "is analogous to" between features, and "is deduced from" to specify a logical dependency among objects. These two relations can be thought of as an undirected and a directed arc, respectively, among objects of the model.

3.2. Visualizing uncertainty and design decisions

Our approach to improving the situation described above is to extend visualizations so as to include uncertainty and design decisions. Non-photorealistic rendering was chosen as the visualization technique for the information specified above. Such renditions often have considerable esthetic appeal, while by using different line styles a considerable amount of information can be conveyed to users over and above the geometry without conflicting with the latter.

The SKETCHRENDERER developed at the University of Magdeburg [6] was used to carry out the visualization of the models. In particular, once the correlation between reasons and design decisions has been defined, it can be visualized. We chose to predefine a set of line styles for different levels of uncertainty. As can be seen in Figure 4, the attribute *uncertainty* can be visualized in different ways: The figure shows the variation of sketchiness and the variation of saturation. Users can choose if they want the degree of uncertainty to be displayed using only one of these line style attributes or a combination. Users can choose which kind of representation fits their communication goals best.

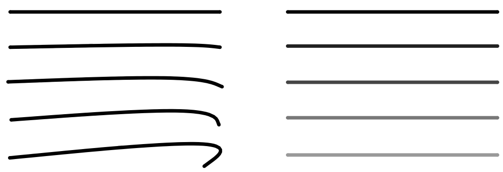

Figure 4. Two sample line styles used for varying degrees of uncertainty (top: high certainty (low uncertainty); bottom: low certainty (high uncertainty)).

This use of sketchiness or line saturation for various degrees of uncertainty is an attractive and intuitive way of visualizing uncertainty because it is used by artists in hand-drawn pictures as well (recall related work in Section 2). Users can interpret the pictures as they are used to doing so in conventional drawings and do not have to learn a new paradigm.

4. The interactive system ANCIENTVIS

In this Section we shall describe the prototypical visualization system ANCIENTVIS which was designed and implemented to meet the needs described above.

4.1. System design

We use 3D STUDIO for modeling and setting up the scene as it is important to benefit from the power of an existing, easy-to-use but nevertheless powerful modeling tool. We also import a hierarchical structure of the model if it has been defined during the modeling process, otherwise the model can be structured in a simple hierarchy editor as described below. The system ANCIENTVIS then renders a quick overview of the plain geometry using OpenGL and displays the results in an OpenGL-view window. Now the user can define attributes of the model in an attribute editor. As all knowledge about the model has to be defined in this editor for later visualization, the enriched scene model can be saved and re-imported. Once the properties of the model have been defined, the scene can be rendered with the non-photorealistic rendering component of the system. A detailed insight into specifics of the non-photorealistic renderer of the system can be found in [6].

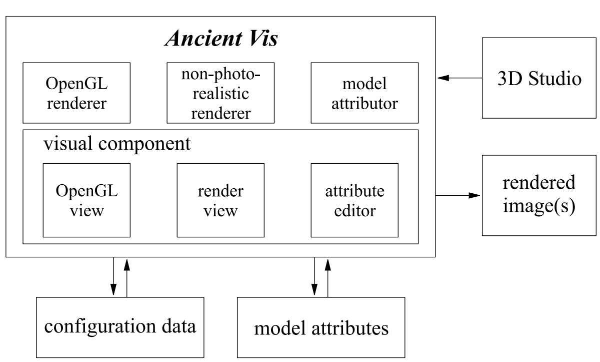

Figure 5. An overview of the system design.

4.2. Model requirements

In order to be able to associate attributes with certain parts of the geometric model, it is of vital importance that it be structured hierarchically in objects. This is not generally the case in commercially available geometric models (such as those of Viewpoint[2]), hence such a structuring may have to take place before any further work can be carried out. This can be achieved with some commercially available editors, as provided in the SBD-window under Alias|*wavefront*. Alternatively, we designed and implemented a more convenient editor which uses fisheye techniques on the hierarchy (in 2D) and on renditions of the objects (in 3D) [6, Chapter 3].

