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HMG/UNESCO/JAPAN TRUST FUND PROJECT FOR PATAN DURBAR SQUARE, NEPAL

Computer-assisted Recording of Historic Buildings Report and Recommendations

Commissioned by:

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Contract Nos. 396.451.4; 396.505.5; 396.525.5; 350.734.6

HMG/UNESCO/Japan Trust Fund Project for Patan Durbar Square, Nepal

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Computer-assisted Recording of Historic Buildings
Report and Recommendations

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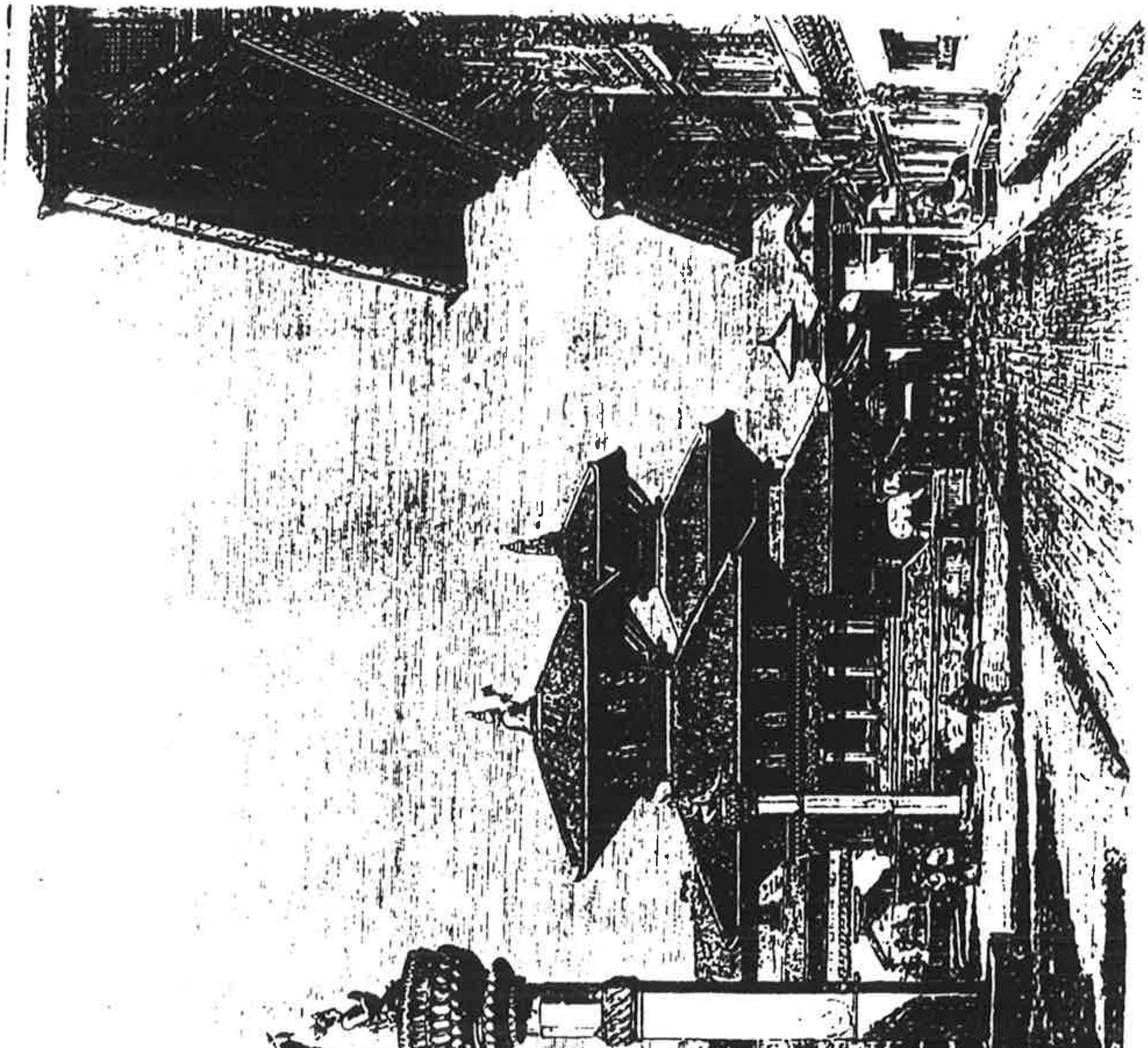

'Patan Durbar Square ... the most picturesque collection of buildings that has ever been set up in so small a space by the piety and the pride of Oriental man.'

Pereval Landon, 1928

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This report is written by Jason Wood and Jamie Quartermaine. The authors would like to acknowledge their thanks to the following individuals and organisations who contributed so much to the success of the project.

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Our fellow UNESCO consultants deserve special mention. Although this report is only concerned with the application of computer-assisted recording, our work was not undertaken in isolation but as an integral part of a multi-disciplinary conservation project. The success of this approach is due to the enormous contribution of the project manager, Mr David Michelmore (UNESCO ITA). We are also grateful for the advice and assistance given to us by Dr Hans Bjonness (former UNESCO CTA) who managed the project in its initial stages, and Mr Hari Ratna Ranjitkar (UNESCO local consultant) to whom we all owe a great debt of thanks. The participation of Dr David Yeomans and Professor Chikaosa Tanimoto, together with the ICOMOS UK team of Mr Jack Kirby, Mr Wayne Kirby, and Mr Charles Lee, was also much appreciated.

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EXECUTIVE SUMMARY

This report combines the results of work undertaken by LUAU on behalf of UNESCO (Contract Numbers 396.451.4; 396.505.5; 396.525.5; 350.734.6) concentrating particularly on the application of instrument survey and computer-assisted recording techniques within the context of the HMG/UNESCO/Japan Trust Fund Project for the conservation of Patan Durbar, Nepal (536/NEP/71).

Patan Durbar Square is one of seven Monument Zones of the Kathmandu Valley World Heritage Site. The Durbar (palace) dates mostly to the seventeenth century and encompasses a series of courtyards (chowks) and temple towers.

During 1994 and 1995, LUAU advised on the selection and purchase of survey and computer equipment, performed an evaluation of instrument survey and computer-assisted recording techniques, and actively participated in local training of a Nepalese team.

The results of the evaluation led to a revision of the previous project survey methodology and timetable. It was concluded that instrument survey, as opposed to hand-measured survey, would form the basis for the generation of plans and cross-section profiles by the Nepalese team, and that a photogrammetric survey would be implemented to compete the generation of elevations. Both survey techniques were to be linked to CAD systems to allow for the onward processing of the survey data by digital means.

For the Nepalese team to continue to work effectively, it is recommended that future survey and computer needs are addressed. It is further recommended that the feasibility of the application of computer-assisted recording to other parts of the World Heritage Site, concentrating initially on the Patan Durbar Square Monument Zone, be explored.

1. INTRODUCTION

Kathmandu Valley World Heritage Site

The Kathmandu Valley World Heritage Site, as inscribed on the World Heritage List in 1979, consists of seven Monument Zones, of which Patan Durbar Square is one. The other Monument Zones are the Durbar Squares of the cities of Kathmandu and Bhaktapur, the Buddhist temples of Swayambhunath and Bauddhanath and their stupas, and the Hindu temples of Pashupatinath and Changu Narayan.

1979 also saw the launch by UNESCO of an International Campaign for the Safeguarding of the Kathmandu Valley. This campaign has provided a funding and organisational base for a series of projects focused on individual monuments within the World Heritage Site. In this respect, the campaign has built on the success of earlier work carried out under the aegis of UNESCO, most notably that of the conservation of the Hanuman Dhoka Palace in Kathmandu in the early 1970s. In 1993, the campaign Plan of Action was updated for the additional conservation of selected buildings, particularly in the Monument Zones of Patan Durbar Square and Changu Narayan.

Patan Durbar Square Monument Zone

Patan (or Lalitpur - 'The Beautiful City' as it is often called) lies across the Bagmati river south of Kathmandu. The Patan Durbar Square Monument Zone consists of the Durbar (palace) itself, a temple-filled square at the intersection of the principal roads in front of it, and a network of dwellings and isolated monuments in the area around the whole, roughly in the centre of the old city.

Patan Durbar

The present palace dates mostly to the seventeenth century and the reigns of the Malla kings Siddhi Narasingh (1619-61) and his son Shri Nivas (1661-84), and derives its style from the distinctive canon of Newari architecture. Originally, the palace buildings were simply grander versions of the traditional Newari house, but overtime they developed into extensive complexes, integrated architecturally around courtyards (chowks) and commonly attached to pagoda temple towers with their characteristic multi-tiered roofs.

The main buildings of Patan Durbar are Sundari Chowk, Mul Chowk, Nasal Chowk, and Keshav Narayan Chowk, and the temple towers of Agan Mandir, Taleju Mandir, and Degu Talle. The backbone of the palace ensemble, which runs on a north-south axis and measures approximately 100m long, is the monumental facade of the three principal courtyards (Sundrai Chowk, Mul Chowk and Keshav Narayan Chowk) and the largest temple tower (Degu Talle). The palace buildings and temples are all built in much the same way, using the same materials: wood with bricks, tiles, clay mortar and stone. Windows, doors and structural elements such as posts, lintels and beams are always constructed in wood, while the brick masonry comprises two face veneers with thin clay-mortar joints. Wooden struts support heavy roofs with wide overhangs. The struts are elaborately carved and painted and many windows with their intricate latticework are more decorative than functional, allowing for considerable elaboration in their forms (Korn 1976; NIT 1981 and 1985; Hutt 1994).

