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Personal computer-based three-dimensional reconstruction modelling of standing buildings

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37.1. Introduction

The paper will show how the type of computing technology which archaeologists are beginning to use, personal computer-based CAD and rendering software, can be used for three-dimensional archaeological reconstruction and visualisation. It is also shown how such a visualisation process can be an aid to archaeological interpretation. By way of example, a collaborative project between the University of Teesside and English Heritage to "reconstruct" the chapter house of Rievaulx Abbey using AutoCAD and 3D Studio software (Autodesk 1990a–d) on a 386-based personal computer, is described.

The original aim of the project was to determine whether there may be any base for the theory that the quality of light in the chapter house might have contributed to the decision to give the Abbey an unusual orientation. The monks of the Medieval Cistercian order regarded sunlight as a manifestation of the Holy Spirit. Is it possible that the desire of one group of 12th Century brethren to have sunlight illuminate the daily business of monastic life was strong enough to rotate Rievaulx Abbey ninety degrees from the conventional ecclesiastical east-west orientation?

The aim of this paper is to demonstrate that PC-based three-dimensional computer-aided "Archaeological Reconstruction Visualisation" (ARV, Fig. 37.1) has begun to be used to address questions such as this, and that it could play an important role in future archaeological interpretation.

37.2. Rievaulx Abbey chapter house

Rievaulx Abbey lies in the valley of the River Rye beneath the Yorkshire Wolds (Fig. 37.2). The chapter house of Rievaulx Abbey, where the chapters of Saint Benedict were read and day-to-day monastic affairs discussed, was unusually large and ornate with an apsidal end and clerestory windows. Its unusual orientation (Fig. 37.3) gave the apse a southern aspect along the valley of the River Rye. This would have optimised the light coming in through the windows on two levels.

On a conventional orientation the apse would have faced east, which in this situation would have pointed it towards the steep, overshadowing valley side (see Fig. 37.4). This would have reduced its illumination levels.

37.3. The brief

The initial practical project brief was to use ARV to reconstruct the chapter house as a computer model, with the ultimate aim of visualising the interior to see just how spectacular its illumination would have been, and thus to determine whether the final result would have justified such a dramatic break with tradition. Solid modelling reinforces the reconstruction model's purpose as an analytical tool. Initial discussions led to the decision to make a solid model instead of a surface model. Solid models are easier to take apart, to puncture, and to cut sections through, *etc.* They also incorporate volumetric information, which facilitates structural analysis. Table 37.1 presents a full comparison of the features of surface and solid models.

37.4. Implementation.

37.4.1. Software and hardware selection

The decision to use a solid model was one of the reasons behind the choice of AutoCAD as modelling software. It has an integrated solid modelling arm, the "Advanced Modelling Extension" (AME), and the project used the then current version (Release 11, see Omura 1991).

The renderer available was Autodesk's 3D Studio, which Autodesk had loaned to the University of Teesside for evaluation purposes. It was designed to import AutoCAD models with de-facto standard `.DXF` file format, for rendering and animation. It is also a surface modeller in its own right. Some simple models were made during familiarisation with the package. 3D Studio has a very user-friendly interface which was found to be a lot easier to learn than AutoCAD (although Release 12, the latest AutoCAD version, is much more user-friendly than its predecessors).

The hardware platform used was a 386 Personal Computer with an 80387 maths co-processor, a 200Mb hard disk, 8Mb of RAM, 8Mb of cache RAM, a colour display card and a high resolution monitor.

37.4.2. Methodology

About 10 days were spent learning to use AutoCAD, including modelling the whole abbey as a block model, and about 15 days modelling the chapter house. Some initial architectural training was undertaken to become familiar with three-dimensional modelling. No previous experience of a solid modelling application had been obtained, but the surface modeller CGAL on Hewlett Packard/Apollo Workstations had been used. Solid modelling was found to be a more intuitive technique than surface modelling. Given a tight project timetable, it was decided to concentrate on working in three dimensions from the start, rather than first attempting to become fully conversant with two-dimensional drafting as is commonly the manner of traditional AutoCAD tuition. Working in 3D was not found to be a problem,

