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The Dresden Frauenkirche — rebuilding the past

Brian Collins[1], Dave Williams[1], Robert Haak[2], Martin Trux[2], Herbert Herz[2], Luc Genevriez[3], Pascal Nicot[3], Pierrick Brault[3], Xavier Coyere[3], Burkhard Krause[4], Jens Kluckow[4] & Armin Paffenholz[4]

([1]IBM UK Scientific Centre, [2]IBM Deutschland Informationssysteme GmbH, [3]ARC (Audiovisuel Realisation Conseil), [4]TransCAT Nord GmbH)

3.1. Historical background

For two hundred years, the marvellous bell-shaped cupola of the Frauenkirche, or Church of Our Lady, stood above the roofs of the historic centre of Dresden and dominated the famous Elbe panorama. Built between 1726 and 1743 from a design by the architect George Bahr, the Dresden Frauenkirche was the most important church building of German Protestantism and at the same time one of the great masterpieces of European architecture (Fig. 3.1). On 15th February 1945, two days after the devastating bombing of Dresden, the domed building, constructed entirely of stone, became so weakened by the subsequent fire-storm that it collapsed.

Only two fragments of the walls and an enormous heap of rubble remain (Fig. 3.2). The ruins of the Frauenkirche came to symbolise the destruction of Dresden and have stood as an admonition for more than forty-five years. However, the beauty of the baroque Frauenkirche was never forgotten. Its rebuilding, planned since the end of the war, was prevented by the economic and political conditions that existed under communist rule. But the time for the rebuilding has now come and Dresden, the "Florence on the Elbe", will be able to recover its symbol and an important part of its former beauty. At the same time, world culture will be given back one of its great works of architecture.

The Frauenkirche is to be rebuilt entirely in its original form, using historic building techniques and the original material, sandstone from the Elbe valley. The surviving documentation and detailed architectural drawings, produced during an earlier restoration between 1938 and 1943, will make this possible. The surviving building fragments will be incorporated and most of the original stones reused. The baroque interior furnishings including the famous organ, originally built by Gottfried Silbermann, are also to be restored. When completed the Frauenkirche will once again be used for church services and for concerts.

The rebuilding of the Frauenkirche will cost approximately 160 million German Marks and will take about ten years. In view of the difficult economic problems and high costs of redeveloping former East Germany, it will not be possible to make use of German federal, state, or church funds. For this reason, a "Society for the Rebuilding of the Frauenkirche in Dresden" has been formed to take on the enormous task of collecting donations from all over the world. The building plans are now under way, the ruins have been stabilised, and the work of rebuilding will soon begin. Before long the bell-shaped cupola of the Frauenkirche will tower over the Elbe river and roofs of Dresden once more.

It is a tradition for IBM to make contributions to social, educational and cultural activities. IBM supports many projects of public interest under the framework of its Corporate Social Responsibility Program. For the reconstruction of the Frauenkirche, IBM is providing support with technical equipment, administrative assistance and the organisation of events in order to increase the awareness of potential sponsors. This current project, the computer reconstruction, is one major activity within the context of the actual reconstruction of the Frauenkirche.

3.2. Computer reconstruction

The use of computer graphics in Archaeology and National Heritage has a surprisingly long pedigree. One of the first animations was shown as part of a BBC *Chronicle* program which was broadcast on 27 March 1984 and showed a reconstruction of Roman Bath. Though the computer reconstruction was done by Woodwark in the early 1980s, the work was not published until 1991 (Woodwark 1991). Another animation of a computer reconstruction, this time of the Saxon Minster in Winchester, was made at the IBM UK Scientific Centre in the mid 1980s (Burridge *et al.* 1989). A comprehensive survey of the field is to be found in Reilly (1989) and the references therein.

More recently one of the authors of this paper, Genevriez, has directed animations of a computer reconstruction of Paris in 1789, and of an Abbey, that of Cluny in France. The latter animation was presented at the recent *Imagina '93* conference.

The following sections describe the technical stages which were used to reconstruct the Dresden Frauenkirche. However, this project was not just a technical exercise. To make this kind of animation both serious and credible it was necessary to work with curators and archaeologists, and to perform exhaustive research of the available documentation. This was crucially important to ensure that what was reconstructed was not only historically correct but also conveyed an "atmosphere" and "emotions" that were authentic.