Following the establishment of Kathmandu as capital of Nepal in 1770, Patan Durbar lost its function as a royal residence, even though it continued to house various administrative departments for some time after. As a result, the palace was not substantially altered by the later Shaha and Rana dynasties. Some buildings however were considerably damaged in the large 1934 earthquake but were mainly rebuilt to replicate the Malla dynasty style and shape. Today, sections of the palace serve as schools, museums, offices, and until recently a police station, but many parts remain unused.

Previous Work

The most recent and major study on Patan Durbar is that undertaken by the Nippon Institute of Technology in Japan between 1978 and 1980, under the leadership of Dr Michio Fujioka and Dr Katsuhiko Watanabe (NIT 1981 and 1985). Keshav Narayan Chowk, which was extensively renovated in the nineteenth century, is now the subject of on-going restoration work by the Austrian Institute for International Cooperation.

Funding Arrangements

The Japan Trust Fund Project for the conservation of Patan Durbar established in 1991 is controlled by UNESCO through the aegis of the Department of Archaeology. The fund currently meets the budgets for the provision of scientific documentation (archaeological and architectural recording and historical survey), structural analysis, preparation of conservation design proposals and cost estimates, and training (including the purchase of capital equipment). At the outset, the funding was limited to Sundari Chowk and Mul Chowk but the arrangements have subsequently been extended to cover Nasal Chowk, Agan Mandir, Taleju Mandir, and Degu Talle.

Project Background

The project as originally conceived envisaged the involvement of one Japanese team and one Nepalese team with international support and leadership to implement the scientific documentation and conservation design proposals. However, Dr Watanabe of the Nippon Institute of Technology declined UNESCO's invitation to become involved in the project. In 1992, UNESCO appointed Dr Hans Bjonness of Trondheim University to draw up preliminary recommendations, guidelines, and plans for the scientific documentation of Patan Durbar (UNESCO/JTFP 1993). The aims of the report were primarily to establish manpower requirements, costs, availability of Nepalese expertise, and to stress the need for a multi-disciplinary approach to the project. Acting as UNESCO CTA in Nepal, Dr Bjonness was then appointed to mobilise a Nepalese team charged with the responsibility for archaeological and architectural recording and historical survey, in order to facilitate both the conservation works to be carried out and enhance knowledge of the history of the palace. Commencing with Sundari Chowk, a team of conservation architects and draughtpersons began recording work in May 1994, with historical survey being conducted by senior representatives of the Department of Archaeology (HMG/UNESCO/JTFP 1994a: 1994b; 1995d).

2. AIMS AND OBJECTIVES

Introduction

A joint UNESCO/ICOMOS review mission to Nepal in 1993 highlighted the extent of the threat to the Kathmandu Valley World Heritage Site (UNESCO/ICOMOS 1993). Following the recommendations outlined in this report, the need for increased awareness of scientific documentation of historic buildings, structural and engineering diagnosis, and principles of traditional conservation practice were identified. At the instigation of UNESCO, an additional need to examine the application of computer-assisted recording techniques was proposed and LUAU were invited to act as consultants. To address all these issues a two-week training workshop and professional seminar were organised. Although originally scheduled to take place in May 1994 to coincide with the commencement of fieldwork at Patan Durbar, the workshop and seminar were deferred to September/October.

UNESCO Contract No 396.450.4

LUAU's initial contract was to advise on the selection and purchase of survey equipment which UNESCO wished to acquire for the Patan Durbar project. As required by the contract, LUAU's report (HMG/UNESCO/JTFP 1994c) outlined the choice of appropriate total station, data logger and peripheral equipment; identified suitable suppliers; described the testing procedure to ensure compatibility, and made recommendations for operating efficiency in Nepal. The work was undertaken in September 1994 but the equipment itself was unavailable for testing until late October. It was not possible therefore to ship the equipment to Nepal prior to LUAU's second contract.

UNESCO Contract No 396.451.4

The purpose of LUAU's second contract was to explore various options for the implementation of instrument survey and computer-assisted recording techniques within the context of the Patan Durbar project. Following a two-week lead-in period in the UK, fieldwork took place at Sundari Chowk and Taleju Mandir between 16th September and 7th October 1994 using LUAU's own survey and computing equipment. This was to be followed by the submission of a report with recommendations for future survey and recording methodologies as appropriate to the nature of the project and local conditions in Nepal. The bulk of the present report is in response to this contract obligation, and was delayed so that the experience and results of the subsequent contracts awarded to LUAU (see below) could be included. During September/October 1994, LUAU staff were also required to train the existing Nepalese team in survey and computing skills and take part in the professional seminar which ran concurrently with the training workshop.

Instrument Survey Evaluation

In order to assess the most appropriate survey methodologies, it was decided to conduct an evaluation based on the following tasks:

- Scanning and/or digitising of a selection of existing hand-measured drawings
- Editing of the resulting digital data in advance of the fieldwork
- Verification of the edited data using instrument survey to assess accuracy
- Instrument survey of a plan of a selected building
- Instrument survey of a selected elevation to different levels of completion (outline, features, and detail)
- Instrument survey of a profile of a selected building.

Training Workshop

The purpose of the scientific documentation training workshop was to provide both elementary and advance training in instrument survey and computer-assisted recording for the members of the Nepalese team working on Sundari Chowk and various representatives of the Department of Archaeology. A principal objective was to identify those staff who showed particular potential as retrainers. The opportunity was also taken to assist the trainees with their on-going survey requirements, particularly in those areas of the building inaccessible for hand measurement.

The 12 trainees comprised 4 architects and 4 draughtspersons from the recording team led by Dr Bjonness, together with 4 representatives from the Department of Archaeology. The *Elementary Training Course* was subdivided into four blocks so that all 12 trainees received a basic grounding in instrument survey principles and methodology. The *Advanced Training Course* was limited to the 3 trainees who proved the most adept and interested in pursuing further instruction in instrument survey. The selection process was undertaken in consultation with Dr Bjonness. Finally, an *Introductory CAD Training Course* was offered to the 2 trainees who showed the most enterprise in the manipulation of computer data. The workshop ran from 20th September to 2nd October 1994. Details of the programme and participants are listed in Appendix 1.

Professional Seminar

A professional seminar entitled 'Innovative Conservation of Cultural Heritage in Nepal' was held at the Summit Hotel, Kathmandu between 25th-30th September 1994. The main objective of the seminar was to inform the donor organisations of the new developments in conservation practice, while at the same time broadening the professional and technical skills of the decision-makers to ensure that future work meets the necessary high standards. LUAU contributed to the day-long session on scientific documentation and the concluding plenary session, describing the use of various survey methodologies (both instrument-based and photographic-based) in the context of recording and conservation projects. Full details of the programme and the accompanying press release are listed in Appendix 2.

UNESCO Contract No 396.505.5

The third contract awarded to LUAU involved advice on the selection of computer equipment, additional training for the Nepalese recording team, and the drafting of specifications for a proposed photogrammetric survey.

LUAU's report on the selection and purchase of computer equipment (HMG/UNESCO/JTFP 1995a) outlined the choice of appropriate computer, digitiser, plotter and software; identified suitable suppliers; described the testing procedure to ensure compatibility, and made recommendations for operating efficiency in Nepal. The work was undertaken in December 1994 and the shipment of the equipment itself took place in January 1995, prior to LUAU's return.

A second training workshop, organised by LUAU between 26th February and 12th March 1995, was able to demonstrate additional survey and computing skills but this time using the equipment bought by UNESCO for the project. Training focused on computer digitising and plotting, which had not been possible during the first workshop, and on ensuring that the most appropriate coordination was maintained between the computer-assisted methodology and the on-going hand measurement, particularly in the case of Sundari Chowk. The participants of the earlier *Advanced Training Courses* were singled out for special attention in order to assess their overall competence in the use of the new technology. The results and recommendations stemming from this exercise are discussed later in this report.

The third element of the contract required the preparation of photogrammetric specifications, cost estimates and tender documentation. This work, which was subcontracted to a recognised specialist consultant, is reported fully elsewhere (HMG/UNESCO/JTFP 1995b), though relevant sections will summarised in this report for ease of reference.

UNESCO Contract No 396.525.5

LUAU's fourth contract was to complete the training of those members of the Nepalese team selected to advance the use of computer-assisted recording techniques within the project. Supervision of the team in field by LUAU took place between 18th April and 31st May 1995. During this period the area of fieldwork was extended and new instrument survey was commenced in Mul Chowk and Taleju Mandir, primarily aimed at the production of ground and first floor plans.

