

## Article



### The Photogrammetric Recording of Bet Giorgis

*The Rock Churches of Lalibela*

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ISPRS is delighted to announce that it has received funding from UNESCO through its affiliate UATI (Union International des Associations et Organismes Techniques) to undertake photogrammetric mapping of the ancient rock churches in Lalibela, Ethiopia. A description of the work undertaken as part of this project, by Professors Heinz Ruther (South Africa), Armin Gruen (Switzerland) and Clive Fraser (Australia) is presented below. The work was also published in International Archives of Photogrammetry and Remote Sensing Vol. XXXIV, Pt 5/W1 pp 62-68.

The town of Lalibela lies in the province of Wollo in northern Ethiopia, some 640 km from Addis Ababa. Other than on market day, Lalibela is not much more than a quiet mountain village, yet it is internationally renowned for its



Figure 1: Bet Giorgis rock-hewn church, Lalibela.

rock-hewn churches. The creation of these churches is ascribed to King Lalibela, one of the last kings of the Zagwe dynasty. All 12 churches in the town are thought to have been constructed within a 100-year period around 1200 AD. The denomination of the still functioning churches is Ethiopian Orthodox, which is part of the Coptic Christian Church headquartered in Alexandria.

Of the three basic types of rock-churches in Ethiopia: built-up cave churches, rock-hewn cave churches and rock-hewn monolithic churches, the last, which is of current interest, is unique to the Lalibela region. Arguably the most significant of Lalibela's four strictly monolithic rock-

hewn churches is Bet Giorgis (the Church of Saint George), which is regarded as being the most elegant and refined in its architecture and stonemasonry. Figure 1 shows the 12 x 12 x 13m Bet Giorgis standing within its 25m square trench.

Legend has it that Bet Giorgis, which stands apart from the two main groups of rock churches in Lalibela, was built only after King Lalibela was reproached by Saint George (the national saint of Ethiopia) for not having built a house for the saint. King Lalibela's response was to build a church, the construction of which, legend tells, was supervised by Saint George in person. As is apparent from Figure 1, the 'construction' of the monolithic rock church was in fact an excavation, the procedure being to first cut free a block of stone in the volcanic tuff, after which stonemasons chiselled out the church, shaping both the exterior and interior. One can only marvel at the extent of the work and detail involved in this process.

The roots of Lalibela rock churches are thought to lie in Axumite architecture and in the early Christian basilica, yet while they may reflect a blending of eastern Mediterranean Christianity and Axumite tradition, they are also a truly unique contribution to Ethiopian Christian heritage. In recognition of their significance they have been accorded UNESCO World Heritage status.

#### Photogrammetric Documentation

As an aid in the long-term preservation of Bet Giorgis, and as a contribution towards making this remarkable heritage site more accessible via the 'digital world', a project was undertaken to photogrammetrically document the church. The project, which was initiated by the Prof. Heinz Ruther of the Department of Geomatics at the University of Cape Town, with the support of government agencies in Addis Ababa and later UNESCO, has as its ultimate aim the creation of fine-detail visually realistic digital models of both Bet Giorgis and other Lalibela rock churches. Also participating in the project are groups from the Institute of Geodesy and Photogrammetry at ETH-Zurich and the Department of Geomatics at The University of Melbourne. These efforts are being respectively led by Prof. Armin Gruen and Prof. Clive Fraser, with direct logistical support being given to the project by the Ethiopian Mapping Authority. Photogrammetric recording commenced in October, 2000 with a field trip to Lalibela.

Three fundamental data sources were involved in the Bet Giorgis documentation. The first of these was existing 1:10,000 scale aerial photography from which ortho-imagery and a DTM of the Lalibela area and church surroundings could be generated. The second was ground survey data to facilitate control for the aerial imagery and to provide a tie between the local XYZ reference coordinate system used in the close-range photogrammetry and the geodetic network. The third was imagery, to facilitate photogrammetric triangulation, ortho-image generation and texture mapping for the visually realistic Bet Giorgis model.

In recognition of the flexibility and favourable metric performance of modern low-cost, off-the-shelf digital cameras, a decision was made to accomplish the 3D measurement of significant feature points on the church and pit walls by photogrammetric means, and to fully carry out this task on site. As a consequence it was planned that upon leaving Lalibela after the 4-day fieldwork phase, a sufficiently dense array of feature points would have been surveyed. These would provide a preliminary point cloud for the later to be determined CAD model of the church, and facilitate straightforward exterior orientation determination for any images that were to be employed in subsequent ortho-image generation and model rendering. Comprehensive sets of imagery were recorded with three digital cameras, a Kodak DCS330, a DC210 and a SONY Cybershot, and the Australis software system for digital close-range photogrammetry was employed for in-field camera calibration and photogrammetric triangulation.

The result of the photogrammetric triangulation phase was a point-cloud of several hundred feature points. Most of these were central to the CAD model/wireframe generation process, though some were not of prime importance in this regard but were nevertheless crucial to the later processes of image registration and texture mapping. Visual interpretation and manual measurements were found to be absolutely necessary for producing a decent CAD model, and at this point there was little room for automation. The church possesses a much larger amount of surface detail than was expected at first sight, and the primary surfaces contain many irregularities in geometry, such that straight edges of substantial length and planar surfaces of significant size are not in abundance (e.g. features include horizontal mouldings, projecting corner beams in the doors, projecting gutter spouts and crowned ogee-arches in the upper row of the windows). Therefore, a hierarchical measurement strategy was used with feature refinements at each iteration step. The resulting point cloud was then turned into a line model and finally into a surface model. Since these two operations were carried out manually, they constituted the most time consuming of the building reconstruction processes.



Figure 2: Screen capture from preliminary VRML model.

In order to realise the goal of a fine-detail visually realistic model of Bet Giorgis, a fully rendered solid model is required, as illustrated by Figure 2. The modelling process for the Bet Giorgis church is ongoing, with a primary aim of building the visually realistic digital model being to make it available to as wide a group of interested parties as possible. This naturally implies dissemination of the model in an international standard format that will support 3D interactive viewing, for example VRML for web delivery.

Recent trends in the photogrammetric recording and documentation of cultural heritage sites include a move away from stereomodels to multi-image surface reconstruction; the use of low-cost, amateur digital cameras and user-oriented image measurement and data processing systems; the potential for multi-sensor integration; the widening acceptance of image-enhanced information systems; and the widespread use of 3D modelling, visualisation, web-authoring tools and information delivery via the Internet. The aims and conduct of the Bet Giorgis documentation are very much in accordance with these trends, and it is the hope of those conducting the project that with the completion of the digital modelling of the church, a valuable information source will have been generated for use in site conservation, historical and architectural studies, education related to Ethiopia's rich heritage and history, and in visualisation for web-surfers and tourism.