3.2.1. Geometric CATIA 3D model

The detailed architectural drawings which were produced, and contemporary photographs which were taken during

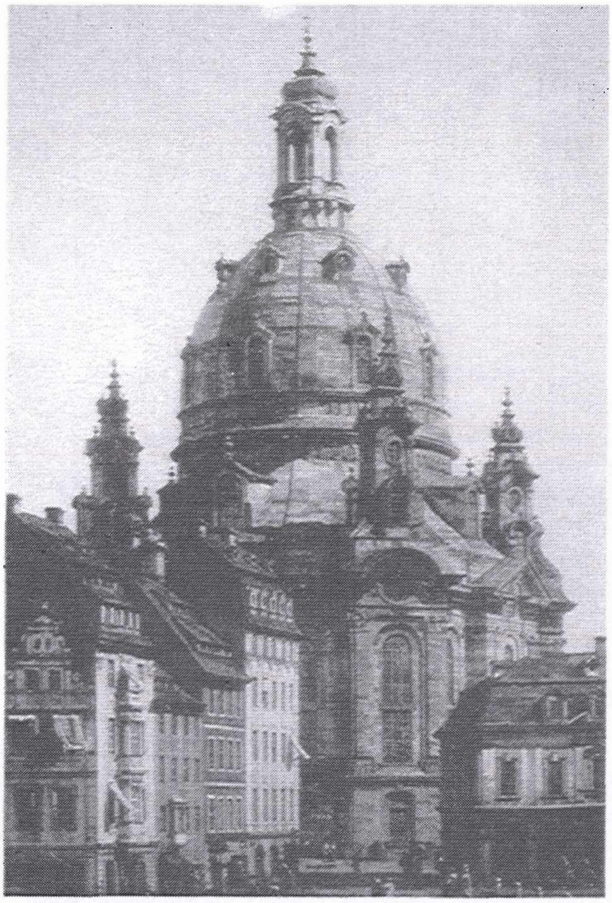

Figure 3.1: A painting of the Dresden Frauenkirche, from the 18th Century.

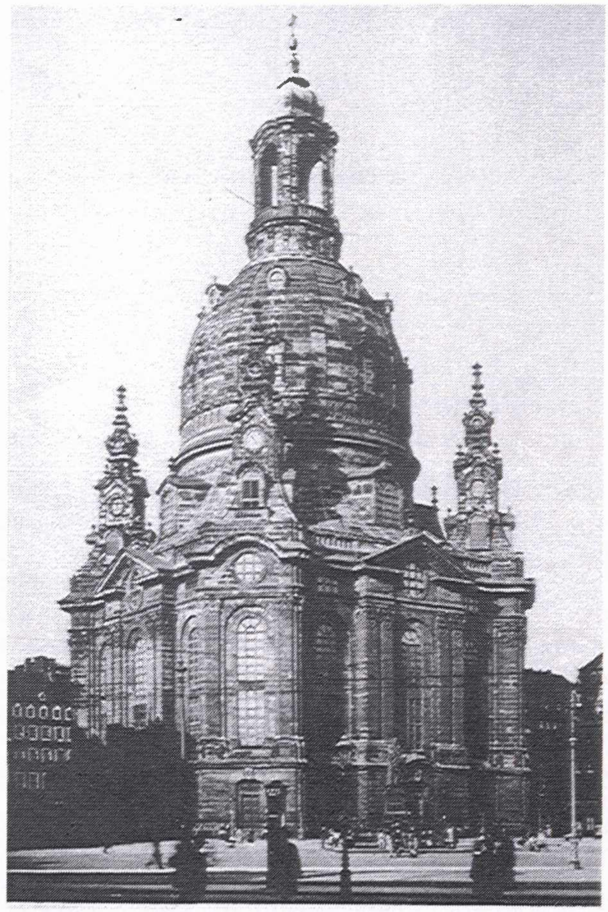

Figure 3.3: A photograph of the Dresden Frauenkirche taken before its destruction in 1945.