The greater part of the contract however was concerned with the provision of photogrammetric survey of the remainder of the palace. This was achieved through a specialist subcontractor following a competitive tender process. Fieldwork was undertaken between 30th April and 22nd May 1995 under LUAU's supervision, during which time the external elevations and details of Mul Chowk, Nasal Chowk, Agan Mandir, and Degu Talle were surveyed and photographed. Unfortunately, it was not possible to photogrammetrically survey Taleju Mandir owing to the building being scaffolded and partially roofless at the time of the fieldwork. Back in the UK, a tight ten-week schedule for the processing of the photographs and digital data and plotting the resulting drawings was successfully adhered to. This work was overseen by LUAU in conjunction with the specialist consultant who had earlier prepared the photogrammetric specification.

UNESCO Contract No 350.734.6

LUAU's fifth and final contract oversaw the translation and delivery of the photogrammetric data to Nepal and the enhancement and completion of all plan, elevation and cross-section data produced during the training workshop and undertaken by the Nepalese team subsequent to LUAU's final departure from Nepal on 31st May 1995. The contract also required LUAU to collate all archive material resulting from the computer-assisted recording project and to duplicate all digital files and drawings for delivery to Paris and Kathmandu. Full details of the contents of the archive are listed in Appendix 3. A brief manual to facilitate the operation of the system was also prepared by LUAU (HMG/UNESCO/JTFP 1996a). Finally, LUAU's attendance at a symposium in Paris on 14th August 1996 was required to report on integrated project management for conservation projects, with particular reference to new systems for documentation and non-destructive structural investigation.

3. SURVEY AREA AND METHODOLOGIES

Area of Work

As stated above, the Japan Trust Fund Project for the conservation of Patan Durbar is confined to works relating to Sundari Chowk, Mul Chowk, Nasal Chowk, Agan Mandir, Taleju Mandir, and Degu Talle. Works to Keshav Narayan Chowk at the northern end of the palace are being funded separately by the Austrian Institute for International Cooperation.

As part of the 1994 mission, LUAU's instrument survey evaluation and training workshop were concentrated mainly on Sundari Chowk, though limited work was also undertaken on Taleju Mandir. In addition, LUAU were also asked to provide survey information relating to the Palace of Fifty-Five Windows in Bhaktapur. This one-day exercise took place on 21st September 1994 and is reported in Appendix 4.

The first 1995 mission again focused on Sundari Chowk but by the time of the second 1995 mission the Nepalese team were ready to extend their new skills to Mul Chowk, Taleju Mandir and Degu Talle. With the introduction of photogrammetry to the project during the second mission, the area of work was greatly increased to provide survey of all the buildings included in the Patan Durbar project other than Sundari Chowk.

Before considering in more detail the survey methodologies applied to the palace, a brief description of each building is given below indicating their size and nature. That the courtyards and temple towers belong to different building campaigns spanning the mid to late seventeenth century is accepted, although there are conflicting secondary sources regarding the exact chronology of construction (Korn 1976; NIT 1981 and 1985; Hutt 1994) (Figure 1).

Sundari Chowk

At the southern end of the palace complex is Sundari Chowk comprising a small courtyard surrounded by three-storied buildings. The buildings display very ornately carved wooden windows, doors and roof struts, and a series of carved figures set in niches. The principal feature however is the sunken royal bath (Tusa Hiti) set into the courtyard floor and covered in intricate stone carvings. The east wing, and parts of the north and south wings were damaged in the 1934 earthquake and later rebuilt.

Mul Chowk

The main courtyard or Mul Chowk lies immediately to the north of Sundari Chowk, although there is a gap (now roofed over) between the two. Mul Chowk comprises a large courtyard with a small shrine in the centre, surrounded by two-storied buildings. The buildings again display the elaboration of carved wooden detail, typified in Sundari Chowk.

Taleju Mandir
In the north-east corner of Mul Chowk is the temple tower Taleju Mandir. This consists of an octagonal, triple-roofed pagoda temple set on a square, four-storied base. The western approach to the temple is via a four-storied building between Mul Chowk and Degu Talle.

Agan Mandir
Agan Mandir is a small four-sided, triple-roofed replica of Taleju Mandir lying between Sundari Chowk and Mul Chowk, with access only via the south wing of Mul Chowk.

Degu Talle
By far the largest and tallest of the temple towers is Degu Talle. This triple-roofed pagoda set on a four-storied square base stands between Mul Chowk to the south and Keshav Narayan Chowk to the north. It was almost totally destroyed in the 1934 earthquake and subsequently rebuilt.

Nasal Chowk
Nasal Chowk is a small courtyard to the east of Degu Talle of little architectural pretension.

Previous Survey Methodologies

As part of the research mission for the study of the royal buildings of Nepal conducted by the Nippon Institute of Technology between 1978 and 1980, a number of plan, elevation and cross-section drawings of Patan Durbar were produced. These were later published as an incomplete series of 1:400 and 1:200 plans, 1:100 elevations, and 1:50 cross-sections (NIT 1981). Restricted funds and a tight schedule (the entire study of the Patan buildings including their survey was completed in under ten days) led to compromises in the accuracy of the survey control system. While admitting to this, the published report does not offer any method statement as to how the drawings were generated. We are simply told that the decision was taken to use a stereometric camera in conjunction with hand-measured control (NIT 1981, 2) (Figures 1 and 2).

Project Survey Methodologies

Initial Methodology
Regardless of the potential shortcomings of the Nippon Institute of Technology drawings, the non-participation of Dr Watanabe in the Japan Trust Fund Project meant that the original drawings and their copyright were unavailable to UNESCO. In May 1994, the Nepalese team mobilised by Dr Bjonness began to survey Sundari Chowk. The intention was to produce very detailed 1:20 (soon revised to 1:10) record drawings of the plans, elevations and cross-sections of the courtyard, sunken bath and surrounding buildings, together with constructional and architectural details

at 1:5 and 1:1 scale. The parts of the building damaged by the 1934 earthquake and subsequently rebuilt were not to be recorded to the same extent.

Fixed ground control points had earlier been established by a consultant surveyor (HMG/UNESCO/JTFP 1994b) but there was limited control on the elevations and none at all in the upper parts of the buildings. The methodology for producing the drawings relied on hand measurements offset from a string grid of 1m squares. The initial pencil drawings on plastic film were then inked up. Although very labour intensive, the argument was put forward that it was desirable to employ a large number of local staff and that such staff may not be able to handle or understand more advance methodologies (Figures 3, 4 and 5).

Revised Methodology and Timetable

Despite the labour intensive methodology initially employed on the project, production of the drawings proved to be a slow process. UNESCO were keen to accelerate the recording system as the drawings were urgently needed to serve as the basis for conservation proposals. To this end, LUAU's training workshop in September/October 1994 set out to explore the application of instrument-based and photographic-based survey methodologies and computer-assisted recording techniques for use within the project. The use of this technology was subsequently approved by UNESCO and in February/March 1995, LUAU were encouraged to step up the training with the intention of identifying likely candidates from the existing Nepalese team who could continue with computer-assisted recording work in the areas of the palace beyond Sundari Chowk. At the same time it was ensured that the remaining work on Sundari Chowk was completed efficiently using new instrument survey to digitally record the upper plans of the building, while new hand survey drawings and earlier drawings not yet inked up were digitised. Guidelines for revised hand survey methodology were also issued (UNESCO 1995, appendix 1).

To satisfy UNESCO's wish to rapidly complete the project in order to proceed with the proposed conservation and presentation phase of work, a draft plan of action was discussed in March 1995 (Nepal/UNESCO/JTFP 1995). A change in project management, and one in which the Department of Archaeology was able to play an enhanced and central role, was agreed. In addition, the completion date for the scientific documentation, structural analysis, conservation design and cost estimates was brought forward to the end of 1995.

As far as the architectural recording was concerned, the revised timetable allowed for the completion of work at Sundari Chowk by the end of March 1995. A reduced Nepalese team, made up of the three most adept individuals from the existing team and two representatives from the Department of Archaeology, were then to carry out instrument survey and computer-assisted recording of Mul Chowk, Taleju Mandir, and Degu Talle. This work was to be completed by the end of September 1995 and confined to the production of plans and cross-sections and, only where necessary, internal elevations. Hand-measured survey would still be required to record inaccessible areas such as roof spaces. Drawn records of construction details such as carpentry joints would be deferred to the conservation phase of work, while architectural details would be very selectively drawn, in preference to the use of photography.

The use of photogrammetry was considered particularly appropriate to complement the work of the Nepalese team and to considerably speed up the process of recording the complexity of the external elevations, high level plans and cross-sections. Indeed, it would have been difficult to survey the tall temple towers of Agan Mandir, Taleju Mandir and Degu Talle by any other method. Specifications for photogrammetry were to be drafted by the end of March 1995 in order to seek competitive tenders from five reputable UK survey companies. Fieldwork was to take place in May with delivery of all material by the end of July 1995. In the event, emergency repairs to the roof of Taleju Mandir in advance of the main conservation scheme meant that it was not possible to survey this particular temple tower.

4. INSTRUMENT SURVEY AND COMPUTER-ASSISTED RECORDING

Introduction

The following section will consider the application of instrument survey techniques, and the development of computer-aided draughting (CAD) systems, for the digital recording of historic buildings. The merits of instrument survey methodologies and related software packages will be described, and the different levels of accuracy and detail which are obtainable in the production of two-dimensional drawings will be reviewed. Further details are provided in the project's training manual (HMG/UNESCO/JTFP 1996a).