Our experience has shown that models designed for use with photorealistic renderers may need an extra refinement before they can be used with non-photorealistic renderers. In particular, care must be taken to ensure that the following properties of geometric objects generated by the modeller are not found in such models:

- *Non-uniform surface normals.* Some modeling software like 3D STUDIO does not require that the surface normals point in the right direction, because it enables two-sided rendering. However, this is not possible when rendering line drawings.
- *High number of polygons.* Models for rendering line drawings do not need to have as high a resolution as models for photorealistic images; too high a resolution only prolongs the computation time.
- *Irregular mesh structures on plain surfaces.* During the process of modeling, the Boolean function of some modellers like 3D STUDIO has to be used carefully because it can produce results that might look fine in photorealistic images, but have undesired effects in line renderings. We encountered additional lines showing up where there should not be any, e.g. triangulation faces caused by degenerated polygons.

While ideally such problems should not turn up in models, they did in fact arise in our case because they go unnoticed when using photorealistic renderers. Considerable

[2] see www.viewpoint.com

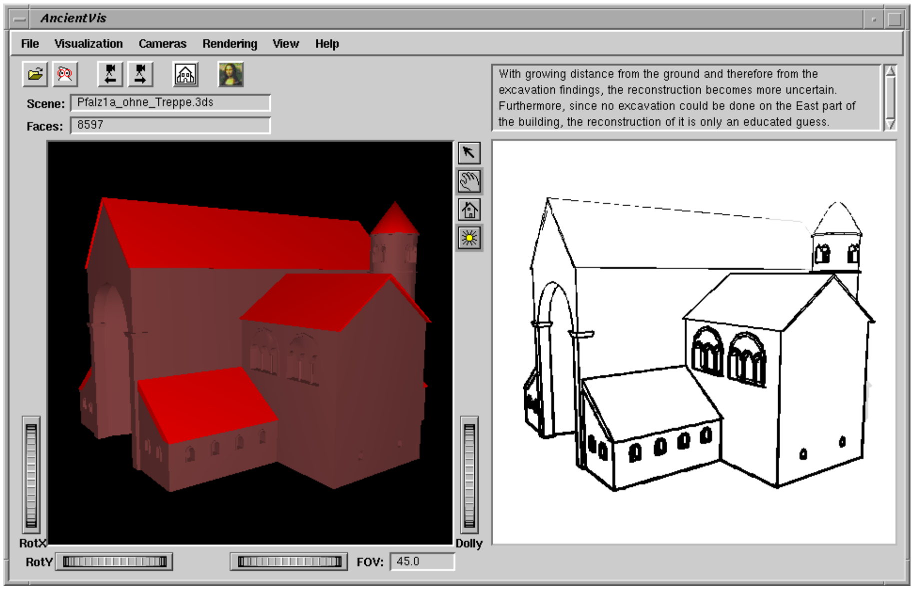

Figure 3. Screenshot of the system.

work had to be put into the model used for the examples shown below before such artifacts could be removed.

4.3. Enriching the scene model

Once the model has been structured, it must be enriched by adding information according to the classification of Section 3 with respect to the sources of information about design decisions as well as their certainty. In particular, a slot is created on every object for which information is to be entered and the data specified. The information is structured according to the classification of Table 1 above.

For the visualization of the different categories of information which can be grouped as shown in Table 1, we chose to assign default line styles. If the user wishes, these default styles can be customized or exchanged with other ones. Our experience with the system shows that users have no problems deciphering the images with respect to the use of the different line styles. The reason is that users themselves tune which information is to be expressed, and all that matters is that the different kinds of information are each presented in a different style. Thus the styles only have to be clearly distinguishable from each other.

4.4. Rendering specific line styles

The non-photorealistic line renderer performs a line rendering pipeline [6, Chapter 4]. The output of the rendering process is a set of visible lines that are still associated to the original objects. Then, ANCIENTVIS applies to the visible lines of each object a specific line style, which has been defined as an attribute when enriching the scene as described in Section 4.3.

In addition to the use of object-dependent line styles, it is possible to define style property functions which have an object-independent effect on the parameters of line styles used for the rendition. For example, a user can define a three-dimensional vector and an associated function that influences the layout of the lines depicted. This could result in fading line width and line saturation with rising distance from the ground. The resulting image gives the overall impression of higher uncertainty of the upper parts of the building as shown in Figure 6. In addition, a second function has been used to illustrate that the information about the back of the building is very uncertain because no archaeological excavations could be performed at this part of the site.

5. A case study: the palace of Otto the Great

We shall illustrate the capabilities of our system using as an example our own virtual reconstruction of a building of the Magdeburg “Kaiserpfalz” of the first German emperor Otto the Great (912-973 A.D.).