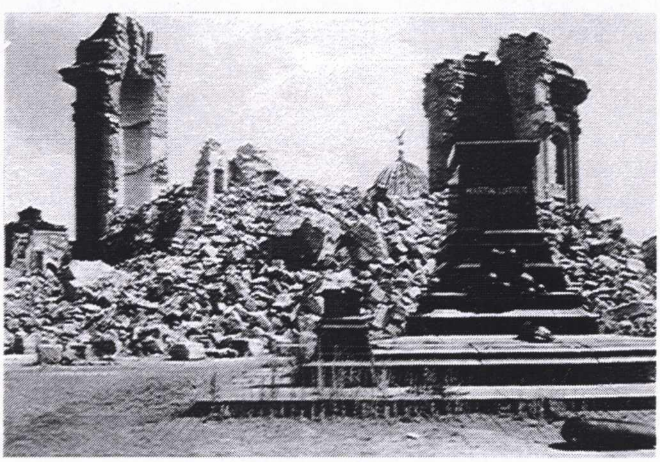

Figure 3.2: A photograph of the ruins taken after 15th February 1945.

the 1938-43 restoration, were the main sources for the generation of the geometric CATIA 3D model (Figs. 3.3 and 3.4). The whole model was input manually, but it was split into several parts to make the project more manageable. Thus, separate models were produced for the "outside" and the "inside" of the building so that, for example, the altar is included in the "inside" model but is excluded from the "outside" model. Similarly separate models were produced for the existing "ruins" and for the whole "reconstructed" building.

As the Frauenkirche is not a "normal building" with rectangular walls, beams *etc.*, geometric reconstruction presents a major problem. The structure of the building is very complex, especially the inside of the church and the roof parts. To create these objects, CATIA works with "complex solids" and "advanced surfaces". Only CATIA allowed us to achieve these results in a period of just five weeks. One example is the very complex roof of a staircase tower. This object was constructed with the help of solids and "Boolean operations". Two prismatic solids were created using different contours, these were then intersected at an angle of 90 degrees resulting in a "perfect" roof. Such multiple solids were combined into larger objects called workspaces (for example the cupola) and these were in turn combined to form the complete building.

The level of detail varied considerably, but closely mirrored the detail available in the drawings and contemporary photographs. In some cases very fine details were available, for example the pulpit, but in others only gross details existed, for example the outside stonework. The over-rid-

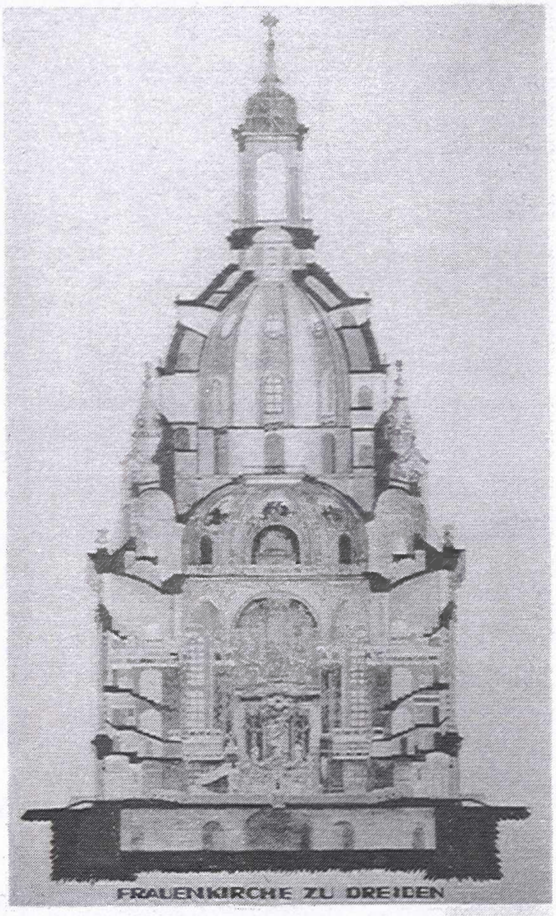

Figure 3.4: An architectural drawing produced for the 1938-43 restoration.

ing philosophy in the construction of the geometric model was not to add detail where it was not available from the drawings or the photographs.

Only geometric information was input to the model and no information about the colour or texture of particular components was included. However, false colours were used to differentiate parts of the model, thus the windows were coloured blue and the roofs red.