Instrument Survey

Instrument survey is typically undertaken using a total station facility, which enables the capture of digital, three-dimensional survey data for manipulation into working drawings. The total station is an electronic theodolite incorporating an internal electronic distance meter (EDM). Distance measurement is obtained by analysis of an infra-red beam reflected off a small hand-held prism placed on the point of detail. The comparison of the phase differences between the emitted and returned wave lengths provides a precise measure of the distance travelled. The accuracy of the equipment is typically of the order of +/- 4mm over distances of less than 100m. The data is digitally output to a small logging computer attached to the total station, which converts the raw polar data into XYZ rectangular format. At the end of the working day the data can then be transferred to a desk-top computer for analysis, long-term storage, processing and plotting. This is undertaken using specialist survey software which also enables the formatting of the data (via DXF) for transferral to a CAD system.

There are two main elements to instrument survey; the production of survey control and survey detail. The aim of the control procedure is to provide a limited number of very accurate survey points (stations) scattered across the site, over which a total station can be positioned. The process is biased towards maintenance of accuracy rather than speed of survey. By contrast the aim of the detail procedure is to rapidly capture a large number of detail points over the building which are located to facilitate hand editing. The process is biased towards speed of survey at the expense of a limited reduction in accuracy.

Survey Control

Survey control is established using a closed traverse, which extends out from a known control point along a series of survey control stations and ends on a known point, often the initial point. The procedure at each station is to double check all readings. Observations are made from both faces of the instrument to reduce instrument error and the distances are read using an accurate measurement mode to tripod-mounted prism. The accuracy of the traverse is checked by comparing the original and final coordinates and any error is reduced by mathematical adjustment of the original coordinates. Survey control stations are stored both within the logging computer and the desk top survey processing package and are accessed during the polar to rectangular conversion process.

Detail Survey

Detail survey is achieved by EDM tacheometry and involves the measurement of horizontal/vertical angles and distances to the prism. The prism is traced around the features to be recorded to define their extent, and the location of each detail point is marked on the ground with chalk. The raw digital data is transferred to the logging computer and stored along with descriptive and coding information. Coding can be input during the data capture process to define lines between specific points and hence a crude digital map can be generated while on site. The recording of an individual survey point typically takes between 10 and 25 seconds and it is therefore possible to capture considerable numbers of points in a working day (up to *c*750). The accuracy of the system is typically in the order of +- 10mm and the main source of error is normally from incorrectly positioning the prism on the detail.

On completion of the survey, the raw or rectified data is transferred to the desk-top computer which is used to edit and compartmentalise the data blocks. Once edited the crude survey drawing can be output to a portable plotter. The raw plots may then be annotated by hand on site and the edits either drawn directly within the CAD system or digitised. In the former case, the hand survey is required to produce a detailed dimensioned sketch rather than a precise, accurate drawing, enabling the direct transfer of the edits via a mouse rather than a digitiser (see below).

To summarise, the advantages of using instrument survey over manual draughting are: improved accuracy and speed, generation of three-dimensional data, provision of direct digital output for subsequent manipulation in CAD, and the ability to record complex, multi-planed features often in inaccessible areas.

Computer-assisted Recording

The CAD system is the computer equivalent of a draughting board. The system enables total flexibility in the creation and editing of drawings and is not subject to the inevitable variation and fluctuation of manual draughting. Digital drawings may be output via an electronic plotter which draws the computer drawing onto paper or film at a very high speed. The data can be input by a variety of means: by digital transfer from a total station; by use of a digitiser (which is essentially an electronic pen); or by use of a mouse. There are a variety of CAD packages on the market all of which can represent drawings in both two and three dimensions. However, they vary enormously in their ease of use, their ability to manipulate complex drawings, their speed of processing, and their hardware requirements.

The advantages of digital processing over conventional graphic production are primarily accuracy, security, flexibility, visual impact and economy.

Accuracy

The raw data is incorporated into the system with no loss of accuracy and the data is manipulated again with no loss of accuracy; thus the survey points will still be accessible at a basic accuracy of +- 4mm. The net result is that the drawings generated by instrument survey could be output at any practical scale (up to 1:3) with no resultant degradation of the accuracy.

Security

With conventional graphic techniques there is only ever one original and all the copies from it are of a lesser quality and accuracy. Therefore there is an inherent risk of damage, loss, degradation or restrictive access to this unique original. However, with CAD the original data can be copied cheaply onto floppy disks and as all plots are of the same high level of quality and accuracy each one is effectively a graphic 'original'. The drawing can be distributed in its most original form to any individual, or client as required, and even to anywhere in the world by e-mail.

Flexibility

Because the method manipulates data it is possible to view information in a multitude of ways, at different scales, different sizes, in a conventional two-dimensional reproduction or alternatively as a three-dimensional isometric view. The data is stored within layers, so it is possible to show some aspects of a drawing or omit others. A multitude of different depictions of the drawing may therefore be produced from a single drawing file. Changes and alterations can be made to the drawing at any stage with little effort; by contrast graphical drawings are limited to the format, scale, pen range, and size conceived at the outset. CAD drawings can be incorporated within a relational database to enable a close interaction between elements of a drawing.

Visual Impact

The drawing output can be very effectively depicted on the computer screen and also as multiple plots. The various elements can be illustrated using different colours and an enormous variety of shading patterns can be used to highlight significant elements.

Economy

The flexibility of the system prevents the need for repeated redrawing and many of the more repetitive drawing processes can be undertaken automatically, drastically reducing draughting time. By conventional methods drawings would have to be completely redrawn to obtain scales, sizes or formats, but with CAD there is only a need to edit and adapt the raw drawing files.

To summarise, the advantages of using CAD over manual draughting are: maintenance of accuracy, security of original, scale and presentation flexibility, visual impact, economy, plus relational database and networking possibilities.

Digital Transferral from Hand-measured Drawings

When survey data has not been captured digitally, but instead has been produced by hand (as with the survey of Sundari Chowk), it is necessary to translate the drawings into a digital format. There are two methods of generating this digital data, by scanning or digitising.

Scanning is an automatic process which reads the drawing as a mass of digital dots called a raster map, and this is then converted automatically to lines by effectively joining up the dots. The process is very quick and therefore cheap; superficially it produces an acceptable CAD drawing but on zooming into the drawing the flaws become evident. Because it is an automated process it is liable to make mistakes, particularly where two lines on the drawing run close together. To correct the automated errors can necessitate a considerable amount of CAD editing and so the overall economy of the process is compromised.

The other process, digitising, involves manually tracing around every line on the original drawing with an electronic puck or pen. Initially it is fairly labour intensive but once the drawing has been digitised, it requires relatively little CAD editing and it becomes comparable in cost with the scanning process. As long as the operator of the digitiser is very conscientious and consistent, this method produces a higher resolution or accuracy by comparison with the scanning process.

5. INSTRUMENT SURVEY EVALUATION

Introduction

The purpose of the evaluation was to explore various options for the implementation of instrument survey and computer-assisted recording techniques within the context of the Patan Durbar project.

Digital Transferral from Hand-measured Drawings

The initial task was to scan and/or digitise a selection of existing hand-measured drawings and to edit the resulting digital data in advance of the fieldwork.

Sundari Chowk: Scanning

Copies of the hand-measured ground plan and two elevations of Sundari Chowk were scanned by a UK-based company (Data Capture Ltd). The decision was taken to undertake an automated scan process because of the lower cost by comparison with the full manual scanning process. The cost for the automated scanning of each drawing was *c*$90; whereas the full manual scanning process can cost up to $600 per drawing.

The automated process generated a DXF file which transferred easily into the chosen CAD system (FastCAD). A global view of the drawing looked perfectly acceptable, but zooming into detail revealed considerable discontinuity. Of particular concern were line cross overs between individual floor slabs, meaning that it would not be possible to select individual stones. To use the drawings effectively required considerable editing and it was found that up to 12 hours of CAD editing time was required to produce an acceptable drawing file. The prime limitation of the method, however, was that it depended upon the use of an extremely large (A0) scanning machine which was too expensive to consider purchasing for the project as no such machines were available in Nepal. The application of the technique would therefore have required the transfer of drawings out of Nepal and the subsequent return of digital data. This would mean that it was impossible to operate an independent computer-assisted recording system in Nepal, and because of this, and the expense of the overall process, the option of digitising was explored.

Sundari Chowk: Digitising

Because the digitising process is entirely manual, there was no cross over between the various entities and there was consequently considerably less editing required by comparison with the scanning process. The raw digitising represented a significant proportion of the overall production time, but because there was a reduced editing requirement, the digitising was more time effective than the editing stage of the scanning process.

Once the A1 digitiser purchased for the project had been set up, the Nepalese team were able to quickly adapt to its use and were soon producing usable drawings, although initially there was some variance in the quality of the output by the different operators. Although all editing and layer attribution could be undertaken from the digitiser, this was found to be impractical because the monitor could not be located sufficiently close to the digitiser table. It was therefore decided to utilise a secondary editing stage to complete the drawings by use of the mouse rather than the digitiser.