	Surface Models	*Solid Models*
Main Applications	Computer graphics for presentation, entertainment and advertising.	Computer graphics for design and manufacture.
Accuracy	Lower (designed to fulfil the more superficial presentation needs).	Higher (fulfilling the needs of CAD for "complete, accurate and unambiguous models").
Ease of construction	It is not so easy to construct purely cosmetic structures which produce an illusion, particularly for people who are not computer graphics experts.	Easier. One of the great advantages of such accurate models for graphics is that they are usually much easier to construct than surface models . They do not rely on the user to create the required set of faces.
Robustness	Good.	Not so good.
Flexibility	Good.	Representation of non rigid, jointed objects is not possible. Bending and twisting of objects is still undergoing development.
Renderability	There are more highly developed algorithms available, but highest possible quality is lower than with solid models.	Fewer rendering algorithms exist for solid models, but a higher degree of realism is possible.
Ease of analysis	Harder (it is difficult to cut holes in surface models and to take them apart, cut sections through them, etc.)	Easier (especially analysis which requires volumetric information). It is easier to cut sections in and holes through a solid model. They are easily interfaced to programs which can do finite element analysis or test for the effect of stresses on construction.
Memory requirements	Generally smaller, because volumetric information is not stored.	Generally greater because volumetric information is stored.
Validity	"Impossible" surface objects are possible.	Invalid representation is impossible.
Future Potential	Probably not so great in scientific and analytical applications, for reasons shown above.	Greater in scientific and analytical applications.

Table 37.1: Comparison of surface and solid model properties.

since in any case 2D orthographic views of the 3D model are used to facilitate editing.

The building was initially divided into three-dimensional blocks. Elements which belonged together were grouped on the same layer (each layer distinguished by its own colour). The first objects constructed (the columns) were given a lot of detail. Thereafter the level of detail was reduced, as a great deal of memory was involved in creating each object. The model was not over-simplified, however, since it was desired to give a reasonably accurate impression of what the space would have looked like.

The level of detail to be modelled is a crucial decision in ARV, which should be made at as early a stage as possible in the modelling process, taking into account both the resources available and the purpose of the model.

In AutoCAD's Advanced Modelling Extension (AME), models can be made by using both the ready-made building blocks (sphere, cube, torus, wedge, cylinder) with user-specified dimensions, and also user-defined solids of revolution and solids of extrusion (i.e. shapes made by rotating a 2D profile about an axis in 3D space, or pulling a 2D profile up into 3D, Fig. 37.5). Whichever method, or combination of methods, is chosen to create the initial shapes, Boolean operations (intersection, subtraction, union) can then be used to fine-tune the result.

The most complicated modelling tasks were presented by the cross-vaulted ceilings. For the side aisles, a shape made by intersecting two cylinders was subtracted twice from a rectangular block (Fig. 37.6).

Once the basic building blocks had been created (a column, a ceiling vault, a window, walls, roofs *etc.*) it was a fairly simple matter to copy and then position them.

37.4.3. Problems

The main problems encountered resulted from the large amount of memory occupied by the model. This was to be expected as solid models do require more memory than surface models. Some time-saving techniques — including ways of minimising file size — were discovered during the project, and many of them were incorporated in the work, but annoying delays still existed while operations were carried out.

One task which proved to be much harder than anticipated was the transfer of the model file into 3D Studio. The model proved to be too complex for 3D Studio Version 1, but in the end a successful transfer was made to Version 2, and a number of images were produced of the interior and exterior of the chapter house, with experimental colours, surface textures, lights, shading modes, etc. A quick, monochrome, rendered walk-through was also produced (Fig. 37.7).

Unfortunately, access to Teesside's version of 3D Studio was not gained until fairly late on in the project, and by the time its file import limitations were discovered and Version 2 was obtained, the project deadline had almost arrived. The images produced in the last few days of the project do not, therefore, represent the highest possible degree of realism. They are thus limited in their potential to provide answers to that original question of whether the illumination of the chapter house was a deciding factor in Rievaulx Abbey's orientation. The conclusion must be that further experimentation is necessary.