3.2.2. Photo realistic model — 2D

The geometric model was not detailed enough to produce a photo realistic reconstruction. Therefore, it was necessary to supplement it with details of the baroque furnishing, the pulpit and the organ. Where possible scanned images of photographs from both before and after the 1938-43 restoration were used. For the remaining details photographs from contemporary churches in Germany and the United Kingdom (St. Paul's Cathedral) had to be used.

All these images, some black and white, some in colour but over 60 years old and some in colour from 1992, had to be colour matched. This was achieved using a colour palette editor. The images were also scaled and warped where necessary. Thus the painted inner-wooden dome was reconstructed by warping the 2-dimensional scanned image into a 3-dimensional image to be texture mapped onto the hemispherical geometric model of the dome. NEFERTITI was used for these image manipulation stages.

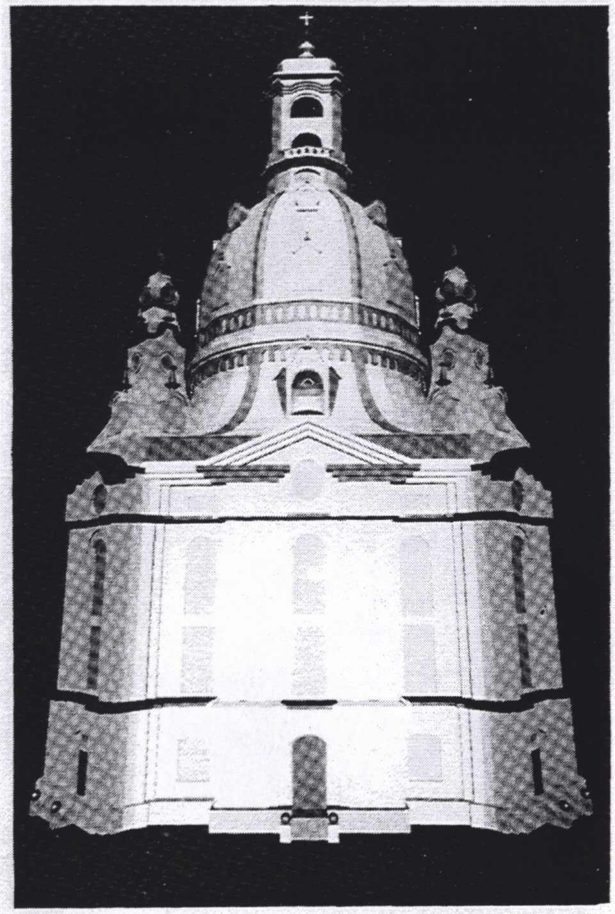

Figure 3.5: A geometric model of the "outside" using CATIA.

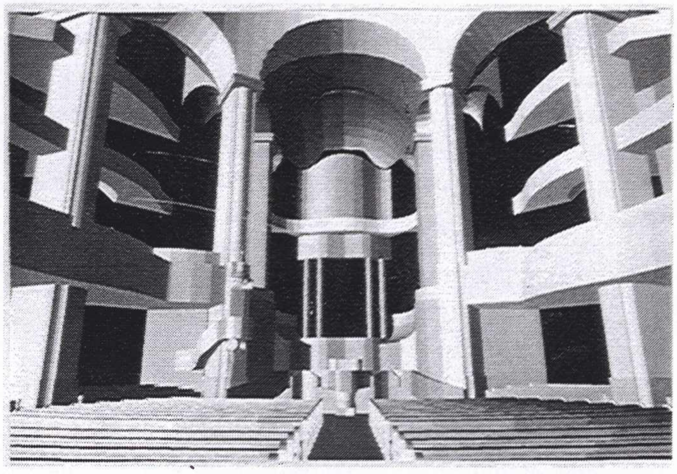

Figure 3.6: A geometric model of the "inside" using CATIA.

Figure 3.7: Image of the "reconstruction outside" rendered using TDImage.