Verification Exercise

The second stage of the evaluation involved a comparison of the digitised and edited data derived from the hand-measured survey with newly captured digital data from instrument survey. This exercise permitted verification of the levels of accuracy which had been attained using the hand-measured techniques and provided a benchmark of acceptable tolerations of accuracy against which it would be possible to gauge future work.

Sundari Chowk: Survey Control

The original survey control for the Patan Durbar project had been established on a world coordinate grid using stadia tacheometry, which typically maintains an accuracy of +- 100mm at best (HMG/UNESCO/JTFP 1994b). This is considered to be an unacceptable level of accuracy for a major building survey and it was therefore decided to check and adjust the control network. Using the total station a traverse was extended through all the Sundari Chowk courtyard control stations and also between Mul Chowk and Sundari Chowk. Additional stations were also established within both the Mul Chowk and Sundari Chowk courtyards. The accuracy of the original stadia tacheometry control was found to vary from +- 60mm to +- 140mm, and confirmed the need for the application of more precise control techniques. The accuracy of the new control was monitored by closing all the traverses onto known points and was found to be between +- 3mm and +- 8mm.

Sundari Chowk: Ground Plan

The hand-measured ground plan of Sundari Chowk had been generated using a local grid which was independent of the survey control described above. Therefore, to enable verification of the plan it was necessary to translate the survey onto the world coordinate grid using points common to both the new total station survey and the original hand-drawn survey. This had the effect of eliminating any systematic errors present within the original survey and the verification exercise could therefore only highlight the erratic errors.

Verification of the ground plan was undertaken using the total station which accurately located selected sharply defined detail; this included stone slabs, detail within the central bath, and the holy stone to the south of the bath. This digital survey was undertaken to a high level of precision (of the order of +- 4mm) to ensure that any discrepancies between this and the manual survey reflected any imprecision of the earlier work. Within the CAD system the digital mapping was superimposed over the scanned hand-measured ground plan, and a number of inconsistencies revealed. The identified errors ranged from 20mm to 80mm with a mean value of 39mm. There was no observed consistency of orientation in the errors and therefore they cannot be attributed to discrepancies between the grids used for each survey (Figure 6).

Sundari Chowk: Exterior West Facing Elevation
Selected detail on the exterior west facing elevation of Sundari Chowk was surveyed by total station. The data was rectified into the appropriate axis and superimposed over the scanned outline manual drawing of the elevation. The two drawings were aligned by means of a series of four points that were common to both the manual and digital surveys, thus eliminating any errors between local grids. There was a notable deviation of the manual survey away from its primary grid of the order +- 37mm. This was most apparent where the survey detail extended out from the main plane of the wall (Figure 7).

Sundari Chowk: Courtyard South Facing Elevation
Selected detail on the courtyard south facing elevation of Sundari Chowk was similarly verified. The discrepancy in this case was of the order of +- 15mm.

Instrument Survey

The final stage of the evaluation was to apply instrument survey and computer-assisted recording techniques to the production of a typical plan (Mul Chowk), a typical elevation (Sundari Chowk) to different levels of completion (outline, features and detail), and a typical cross-section profile (Taleju Mandir).

Mul Chowk: Ground Plan
Instrument survey of the ground plan of Mul Chowk concentrated on the courtyard and internal rooms. The first stage was the introduction of survey control into every room to enable the recording of internal detail. This was achieved economically from a total station set up in the middle of the courtyard, from where it was possible to generate accurate coordinates for ground nails in each chamber. Because the rooms are generally small, each could be surveyed from a single instrument set up. The survey of each room defined all significant detail and only very subtle detail was left to the hand enhancement stage. All data were captured with respect to a uniform grid and consequently all the individual surveys in each room were accurately superimposed within the CAD system.

The accuracy and quality of the survey, including the internal accuracy of the detail between rooms, was found to be very high. For example, where the two sides of a wall were independently surveyed from separate room instrument set ups, it was found that the wall thickness corresponded closely with a taped measurement through an aperture. Because the survey does not make assumptions of perpendicularity or regularity, the technique has demonstrated the irregularities of the original design of the building. Such irregularities could easily have been omitted if using conventional hand survey techniques.

The speed of survey was largely dictated by the number of instrument set ups required to complete the plan; up to four instrument set ups were feasible in a working day and hence it was potentially possible to survey four rooms a day. However, in practice the speed of progress was limited by access restrictions. It was, however, possible to survey the courtyard in one day and to complete the all of the ground floor (for which there was access) within three days, which includes delays incurred while waiting for keys.

One of the prime advantages of the process was the ability and speed with which it was possible to move survey control over and into a very complex structure and still ensure accuracy. This meant that it was feasible to survey any elements of the remainder of the palace. The technical problems of achieving manual control over the same complex of structures would have resulted in significantly slower progress or loss of accuracy.

The training time for the Nepalese survey team was inevitably slower by comparison with the equivalent introduction of manual techniques. However, it was found that selected staff members were able to operate the system efficiently, within a matter of days and had developed a level of competence to undertake the whole survey and completion stage of the process independent of external help, within about five weeks.

Sundari Chowk: Courtyard North Facing Elevation
Instrument survey of the courtyard north facing elevation of Sundari Chowk was evaluated at different three levels - outline, features and detail. In order to maximise the survey time, only the eastern quarter of the wall was subject to the evaluation.

The outline survey involved the recording of the external boundaries of each major element; typically the interface between timber and brick components and also the outline of the wall section and any structural discontinuities. The feature survey recorded the extent of more selective elements (doors, windows, niches *etc*) and typically showed the boundaries of individual timbers and also major breaks between carved detail (Figure 8). Finally the detail survey was intended to recorded all intricate carved detail on the timbers and the individual bricks. It was understood at the time that the cost effectiveness of the instrument survey methodology would vary dependent upon the level of recording required and that alternative photographic methodologies may be more effective for the different levels.

The evaluation was undertaken in conjunction with the initial training workshop for the Nepalese survey team, the instrument being operated by a variety of team members who were unfamiliar with the equipment. Consequently the observed times for the various elements cannot be described as typical. To overcome this imbalance the times quoted below are estimates based on the observed speed of the later survey of Mul Chowk undertaken by the more experienced team (*ie* 350-450 points per day).

The outline survey for the eastern section of the wall comprised *c*170 survey points, which at a normal survey pace would take 0.4 days for two staff members. It is therefore calculated that the full elevation would take *c*1.6 days. The level of accuracy for each survey point is of the order of +- 8mm and the resulting data would therefore provide an adequate control framework for more detailed levels of survey.

The estimate for the equivalent survey by hand is unfortunately imprecise, because the individual tasks were not specifically timed. However, it could potentially take up to six times as long by hand survey if an adequate control accuracy is maintained.

The feature survey recorded all significant elements but did not record intricate carved detail. In general the survey detail was found to have an overall accuracy of *c*8mm. However, in some instances, because of the bulk of the prism, it proved difficult to locate the prism tip into restricted corners which resulted in lower levels of accuracy for these points. The eastern section of the elevation required the survey of 480 survey points to upgrade the outline survey to that of a feature survey. This involved 1.3-1.6 days of survey using two surveyors. Although the instrument survey would require hand completion, this would be kept to a bare minimum by virtue of the number of survey points that it was possible to observe. Because of the height of the elevation, the higher detail required the use of a ladder to gain access and consequently some delays were experienced while the ladder was moved along the wall. These delays could be cut considerably by the use of a small (*c*2m high) portable section of scaffolding, located under each raised section of walling. Although precise figures are unavailable for the equivalent task by hand survey, it could take up to two or three times as long. Moreover, a hand survey of features based on a hand-measured outline compounds the errors of both levels of survey. With the instrument methodology the accuracy of the feature survey is identical to that for the outline.

It was realised from past experience of using instrument survey that such a technique could never be used cost effectively to record the intricate carved detail of the woodwork. Too many points were required and it would take an excessively long time to generate. For this reason, and the shortage of available training time, no intricate wood detail was recorded. However, a limited amount of brick detail was surveyed which enabled the estimation of the time required to survey the extent of the brick facade.

The central section of the elevation incorporates the majority of the brickwork (*c*16 sqm), estimated to contain *c*1570 individual bricks. A detailed instrument survey of such a facade would require the surveying of at least two points for each brick and therefore would necessitate the observation of 3140 survey points. This would have taken up to 8 days of instrument fieldwork for two people and there would have been a requirement of up to 7 days of manual draughting to complete the drawing. These estimates did not take into account the CAD work required to incorporate and edit the survey drawings. It was therefore appreciated that such a strategy would not be cost effective. An alternative strategy was to make assumptions as to the regularity of size of the individual bricks and therefore use the CAD facility to duplicate blocks of brickwork, to enable a complete coverage of the facade. This would have needed to have been undertaken in conjunction with a close scatter of control points, by instrument survey, over the extent of the brickwork to prevent any proliferation of error arising out of the assumption of conformity of brick size. With the adoption of this strategy, it would have been possible to provide sufficient detail survey and overall survey control with about 300 points. This would have taken 0.75 days of instrument survey using two team members. In addition, there would have needed to be 2 days of CAD work and 1 day of site verification. Assuming an adequate coverage of survey control points, it would be possible to ensure that the relative location of the bricks was to an acceptable level of accuracy (+- 20mm). The method would provide a considerable time saving on manual draughting; however the character of individual bricks would not be presented on the drawings.