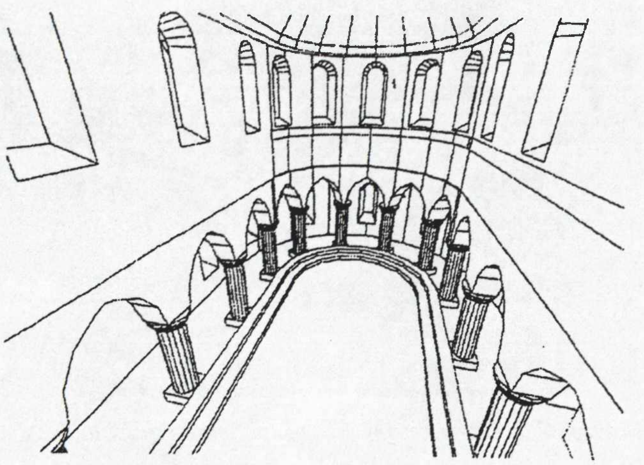

Figure 37.1: Archaeological Reconstruction Visualisation (ARV) applied to the Rievaulx Abbey chapter house.

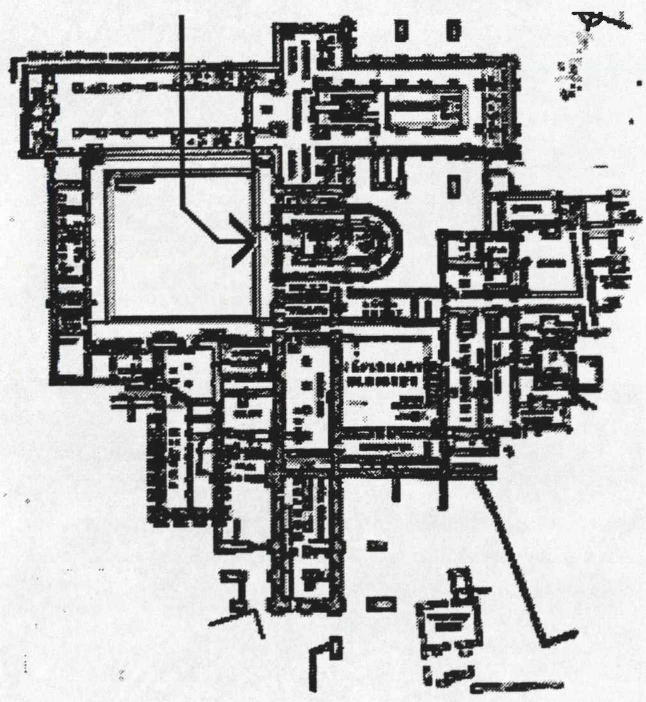

Figure 37.2: Plan of Rievaulx Abbey.

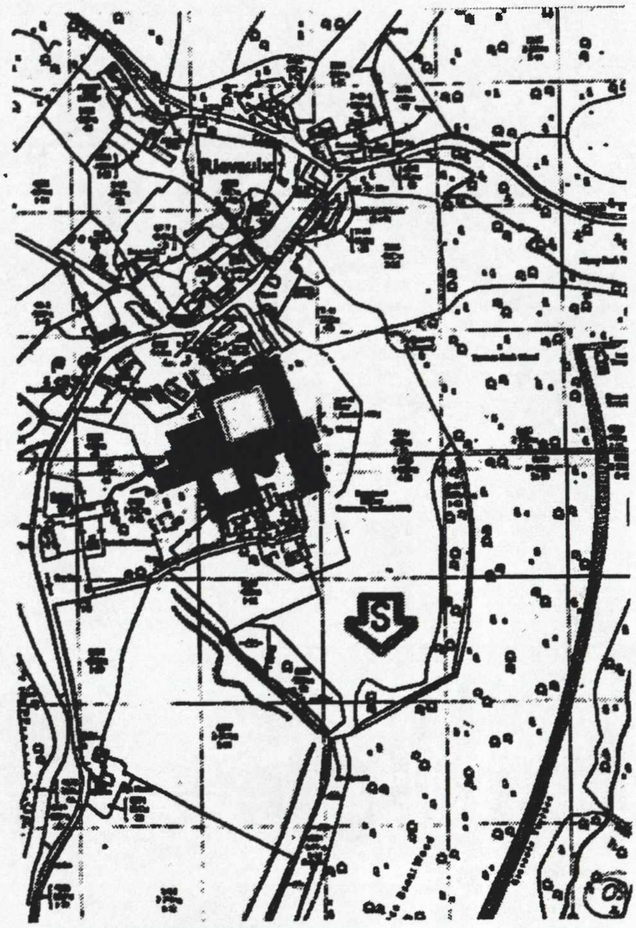

Figure 37.3: Site context plan of Rievaulx Abbey.