5.1. Brief historical background

In contrast to later periods, in medieval times German kings and emperors did not govern the country from a single residence. Instead, they used to travel across their lands, stopping at important towns where they administered law, and judged. Usually those places consisted of several buildings, a palace, a chapel, and several auxiliary buildings. They had to function as a residence for the time the emperor governed in town. Because Magdeburg was one of Otto’s favorite places – documented by a high number of stays –

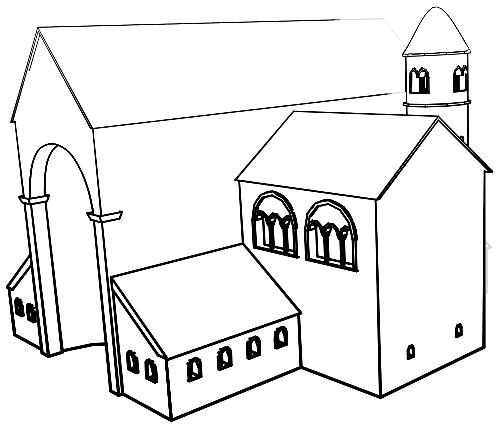

Figure 6. Visualization of the uncertainty rising with growing distance from ground and additional uncertainty of the back part of the building.

he ordered a palace to be built in this city around 960 A.D. Historians consider the “Kaiserpfalz” to have been the most spectacular complex north of the Alps at the time. The buildings were destroyed by fire and subsequently dismantled in 1207 A.D. This, however, makes the reconstruction project an extremely difficult and controversially discussed topic of contemporary archaeology.

Figure 7. Sample photorealistic rendition of a building of Otto the Great in Magdeburg (around 960-1207 A.D.).

An example of a photorealistic rendition of the main building is shown in Figure 7. The fact that many hours of discussions between computer scientists, historians, and archaeologists went into its design cannot be seen by inspecting the image, let alone can the reasons for the design decisionsbe ascertained, nor the uncertainties underlying the decisions.

5.2. Sample visualizations

At the outset, Figure 8 shows an example of a line drawing[3] produced by ANCIENTVIS. This example has a uniform line style applied to all lines and shows the main features of the palace. By contrast, in Figure 9 the user has asked for a rendition with a mapping of uncertainties encoded within the model onto the line styles shown in Section 3.2 above. Note that, for example, the foundation is drawn with straight, bold lines, indicating a high degree of certainty (they stem from the archaeological excavations), while parts of the roof, whose form is quite uncertain, is drawn with a less saturated line style. The windows, about which barely anything is known, are drawn most sketch-like.

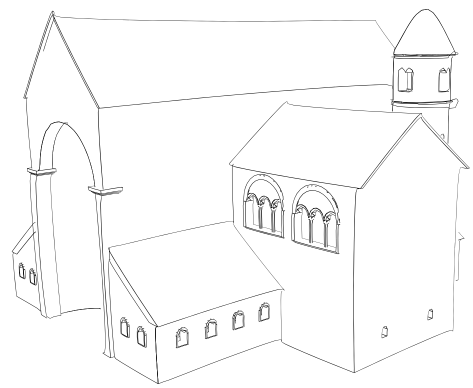

Figure 8. Visualization in a uniform, slightly sketchy line style.

Next, the user selected the spiral staircase in one of the towers and asked for the logical reasons which led to its inclusion (see Figure 10). Encoded within the model is the logical deduction that the existence of the staircase stems from a fragment of a column found on the excavation site. This results in a visualization of the staircase base along with a photograph of the excavation site showing the column fragment. Note that the photograph covers only a part of the tower entrance, hence it appears cut off. In addition, the upper part of the photography has been removed interactively in order to make room for the rendition of the stairs. This is an example of a visualization of extrinsic relations of the geometric model.

The user’s next inquiry relates to periods in history. From a menu, the user has chosen “Romanesque” and asked that all objects whose design was related to this period be visualized in one style, while the remainder of the

[3]Please note that the small size of the renditions shown in this paper do not have quite the communicative power of the larger images presented by ANCIENTVIS on the computer screen.