Because of time restrictions during the training workshop, it was not possible to experiment with the use of a repetitive strategy for the brickwork; however, it was possible to apply the strategy to the recording of repetitive carved detail on the timber frieze between the first and ground floors. The detail incorporated both flower and geometric designs and there was found to be 90% consistency between the carving of the individual elements. The centres of each flower pattern were surveyed and the detail of the flower pattern was recorded by hand survey and then digitised into the CAD system. It was thus possible to generate within the CAD system a perfectly replicated series of the flower section of the frieze by mass duplication of the master drawing. This proved to be an extremely effective and efficient means of recording such uniformly repetitive detail. However the majority of the carved detail, particularly around the windows and doors, was not repetitive and therefore not open to such strategies.

Taleju Mandir: Cross-section Profile

It was requested that a cross-section profile of a tall building be included as part of the training workshop to demonstrate alternative recording strategies. The temple tower of Taleju Mandir was chosen as the subject of this evaluation shortly before its exterior was scaffolded to facilitate urgent roof repairs.

The instrument survey method to be used was triangulation. This is a very time consuming procedure but does generate three-dimensional data and can achieve high levels of accuracy. The basic requirements for such a survey are two total stations, which are set up as far away from each other as possible but yet can consistently sight onto the same detail points. A base line distance was measured between the two instruments to establish the survey control and from there onwards the EDMs were disabled and the instruments were used simply as theodolites. The architectural point of detail was sighted first from one instrument and the angles recorded and then from the other instrument. It required that the operator run backwards and forwards between the instruments to ensure that the same point of detail was observed by both. In the course of one days observation, only 132 detail points were observed and it was soon realised that the method was neither fast nor efficient.

The survey produced a basic outline of the building which was enhanced within the CAD system. The accuracy was high and as such provided a useful frame for further recording work; however, significant elements of the building, particularly those under the over hanging eaves could not be recorded (Figure 9).

The exercise was extremely valid within the training workshop, because it demonstrated the principles of triangulation and the potential of alternative techniques. However, the speed of survey and its inability to adequately record the detail beneath the eaves, meant that it was not a practical solution for the recording of this type of building.

6. INSTRUMENT SURVEY CONCLUSIONS

Introduction

The instrument survey evaluation examined a range of alternative methodologies. All of these had been applied on LUAU projects in the UK and therefore this previous experience was brought to bear during the evaluation. It has been established that almost all of the techniques have a valid application in the particular circumstances operating in Nepal, taking into account factors such as the overall aim of the project, the nature of the workforce, the equipment available, level and accuracy of recording, intended output format, and time/cost effectiveness. The aim of the evaluation was to assess whether a single or multiple strategy was most appropriate for the Patan Durbar project and which techniques could most economically and appropriately be applied. Presented below are the conclusions reached, together with the economic and practical advantages and disadvantages of each methodology.

Hand-measured Survey

Verification

Although survey control had been established for Sundari Chowk using stadia tacheometry, fortunately this was not actually used for either the plans or the elevations. Hence the considerable errors (+- 140mm) revealed during verification of the survey control were not reflected in the hand-drawn ground plan and elevations. Stadia tacheometry should never have been used for the establishment of control within such a building complex. The resultant errors could have had severe implications upon the quality of the final product. In future, primary survey control should be undertaken by traverse using either EDM or steel tape distance measurement.

The verification exercise eliminated any systematic error within the earlier surveys and hence was a measure of erratic error only. Erratic errors of up to 80mm were identified on the ground plan, although the mean was 39mm. This is a higher error than would normally be excepted and clearly resulted in local distortions of the ground plan. The representational accuracy was generally good although problems were clearly experienced with the raised detail associated with the central bath. In general the quality of the hand-measured survey was to an acceptable standard, although this was evidently at the expense of a considerable number of man days.

The hand-measured survey of the elevations were of a higher level of accuracy by comparison with the ground plan; the accuracies for the exterior west facing elevation and courtyard south facing elevation were of the order of +- 37mm and 15mm respectively. In terms of accuracy this is broadly acceptable and the representational accuracy of the draughting was to a high standard. The hand survey methodology was clearly suited to the generation of this level of intricate detail, although the efficiency of the methodology was clearly suspect.

Conclusions

The primary advantages of hand-measured survey, particularly for small recording projects, are as follows:

- Limited and inexpensive equipment
- Can be learnt easily by non-skilled staff once fundamental principles have been established
- Can achieve acceptable accuracies
- Capable of recording intricate detail and awkward corners where obstructions may restrict visibility from an instrument.

To offset the advantages, there are disadvantages, particularly for large-scale recording projects:

- Labour intensive
- Slow, particularly in the recording of the large and complex plans and outline and feature survey of elevations
- It cannot adequately or efficiently record inaccessible or complex multi-plane features.
- Requires scaffolding over each face limiting the flexibility, speed and cost-effectiveness of the technique
- Establishment of survey control is time consuming, and can be prone to proliferation of error if not applied extremely conscientiously
- Necessitates the use of a digitiser to input to CAD which results in further inefficiency and loss of accuracy.

Hand measurement clearly has validity when applied to small-scale recording. It can be effective for recording close structural or ornamental detail, but is slow and has a lower level of accuracy when used to generate the broad outline or feature survey. It is therefore best to use in conjunction with an instrument methodology, whereby the basic outline and feature elements would be recorded by instrument and the detail infilled by hand. The advantage here is that the instrument is not unnecessarily tied up recording considerable amounts of survey detail and that the hand survey is freed from the need to consistently work to a control network, but can instead be referenced to the accurate frame lines provided by the instrument.

Hand-measurement as a basic technique will inevitably be required for survey completion and for recording detail that is inaccessible for other techniques. However, on a major recording project the method is too time consuming and expensive in labour for it to be used in isolation.

Scanning and Digitising

The scanning process was found to have considerable disadvantages by comparison with the digitising alternative:

- The primary scanning had to be undertaken outside Nepal, which increased the overall costs and severely reduced the flexibility of the method
- The editing of the automatic scanning process was more time consuming than the equivalent combined digitising/editing process and was consequently therefore much more expensive
- The graphical accuracy of the method was of a lower order by comparison with consistent quality digitising.

However the advantages are that:

- Scanning does not require the outlay of expensive capital equipment (digitiser).
- The absolute accuracy of the digital drawings is higher than the equivalent digitised drawing, although the accuracy of the graphical representation is lower.

Conclusions

The disadvantages of the scanning considerably outweigh the advantages and from the point of view of cost, quality and flexibility the preferred method for digitally capturing hand-measured information must be to use a digitiser.

Instrument Survey

Plan Generation

The generation of Mul Chowk ground plan was undertaken almost entirely by instrument survey. Control was accurate to +- 2-5mm and the resultant detail was surveyed to an accuracy of +- 10mm. The survey was undertaken very economically, it being possible to complete all of the courtyard and all the accessible rooms within four days.

The advantages of the methodology are as follows:

- High level of accuracy
- Direct three-dimensional digital capture for direct transfer into a CAD system
- Requires only limited amounts of survey control, even for the most inaccessible areas
- Very economic for the capture of widely distributed survey detail, although this becomes less economic as the detail becomes more intricate
- Provides accurate and economic survey of detail that is remote from the floor plane
- Makes no assumptions of verticality or perpendicularity of the structure being surveyed
- No opportunity for proliferation of error, as the technique is dependent upon an accurate control network

The disadvantages are as follows:

- Requires the purchase of an expensive total station, logger and CAD system

- Critical path is the data capture stage and the speed of the survey is not related to the size of the survey team. An ideal size for an instrument survey team is three personnel; increasing that number will not result in a faster survey
- Not economic for the direct capture of very intricate survey detail; however to date none has needed to be recorded in the course of the Mul Chowk plan surveys.
- Not effective at recording inaccessible detail, as it is necessary to get the prism to the point required.

Elevation Generation

Elevations typically contain considerably more intricate detail than plans of an equivalent area. Most of the advantages and disadvantages of using instrument survey for plans also apply for elevations. However, by virtue of the increased amounts of detail on elevations, there is a significant change of emphasis away from the use of instrument techniques alone. If only a broad outline of an elevation is required then the method is the most economic available, because it negates the need for the establishment of hand survey control. But as the level of detail increases then the 15-20 second duration for each individual point becomes an economic liability.

Conclusions

In general the advantages of instrument survey considerably outweigh the disadvantages and once the commitment has been made to purchase the equipment, the technique is undoubtedly the most appropriate for the generation of plans and cross-section profiles in terms of its versatility, accuracy and economy.

The same could not be said for the generation of elevations, and with the knowledge gained from the evaluation, the project then went on the explore the alternative application of photographic survey techniques.

7. PHOTOGRAPHIC SURVEY

Introduction

The following section will consider the application of photographic survey techniques for the digital recording of historic buildings. The merits of photographic survey methodologies and the different levels of accuracy and detail which are obtainable in the production of two-dimensional drawings will be reviewed.