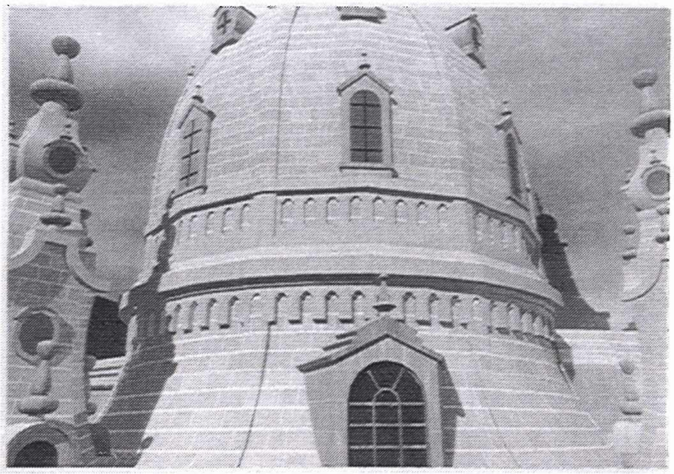

Figure 3.8: Image of the "reconstruction outside" rendered using TDImage.

3.2.3. Photo realistic model — 3D

The geometric model was transferred from CATIA to TDImage which was used for this stage. It was kept as "outside" and "inside" models and as "ruin" and "reconstruction" models. Details which were missing in the geometric model were added where available, based on photographs of the original church or of contemporary churches, in particular the organ, the pulpit, and the galleries. The original colours were added where known and texture mapping and bump mapping, based on the 2-dimensional scanned images were extensively used for the reconstruction of the baroque furnishings. Finally, appropriate illumination, both for the "outside" and "inside" models was chosen.

3.2.4. Animation preview

For the animated sequence the camera trajectory was derived by choosing the camera position for six key frames and using TDImage to interpolate the camera positions for the intervening frames, typically about 500 between pairs of key frames. The complete camera trajectory from TDImage and the geometric model from CATIA were both transferred to Data Explorer. A ray-cast rendered animation sequence was then generated at about 1 frame per second and the animation checked by replaying at the planned rate of 25 frames per second on an IBM POWER Visualization System (see below). This approach was substantially faster than small-size ray-traced rendering of each frame which is the more traditional method. Based on these animation previews the photo realistic model and camera trajectory were refined in an iterative process.

3.2.5. Rendering

Once the camera trajectory and the photo realistic model were finished the final animation sequences were generated by ray-traced rendering using TDImage. This used both the "outside" and "inside" models and the final image resolution was 768 by 460 pixels and 24 bit colour (8 bits each for red, green and blue). Each image took typically 1 to 2 hours to render and a total of 2800 images were produced during this stage (Figs. 3.7–3.10).

3.2.6. Post-production

Because the model was split into an "outside" and an "inside" there were two periods in the animated sequence, (on entering and exiting through the main door), when the camera needed to "see" details from both the "outside" and "inside" models. Thus if only the "outside" model were used and the main door was open there would be no details of the "inside" visible through the door opening. Similarly if only the "inside" model were used and the main door was open there would be no details of the "outside" visible around the door opening. To overcome this two sequences were rendered using the same camera trajectory, one using the "outside" model and one using the "inside" model. As well as the 24 bits of colour for each pixel in the resulting rendered images there were also mask bits. These bits were subsequently used in a compositing stage to decide whether a pixel was used from the "outside" or from the "inside" rendered image was used in the final composited image.

The lettering in the titles, explanatory text and credits were all generated as rendered images and subsequently composited with appropriate still frames from the animated sequences. TDImage was used both for the compositing and for producing the titles, explanatory text and credits.

Where artistically appropriate "fades" were used for the transitions between pairs of title, explanatory text and credit images and between some animation sequences. These were typically for time periods of one to two seconds (25 to 50 frames). This was achieved by blending an increasing percentage of the final image with a corresponding decreasing percentage of the initial image. Data Explorer was used to generate these fade sequences.

The final animated sequence contained nearly 3000 frames with an additional 32 still frames for titles, explanatory texts and credits. The full length computer reconstruction lasts 3 minutes 35 seconds.