Figure 37.4: A section across the Rievaulx Abbey site.

37.5. Precedents

To gauge where this exercise stands in the evolution of ARV, some precedents were researched. Altogether some forty ARV projects were investigated which are listed in the bibliography. Most ARV has been carried out on large, mainframe computers by computer scientists, often using software which has an unfriendly interface requiring users to have programming skills. One example of a workstation-based precedent is the modelling of the chapter house at Kirkstall Abbey in Leeds by the School of Computer Science at Leeds University, which is superficially comparable to the current project.

However, three examples of PC-based modelling were found:

1. Two computer scientists, Janice Cornforth and Craig Davidson of Mechanical Intelligence, used an Apple Macintosh to model Fishbourne Palace in Sussex (Cornforth & Davidson 1990). Their microcomputer was accelerated by transputers. The rendering software used was a pre-release version of Pixar's Renderman, which produced images with a high level of realism (ray-traced).
2. Billingsgate Quay in London was modelled, rendered and animated by Richard Harding, a technical support specialist at Autodesk, on 3D Studio using a 386 PC. The project was for London's Pageant Museum at Tower Hill. It aimed to show the stage-by-stage building of the quay, emphasising the different construction phases. It also trys to show how archaeologists think. As with the Rievaulx Abbey project, the data was taken from paper drawings and a physical model.

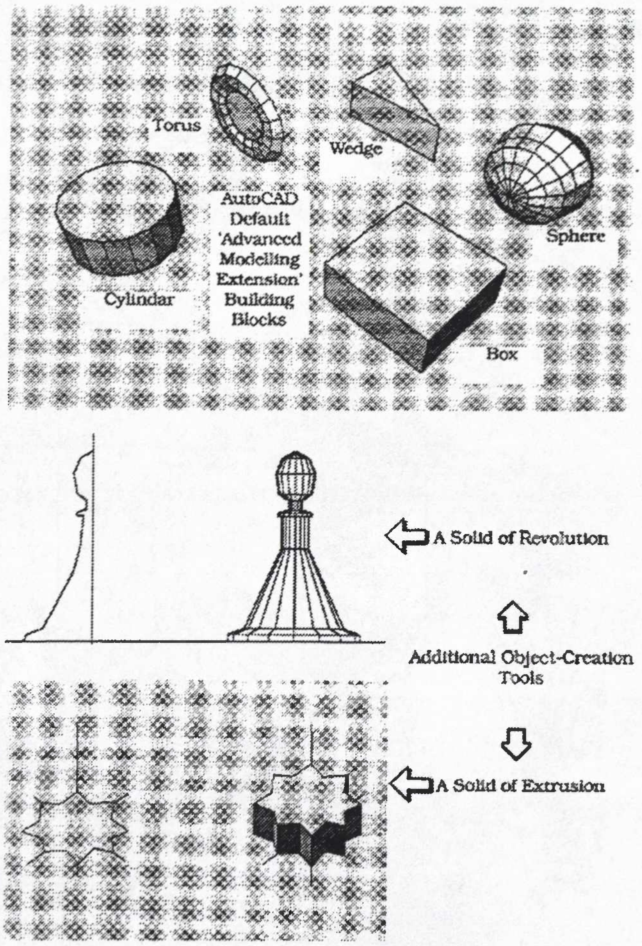

Figure 37.5: Autocad A.M.E. solid modelling tools.