There are two basic photographic-based survey methodologies which may be applied to historic buildings. These are photogrammetry (based on stereopair photography taken using metric cameras), and rectified photography (consisting of single photographs or a mosaic of over-lapping photographs taken using conventional cameras aligned square to the object).

Photogrammetry

Photogrammetry is the technique of precise measurement from photography. Commonly associated with mapping through the use of stereoscopic aerial photography, it is now in the close-range survey of the elevations of historic buildings that the technique of photogrammetry has been most used in its non-topographical mode.

In each photogrammetric survey there are at least three components:

1. The acquisition of suitable stereopair photography (from ground level or hydraulic lift) usually undertaken using a metric or partial metric camera. Metric cameras have near distortion-free lenses enabling consistent resolution of the geometric properties of the photograph. A stereopair consists of two photographs, more or less at right angles to the wall, and with the same area of wall being imaged on each photograph. From this is established a three-dimensional stereomodel or photographic replica in miniature of the original wall.

2. The establishment of necessary control (ideally, three-dimensional coordinate data from instrument survey) so that the scale and shape of the stereomodel may be accurately reproduced and referenced to other stereomodels. At 1:50 scale, an accuracy equivalent to +- 10mm at true scale on the wall is possible.

3. The photogrammetric analysis or measurement, undertaken on a stereoscopic viewing instrument by a skilled operator, where the three-dimensional information is extracted by tracing a measuring mark round the architectural detail, and the data transformed either directly into drawings or digitally passed down-line to a CAD system for scale manipulation or rotation before plotting. The introduction of analytical photogrammetric instruments and the continuing advance of CAD systems has made the use of photogrammetric data even more flexible.

The procedure for editing, enhancing and interpreting photogrammetric data formatted for use in a CAD system is as follows:

- on-site verification (checks and additions) to calibrated hard copies
- on-screen location of areas to be updated from known coordinates on the hard copies
- updating of the digital files by issuing commands or snapping onto points to make the necessary corrections, erasures, additions
- digitising of information for complicated additions
- layering of data for selective plotting and/or specified line thicknesses; analytical and interpretative work; textual information.

Rectified Photography

Rectified photography or photomosaic often provides a cheaper alternative to the production of photogrammetric drawings. The technique consists of the taking of photographs in a plane which is exactly or nearly parallel to the object, and printing them true to scale. There is inherent inaccuracy in this survey methodology due to scale and displacement errors caused by changes in the depth of a facade, and distortion due to inadequacies in the lens and camera and in the enlarging system.

Assuming that the rectified photographs are large and clear enough, the method of inputting the data into a CAD system is to simply digitise straight from the photographs. The flexibility of CAD means that there is no need for the photographs to be printed to precise scales. Scaling can be achieved so long as the distance between control points on the photographs is known. One major advantage of digitising direct from rectified photography as opposed to hand tracing in the field is that it cuts down the amount of fieldwork, which becomes a verification rather than a generation exercise. Another advantage, of course, is the ability to output to a variety of scales.

Conclusions

Rectified photography as a 'stand alone' survey method has its problems, but within its limitations it is a reliable and relatively uncomplicated technique which may be carried out very quickly, especially in comparison to hand survey. The principle disadvantage is that the camera has to be positioned in a parallel plane to the object, which of course may not always be possible. However, high-level mast photography can alleviate certain difficulties encountered in the survey of tall buildings. The most useful results are obtained with the provision of sufficient instrument survey control, but ideally a photogrammetric framework on which to 'hang' the data from rectified photography is the preferred option. Apart from providing infill to existing measured drawings, it is not recommended as the sole basis for two-dimensional draughting other than for the very simplest facades, ceilings and floor surfaces.

Over the years, photogrammetric survey has proved to be a highly accurate two-dimensional draughting technique, and now provides the ideal medium for CAD input. It is an invaluable tool for the recording of wall elevations and complex three-dimensional structures which either have an irregular surface or a significant amount of detail removed from the main plane. Both horizontal and vertical profiles may also be extracted from the photogrammetric data, so that in some cases virtually complete plans and cross-sections can be provided. However, there are some limitations on the use of the technique. Since measurement is made from photography at a much smaller scale than the original, perfect interpretation of every feature is not possible, so that a degree of verification and infilling of missing or obscured detail will still be needed on site. Also, because the methodology relies on an advanced mathematical approach it requires the use of specialist equipment and skilled operators. Having said that, the speed of the fieldwork to photograph a building and provide instrument survey control, and the plotting of the final product, means that the work can be accomplished in a fraction of the time taken to measure the building by hand. Moreover, it is not necessary to erect scaffolding round the building.

8. IMPLEMENTATION OF PHOTOGRAPHIC SURVEY

Introduction

For the generation of elevation drawings, the instrument survey evaluation had demonstrated the limitations of using such methodology for the digital capture of non-repetitive detail. Because of the need to considerably speed up the process of surveying the remainder of the palace, the decision was taken to use photogrammetry to record the complex external elevations of the courtyards and towers. In order to assist the Nepalese recording team's instrument survey of the remaining plans and cross-sections, the photogrammetric work would also include the generation of horizontal and vertical profiles.

Of particular advantage in the case of Patan Durbar is the archival value of the photogrammetric product. Not only would the stereopair photographs provide a very complete record of the appearance and condition of the building at a given date, but precise measurement could be made from them. The photographs may be stored indefinitely in the sure knowledge that should the building suffer earthquake or fire damage it will still be possible to produce accurate measured drawings.

Previous Photographic Survey

The drawings produced as part of the research mission conducted by the Nippon Institute of Technology were based on the use a stereometric camera in conjunction with hand-measured control (NIT 1981, 2). However, the NIT drawings were considered unsuitable for the UNESCO project for the following reasons.

Despite the claim to have used a stereometric camera, the drawings appeared to have been the product of rectified photography rather than photogrammetry. As described above, rectified photography is not well suited to the recording of wall elevations and complex three-dimensional structures which either have an irregular surface or a significant amount of detail removed from the main plane. This inherent problem, together with the inadequacy of the survey control system (there were insufficient control targets on the published photographs to enable successful scaling) suggested that the accuracy and archival value of the resultant drawings was compromised (a fact later confirmed during the emergency repairs to Taleju Mandir). Moreover, the drawings were presented at too small a scale and contained excessive and schematic detail. To generate accurate digital data from them would have required the securing of copyright agreements and a huge investment of resources. Furthermore, the NIT survey had not been able to include all the elevations of the palace.

Photogrammetry

The photogrammetric survey was achieved through a UK-based specialist subcontractor (Atkins AMC) following a competitive tender process. This work was overseen by LUAU in conjunction with the specialist consultant who had earlier prepared the photogrammetric specification (HMG/UNESCO/JTFP 1995b).

To have surveyed the elevations of the palace buildings to one standard would have either shown insufficient detail or been prohibitively expensive. A two-stage technique of photogrammetry was therefore devised. The totality of the elevations were surveyed to allow the production of 1:20 and 1:50 scale drawings to show overall architectural design features (Item 1), such as would be appropriate for repair and conservation work. Then, a series of much larger photoscale metric stereopairs were taken of each individual feature (Item 2), which would permit the production of 1:5 scale detail drawings of the type needed for exacting restoration or indeed replacement in the event of a disaster. No plotting was carried out from these large-scale stereopairs. Essentially the stereopair is the record.

Item 1: Elevations

The elevations were considered as having two components - the courtyards (Part A) and the temple towers (Part B).

For Part A, all elevations of Mul Chowk courtyard and all other external elevations, including the lower walls of Degu Talle, were surveyed with a negative scale of 1:80. Most photography was achievable from ground level. Because the roofs had a deep projecting overhang supported on struts, the camera position and scale were configured to show all the wall surface under the eaves. Extra cover at scales of *c*1:200 were obtained as appropriate from one side only to show roof lines. Approximately 60 stereomodels requiring 80 or more single photographs were required.

For Part B included all elevations of the three temples towers of Degu Talle, Taleju Mandir and Agan Mandir. Degu Talle has elevations reaching to ground level, but the lower elevations were considered in Part A above. Most photography for the towers was obtained from a scaffold platform or adjacent buildings. As far as possible, stereopairs were surveyed with a negative scale of 1:130 but it was accepted that due to the configuration of the buildings non-standard stereomodels would be needed. Photography was therefore obtained as appropriate to ensure full cover. Approximately 60 single photographs making up 36 stereomodels were required.

All elevations as required and as photographed were plotted as orthogonal views of all faces. All architectural outlines of brickwork, rooflines, windows and doors *etc* were plotted, although some obscured areas of detail could not be completed due to the very three-dimensional nature of the facades. The roof struts were only be plotted in outline, a straight line for the solid edge being used, and a dashed line where a decorative feature breaks this line. In general, the fine detail of the very large number of densely carved and decorated features was not plotted, as Item 2 (the large-scale stereopairs) was to provide the detailed record. Typically a feature such as a window and surround was defined by sufficient lines to show the structural form only. Generally there is very little stonework, apart from such features as the plinths of the figures at the entrance to Mul Chowk courtyard. Individual bricks were not drawn. However, any obvious changes or discontinuities in the brickwork, especially notable on the east elevations, were recorded.