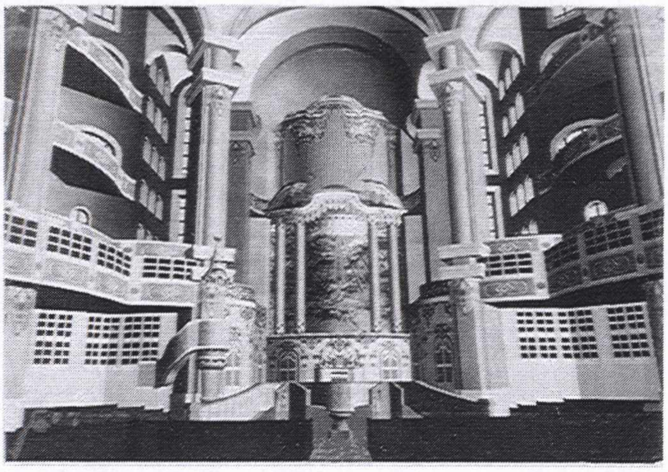

Figure 3.9: Image of the "inside" pulpit and organ rendered using TDImage.

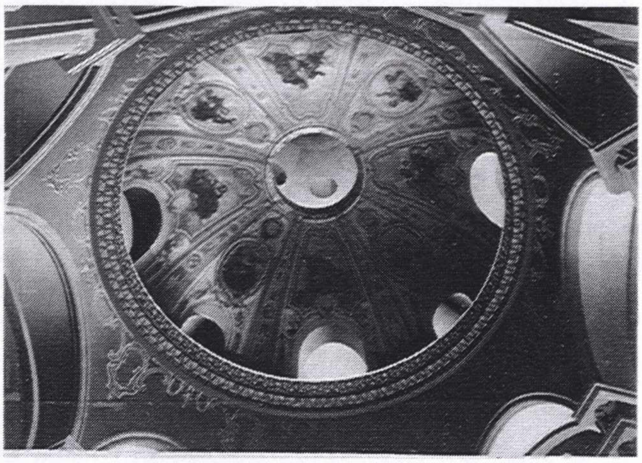

Figure 3.10: Image of the "inside" painted wooden dome rendered using TDImage.

3.3. Hardware

3.3.1. Computers

Two main computer environments were used for the project which, together with the Video and Slide making equipment, were connected on the same local area network. The data files containing the geometric model, the photo realistic model, the scanned and rendered images were shared using the network. This ensured that all of the data were accessible to all pieces of equipment and only one copy of the data was necessary.

The first environment consisted initially of four, and subsequently of eight, IBM RISC System/6000 workstations (both model 530H and 560) running the AIX operating system. For each major stage an appropriate number of workstations were employed, the number depending on the people skills available or the computer resources required. The allocation was approximately as follows:

- Geometric model — one machine for one week
- Photo realistic model — 2D — one machine for one week
- Photo realistic model — 3D — three machines for six weeks
- Rendering — eight machines for four weeks
- Computer Post-production Compositing — one machine for one week

In all a total of nearly 9000 machine hours were expended over an elapsed time of twelve weeks.

The second environment comprised an IBM POWER Visualization System (PVS). This is a parallel machine with 32 processors, 1 Gigabyte of shared memory, a 21 Gigabyte disk subsystem and a 24-bit frame buffer with the ability to display rendered images at up to 30 frames per second. The PVS was used for the following stages:

- Animation Preview
- Computer Post-production Fades
- Storage of the final animation sequence

The PVS dramatically reduced the time needed for these stages to a few days instead of the several weeks that would have been required using single processor workstations. It is intended that future projects will use the power of the PVS during the computer intensive rendering stage as well.

3.3.2. Video

A Supernova was connected to the same local area network via a workstation. Each frame in the final animation sequence was read from the PVS and converted from computer graphics format to a format acceptable to the Supernova. The Supernova performed the digital to analogue conversion and sent each frame to a Betacam-SP video recorder. It took approximately 35 seconds to record each frame onto video tape and nearly 30 hours were required to record the complete animation sequence. Some additional fades and the musical accompaniment were completed in a television editing suite.

3.3.3. Slides

Selected frames from the animation were chosen to be re-rendered for photographic slides. All of the computer graphics figures in this paper were printed from 4 by 5 inch negatives which were produced using a QCR-Z digitising camera; the image resolution was 4096 by 2730 pixels and 24 bit colour (8 bits each for red, green and blue). In addition several 35mm stereo pairs were produced using an PCR digitising camera; the image resolution was 2048 by 1365 pixels and 24 bit colour. Both the QCR-Z and the PCR were connected to the same local area network via a workstation. [Ed. note: colour figures were converted to B/W via a process camera for this paper.]