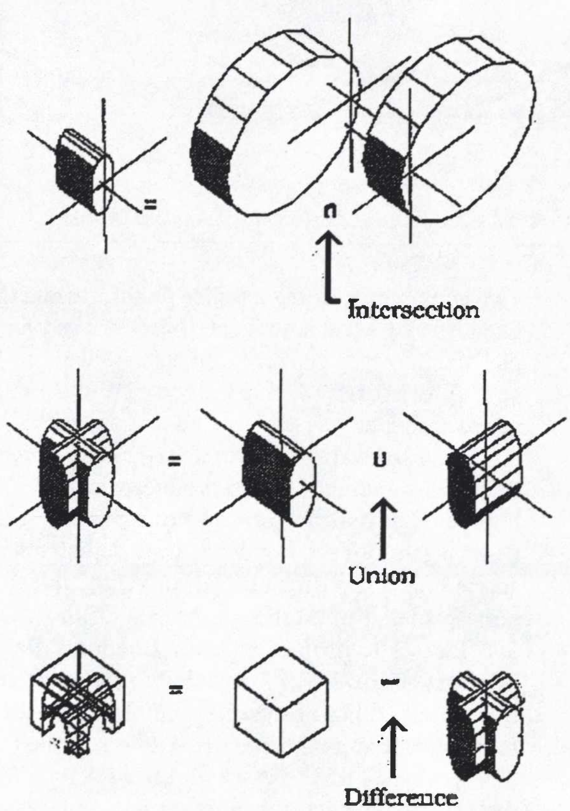

Figure 37.6: Diagram showing the construction of a cross-vault using Boolean operations.

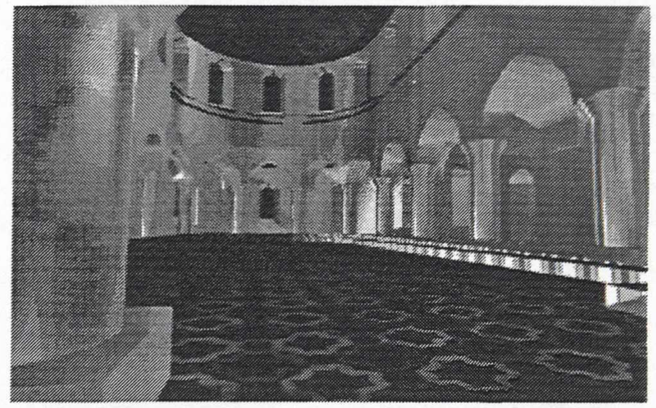

Figure 37.7: Interior view of the rendered model looking south.

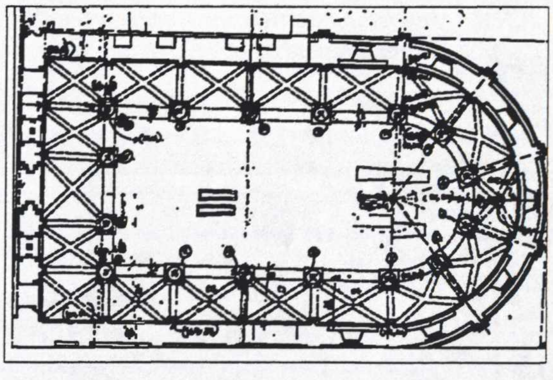

Figure 37.8: One of the original drawings on which the computer model was based.

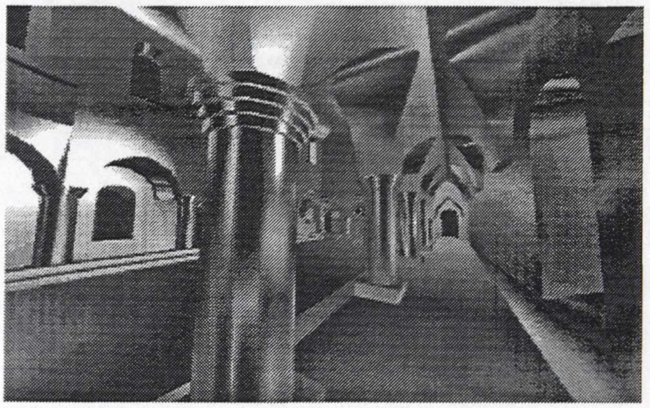

Figure 37.9: Interior view of the rendered model looking north.

3. A reconstruction of a Viking village at Headervey and the Viking river-front at York was modelled and rendered in 3D Studio by Peter Marshall at the York Archaeological Trust on a 386. The project was commissioned by the Museum of Denmark and the models were created for presentation purposes (images and animated sequences were incorporated into an interactive videodisk called "World of the Vikings"). This project is particularly interesting as it is an example of an archaeological unit being involved directly in ARV.

No example of a PC-based solid model being used for ARV, apart from the current project, has been found.

Figure 37.10: Interior view of the rendered model looking south.