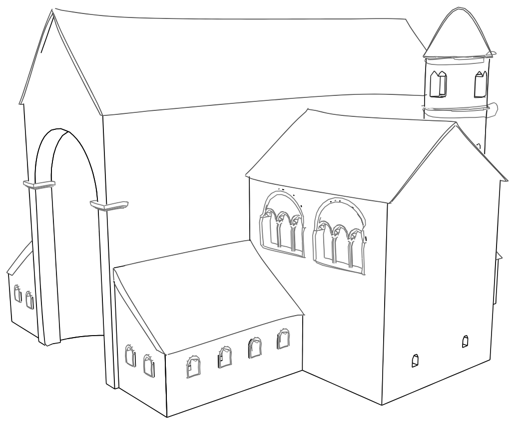

Figure 9. Visualization of the uncertainties encoded within the model.

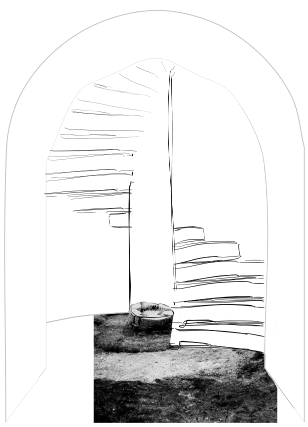

Figure 10. Visualization of the staircase along with a picture of a part of the excavation site as example of a deduction.

image be drawn in another style. The model contains an entry “Romanesque” for the attribute “analogy” for the windows of the palace. The results are shown in Figure 11.

In a final example, the user has chosen to visualize information pertaining to the entrance of the palace (see Figure 12). The system contains the remark that it was modeled after the entrance to the chapel in Aachen as well as a pointer to a picture of this chapel. ANCIENTVIS visualizes this extrinsic property by showing a picture of the chapel within a visualization of the Palace.

6. Concluding remarks

In this paper we have discussed the problem of rendering images of 3D models which convey information over and above that encoded in the geometric model. An application in which such information is of vital importance is the virtual reconstruction of ancient architecture. We suggested a classification of the information which is to be made available to users, and proposed to encode this information in non-photorealistic rendering styles. The concepts are embodied in the visualization tool ANCIENTVIS which can be used to explore the geometric data and the supplementary information pertaining to the model.

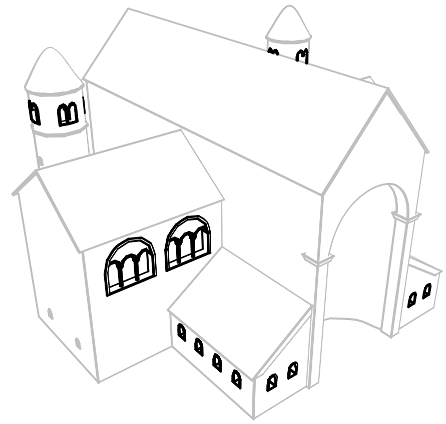

Figure 11. Visualization emphasizing those parts of the model which were attributed to the Romanesque period.

Figure 12. Visualization of the palace entrance together with an image of the chapel of Aachen from which its form was deduced as an example of an analogy.

We consider our tool to be an exploration as well as a visualization software. An archaeologist working with the system and accompanied by a computer scientist can create images to visualize his or her hypotheses. The archaeologist selects a view (from the OpenGL window) which he or she thinks fits his or her needs best. Then the archaeologist decides upon the visualization methods (line styles) that best support and emphasize his or her views. The images generated in this process are used interactively or as printouts to be a discussion basis for experts. We encountered situations in which experts who implicitly and explicitly knew certain facts were surprised by the visualization of the correlation.

Surprisingly, in our case study, users did not wish to refine the rendered image by the use of illustrative techniques like cross-hatching or stippling [17]. Thus, in an early design stage, it is necessary to remain in a high-level presentation of the virtually reconstructed building in order to leave room for alternative design decisions.

Our research opens up several avenues for further work. In particular, more attention ought to be paid to the topic of modeling uncertainty of geometric models.

The images generated by ANCIENTVIS are strictly black and white up to now. It would be of interest to make use of color as an additional parameter to encode information. However, the question as to when an image is "overloaded" with additional information quickly arises. Systematic tests ought be carried out to assess the extent to which end-users appreciate the new functionality.

Although ANCIENTVIS has shown some fine results so far, the capabilities of graphical expression using specific line styles (thick/thin, bright/dark lines etc.) are somewhat limited. We like to experiment with generating animated illustrative effects as proposed in [18].