3.4. Summary

This project to reconstruct the Dresden Frauenkirche can be viewed as a typical application of commercial computer graphics software and hardware to a specific project. By its very nature all the software, though rich in function, had limitations and the pressures of budget and deadlines necessitated compromises at all stages of the project.

Thus, for example, it was always possible to improve some aspect of the camera trajectory or of some particular detail of the geometric model or of the texture mapping. It was always possible to see "flaws" in a particular image or animation sequence and to be tempted to continually strive for "perfection". Thus, if images with "buggy" pixels were generated, it was felt to be acceptable to use a palette editor for 5 minutes to "correct" the offending pixels to circumvent the software problem rather than re-render the image, which could easily have taken one hour. The recent texts (Vince, 1992, Watt and Watt, 1992) and the large body of literature, see (Magnenat-Thalman and Thalman, 1992), on computer animation though excellent on the theoretical aspects rarely discuss the compromises that are always necessary in a typical project.

Nevertheless, we believe that this computer reconstruction recreates the original glory of the Dresden Frauenkirche; a "virtual reality". This animation will also serve as an excellent preview of the long-planned reconstruction, which will soon start in "reality".

3.5. Postscript — How to preserve a computer reconstruction ?

After the completion of this animation we discovered that we had created a new problem, which is "How can a computer reconstruction, which is a new archaeological document in its own right be itself conserved for future generations?". Computer hardware and software evolve and change at such a rate that it will most probably be impossible to render these images on computer systems even in the near future.

A possible solution would be to preserve the computer system which was used for each animation that is produced, but that would ultimately become too expensive to maintain in working order. The only practical solution at present would be to render these images at the maximum resolution possible and record them onto a medium such as 35mm cine-film or CD-ROM which has a reasonably long shelf life. We hope that this will be possible with this project.

Acknowledgements

More details of all of the computer graphics techniques can be found in the documentation for the software and hardware products which were used in this project. In particular:

- CATIA (version 3.2) which is a product of Dassault Systemes
- NEFERTITI (version 2.4) which is a product of Little Big One
- TDIMAGE (version 3.0) which is a product of Thomson Digital Interactive
- DATA EXPLORER (version 1.2) which is a product of IBM Corporation
- AIX (version 3.2) which is a product of IBM Corporation
- IBM RISC System/6000 (models 530H and 560) which is a product of IBM Corporation
- IBM POWER Visualization System (model 3) which is a product of IBM Corporation
- SUPERNOVA (model 24.2) which is a product of Spaceward Ltd
- BETACAM-SP (model BVW-75P) which is a product of Sony Corporation
- QCR-Z which is a product of Agfa Division of Miles Inc.
- PCR which is a product of Agfa Division of Miles Inc.

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Bibliography

BURRIDGE, J. M. ET AL. 1989. "The WINSOM solid modeller and its application to data visualization", *IBM Systems Journal* 28(4): 548-568.

REILLY, P. 1989. "Data Visualization in Archaeology", *IBM Systems Journal* 28(4): 569-579.

MAGNENAT-THALMAN, N. & D. THALMAN 1992. "Six-hundred indexed references on computer animation", *Journal of Visualization and Computer Animation* 3(3): 147-174.

VINCE, J. 1992. *3D Computer Animation*, Addison-Wesley.

WATT, A. & M. WATT 1992. *Advanced Animation and Rendering Techniques*, Addison-Wesley.

WOODWARK, J. R. 1991. "Reconstructing History with Computer Graphics", *IEEE Computer Graphics and Applications* 11(1): 18-20.

Brian Collins and Dave Williams
IBM UK Scientific Centre,
Athelstan House, St Clement Street,
GB-SO23 9DR Winchester

collinsb @ winvmd.vnet.ibm.com
davew @ winvmd.vnet.ibm.com

Robert Haak, Martin Trux and Herbert Herz
IBM Deutschland Informationssysteme GmbH,
Pascalstr. 100,
D-7000 Stuttgart 80

Luc Genevriez, Pascal Nicot, Pierrick Brault and Xavier Coyere
ARC (Audiovisuel Realisation Conseil),
24 rue de Pre St Gervais,
F-93500 Pantin

Burkhard Krause, Jens Kluckow and Armin Paffenholz
TransCAT Nord GmbH,
Otto-Hahn-Str. 20,
D-4600 Dortmund 50