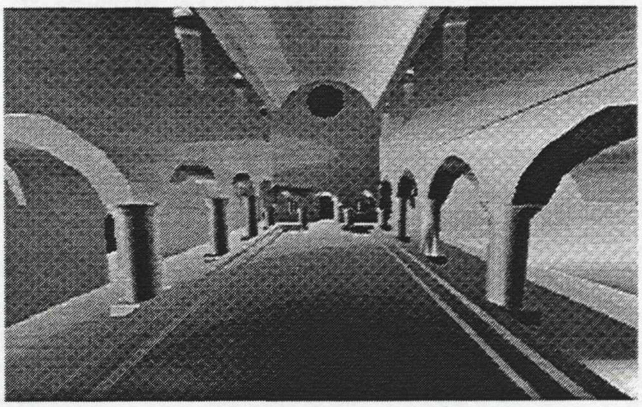

Figure 37.11: Interior view of the rendered model looking north.

In ideal circumstances, as Jason Wood has pointed out (Wood & Chapman 1992), a reconstruction model should be a by-product of the archaeological survey, with direct use of digital data minimising additional work. Also, ARV should ideally be carried out by archaeologists who can use them directly as an analytical tool to test their theories, so that a direct feedback loop can be established. In the case of the current project, neither of these conditions were met.

37.6. Conclusion

This modelling project was carried out by an architect with some training in computer applications and an interest in, but no experience of, the archaeological practice. The data on which the model was based were obtained by measuring from 2D drawings (Fig. 37.8) and from a physical model, since no up-to-date survey data (digital or otherwise) was available. The results are shown in Figs. 37.9–13.

However, this does not invalidate the exercise. The project has demonstrated that it is a reasonably straightforward matter for individuals with relatively little experience of computers to produce reasonably sophisticated reconstruction models using equipment which is becoming increasingly affordable, and which is increasingly used by archaeologists for wordprocessing, drafting and database applications.

Also, despite the fact my choice of a solid model, as opposed to a surface model was the source of most of my practical problems, I believe I have proved that PC-based 3D ARV is viable with solid modelling, and therefore that the PC-based ARV model can be an analytical, as well as presentation tool.

Furthermore, I believe that the future for 3D ARV lies in PC-based applications, because only technology which is user-friendly and affordable can be integrated into the working practices and shoestring budget of the average archaeological unit.

Figure 37.12: Exterior view of the rendered model looking east.

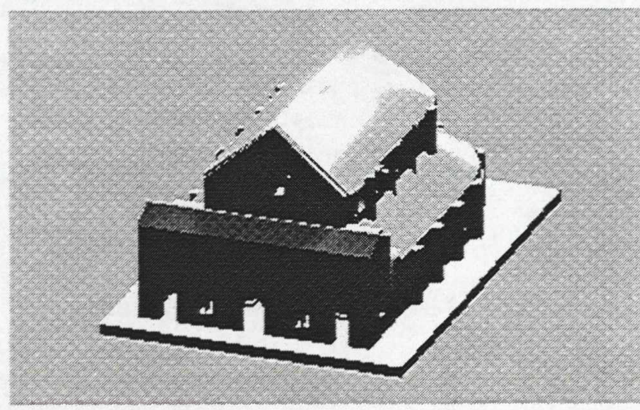

Figure 37.13: Exterior view of the rendered model looking south.

Acknowledgements

The original question, about whether the desire to have sunlight illuminate daily monastic life was strong enough to cause the building of Rievaulx Abbey at a ninety degree rotation from the conventional east-west orientation, was posed by a leading authority on Medieval monasticism, Dr. Glyn Coppack, the Principal Inspector of Ancient Monuments at English Heritage (Coppack & Fry 1986; Coppack 1990). This was the inspiration behind a dissertation project carried out in 1992 at the University of Teesside under the supervision of Janice Webster, leader of the MSc course in Three-dimensional Computer-Aided Graphical Technology Applications. The work is summarised in this paper.

In order to find out the way in which an archaeologist might want to work with PC-based ARV, an English Heritage site archaeologist, Kate Wilson, who uses AutoCAD in her work, was consulted. I wish to thank her for helpful

discussions which led to the decision to make a solid model instead of a surface model.

Jason Wood of Lancaster University Archaeological Unit must be thanked for providing many of the initial leads in the research of ARV projects.

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