Acknowledgments

The authors wish to thank Niklas Röber and Thomas Fuchs for their extensive work on the model of the palace and the environment. Many thanks also to Bert Freudenberg and especially to Stefan Schlechtweg for his constant support in developing the drawing algorithms. We also wish to acknowledge gratefully the excellent cooperation of the Magdeburg Museum of Cultural History, in particular that of Sebastian Kreiker, and his colleagues, and Babette Ludowici from the GWZO, who spent many hours with the authors discussing uncertainty and modeling decisions in ancient architecture. The work reported here is being supported financially by the Deutsche Telekom AG and the State of Saxony-Anhalt.

References

[1] Jutta Schumann, Thomas Strothotte, Andreas Raab, and Stefan Laser, "Assessing the Effect of Nonphotorealistic Rendered Images", in *Proceedings of CHI'96 (Vancouver, April 13–18)*. ACM Computer Human Interaction, 1996, pp. 35–42, ACM Press.

[2] Thomas Strothotte Christine Strothotte, *Seeing Between the Pixels*, Springer Verlag, Berlin, Heidelberg, New York, 1997.

[3] Martin Heller, *Wissenschaftliches Zeichnen*, Museum für Gestaltung Zürich, 2nd edition, 1993.

[4] Maurizio Forte and Alberto Siliotti, *Virtual Archeology: Re-Creating Ancient Worlds*, Harry N. Abrams, 1997.

[5] Horst Cramer and Karl J. Svoboda, *Cluny - Architektur als Vision*, Braus, 1993.

[6] Thomas Strothotte, *Computational Visualisation. Graphics, Abstraction and Interactivity*, Springer Verlag, Berlin, Heidelberg, New York, 1998.

[7] Rudolf Kruse, Jörg Gebhardt, and Frank Klawonn, *Foundations of Fuzzy Systems*, Wiley, Clichester, 1994.

[8] Nahum D. Gershon, "Visualization of an Imperfect World", *IEEE Computer Graphics and Applications*, vol. 18, no. 4, pp. 43–45, July/Aug. 1998.

[9] Suresh K. Lodha, Bob Sheehan, Alex T. Pang, and Craig M. Wittenbrink, "Visualizing Geometric Uncertainty of Surface Interpolants", in *Graphics Interface '96*, Wayne A. Davis and Richard Bartels, Eds. Canadian Information Processing Society, May 1996, pp. 238–245, Canadian Human-Computer Communications Society.

[10] Alex T. Pang, Craig M. Wittenbrink, and Suresh K. Lodha, "Approaches to Uncertainty Visualization", *The Visual Computer*, vol. 13, no. 8, pp. 370–390, 1997.

[11] John Lansdown and Simon Schofield, "Expressive Rendering: A Review of Nonphotorealistic Techniques", *IEEE Computer Graphics and Applications*, vol. 15, no. 3, pp. 29–37, May 1995.

[12] Thomas Strothotte, Bernhard Preim, Andreas Raab, Jutta Schumann, and David R. Forsey, "How to Render Frames and Influence People", in *Computer Graphics Forum*, 1994, vol. 13, pp. 455–466.

[13] Michael P. Salisbury, Sean E. Anderson, Ronen Barzel, and David H. Salesin, "Interactive Pen-and-Ink-Illustration", in *Computer Graphics*. ACM SIGGRAPH, 1994, Annual Conference Series, pp. 101–108, ACM Press.

[14] Georges Winkenbach and David H. Salesin, "Computer Generated Pen-and-Ink-Illustration", in *Computer Graphics*. ACM SIGGRAPH, 1994, Annual Conference Series, pp. 91–100, ACM Press.

[15] Oliver Deussen, Jörg Hamel, Andreas Raab, Stefan Schlechtweg, and Thomas Strothotte, "An Illustration Technique using Intersections and Skeletons", in *Graphics Interface 99*, Kingston, Ontario, 1999, Canadian Human-Computer Communications Society, to appear.

[16] Jörg Hamel and Thomas Strothotte, "Templates in Non-Photorealistic Rendering", 1998, Submitted.

[17] Elaine S. Hodges, *The Guild Handbook of Scientific Illustration*, Van Nostrad Reinhold, 1989.

[18] Maic Masuch, Lars Schumann, and Stefan Schlechtweg, "Animating Frame-to-Frame-Coreherent Line Drawings for Illustrative Purposes", in *Simulation und Visualisierung '98*, P. Lorenz and B. Preim, Eds. Mar. 1998, pp. 101–112, SCS - Society for Computer Simulation Int.