All data was captured in three-dimensional coordinate values and presented in Bentley/Intergraph MicroStation Version 5.0 files. The drawings were layered within the CAD system as follows:

1. Major structural features
2. Secondary wood edges
3. Tertiary wood detail
4. Repetitive architectural features
5. Struts and roof elements
6. Brickwork discontinuities
7. Services
8. Timber detail forward of the main wall plane.

The primary layer, 'Major structural features' results in a readable architectural drawing. The subsequent layers produce a progressively more detailed drawing.

A series of horizontal and vertical cross sections were produced. For each elevation, two horizontal sections were provided, and for the towers, extra sections were generated for each storey. A total of eight vertical sections through all buildings were also produced, two less than originally specified as the profile of Taleju Mandir was obscured by scaffolding at the time of survey.

Item 2: Details

Large-scale stereopairs of decorative features, and samples of repetitive features such as string courses and wooden arcading were surveyed at a 1:25 negative scale. These were mostly concentrated in Mul Chowk courtyard and on its exterior west face, with a further number on the lower levels of Degu Talle. These large-scale individual stereopairs were taken parallel to the wall plane or local surface, such that they could be utilised as rectified photography. Where necessary, two or more stereopairs or a run of models were needed of a feature. Because of the very large number of decorated roof struts (*c*350), these were not specially recorded. Approximately half of the cover was obtainable from ground level. For the remainder, a small scaffold tower was used giving a working height of *c*2m, apart from Degu Talle where a hydraulic lift of 6-7m was required to record the gallery. For all the detailed stereopairs, a scaling strip was provided in each area of stereo overlap. For single features, this was attached to the brickwork. There was no requirement for extra theodolite observation to tie these models in.

To demonstrate the quality and volume of data potentially available from the plotting of one of the stereopairs, 1:5 and 1:2 sample drawings were produced of one of the windows in Mul Chowk (Figure 10).

9. SURVEY RECOMMENDATIONS

Survey Completion

The instrument and photographic surveys of Patan Durbar were successfully accomplished within the timescales laid down at the outset of the revised work programme. However, a number of the plans and cross sections could not be completed due to problems of access. For various reasons, the Nepalese team were denied entry to some of the rooms in Mul Chowk and, because of their religious significance, it may never be possible to survey inside the central holy rooms within Taleju Mandir and Degu Talle. Should it be possible to gain access to any of these areas in the future, it is recommended that the instrument survey be completed.

In order to complete some areas of the plans and cross-sections, LUAU have digitised information from the drawings published by the research mission of the Nippon Institute of Technology (NIT 1981) and added this to the CAD files. However, because of the unreliability of this information (for the reasons stated above), this should be treated as a temporary measure. As such, the NIT survey data has been presented on a separate layer within the individual CAD files and only plotted out on the general plans of the palace, as appropriate.

Future Survey and Computer Needs

LUAU's initial contract was to advise on the selection and purchase of survey equipment which UNESCO wished to acquire for the Patan Durbar project. The report (HMG/UNESCO/JTFP 1994c) outlined the choice of appropriate total station, data logger and peripheral equipment. The third contract included advice on the selection and purchase of computer equipment, the resulting report (HMG/UNESCO/JTFP 1995a) outlining the choice of appropriate computer, digitiser, plotter and software.

Since 1994, when the survey and computer equipment was purchased, there have been considerable developments in both hardware and software which may justify the selective upgrading of elements of the system to improve its overall performance and compatibility with international standards.

Survey Equipment and Software

There are now better total stations on the market than the Sokkia. However, the instrument is still working adequately, it has not caused any undue problems and its data output is still of a universal format. At present, it is not considered necessary to upgrade or replace it.

The Steanne Autograd data logger has worked effectively in its intended role and similarly does not require replacement. However, over recent years there has been considerable development in the application of pen computers as survey loggers, because these cannot only store the data, but also enable the editing and enhancement of the digital drawing on site. In a few years time, once the technology has been adequately refined, there may be a case for the introduction of such a pen computer to be used alongside the conventional logger so that the manual draughting stage can be undertaken straight into the computer.

The survey software was the one element of the equipment package that did not perform as well as was hoped and, particularly as there have been some significant improvements in survey software since its purchase, there is a case for replacing the package with a more compatible system. On the basis of recent research into this software market, LUAU believe that the most appropriate package would be the LISCAD survey processing software which is produced by Leica and is fully compatible with all loggers and CAD formats. It has an ASCii format to enable manipulation of the elevation drawings, and it has the ability to directly view elevations from the original three-dimensional data, which will therefore speed up the survey processing.

Computer Equipment and Software

The 486DX 66 MHZ computer is already becoming outdated. As long as the FastCAD software (see below) continues to be used then the machine is adequate for the proposed applications. However, if the software becomes more sophisticated then the computer will have to be upgraded by the provision of a larger hard disk, additional RAM and the replacement of the processor chip to a Pentium 133Mhz chip.

The Summagrid IV digitiser is still the most appropriate type for this application and there is no need to replace it. However, although the present pen plotter is still working adequately, it is expensive to support in terms of pens, which are becoming increasingly difficult to obtain, and in a few years it may be necessary to replace it with an ink jet plotter, which would offer improved quality for a reduced price.

The FastCAD software has performed exceptionally well. It was found to be easy to use by all project staff and worked at a very fast speed on the particular computer platform used. The Nepalese team have developed considerable confidence in using the package which has enabled them to produce a range of good quality drawings. However, the package is no longer supported and is not being developed. It will not run as a Windows application and its data format is increasingly become non-standard. In a relatively short time, it will not have adequate compatibility with other systems and may need to be replaced. The most appropriate replacement software will largely depend upon when this takes place, as CAD systems are continually developing and the most appropriate package now may not be so in six months time.

Reflectorless Instrumentation

The drawback with the use of the conventional total station is that the hand-held prism needs to be physically placed on the architectural detail. This can result in significant delays if the detail is inaccessible. Sometimes the bulk of the prism restricts the placing of the prism tip precisely on the detail which therefore results in errors. An alternative is to use a reflectorless total station which requires no prism, the reflection being achieved off the architectural detail, thus speeding up the process of capturing survey detail and, as the method only requires one operator, reducing staff costs. Trials by LUAU in the UK have shown that it is possible to capture up to 1250 points per day, which is a significant increase on the 400 points achieved using a conventional instrument. However, the method requires the tracing of a laser beam around the salient detail, and such a laser dot is likely to be invisible on faces bathed in the very bright sunlight typical in Nepal. The reflectorless instrument also has a limited range of *c*100m and therefore cannot be used for other survey applications, unlike the conventional total station.

Computer-based Photo-rectification Systems

Several relatively low-cost proprietary software packages claim to generate accurate two-dimensional scaled drawings from single or multiple non-metric photographs or video stills taken in a tilted plane to the object. Coordinate information from control points imaged on the photographs may be input direct from a total station logging computer. Some programs assume wall verticality, others not. Some can also compute variations away from the main wall plane, though ideally they require an adequate number of control points on each plane, and multiple photographs of each projecting and receding feature, to obtain the best results. The degree of tilt is often not a major problem, though it is recommended that photographs should be taken as square-on as possible.

Of course, the simplest way to produce a lot of oblique photographs, from which to choose the most appropriate, is to use a video camera, and to digitise from freeze-frame images using cross-hairs on a television monitor. For this, a Picture Processing Unit is required to pass coordinate information between the video, digitiser and computer.

A number of conclusions may be drawn regarding the appropriateness of such CAD packages as applied to photographic-based survey of historic buildings. Limited trials by LUAU in the UK have confirmed that the best results are certainly obtained from multiple views and adequate control in all planes, rather than from a single photograph and a single measured distance. In this respect, the use of video recording, and digitising and rectification from still images, is worth further exploration, while acknowledging that such technology is already being superseded by developments in the use of high resolution digital cameras. Certain softwares have been proved to be valuable in the reconstruction of lost buildings for which some photographic and measured data survive. Early photographs can be used, as programs do not require detailed mathematical information about the camera. In this respect these softwares may have a particular value in Nepal as an aid to the reconstruction of buildings damaged by earthquakes for which few records survive.

Although no replacement for a truly photogrammetric product, the relative merits of these increasingly available low-cost systems could be evaluated. The key points in evaluating such programs will be to establish how well they remove the mechanical and optical intrinsic errors of lens distortion, and what cameras and computer hardware platforms and accessories are required to support the software both in the field and in the office. A critical comparison of cost between each of these systems and those of more conventional methods should take into account local conditions in Nepal.

Geographical Information System (GIS) Software

There is an increasing need to fully integrate CAD systems with relational database programs, so that descriptions of complex buildings, and cross-references to other archival material, can be called up on screen in association with the graphical data. Such developments are particularly beneficial, particularly when data is being used for conservation management purposes by allied disciplines (architects, planners, engineers, and building contractors).

GIS software permits the mergence of CAD systems and database programs. It enables analysis and graphical representation of textual database information from within a CAD system. Thus all textual information pertaining to a building or feature can be accessed on screen by clicking with the mouse onto the graphic image in question. Alternatively the system can be interrogated to highlight in plan all buildings or features satisfying specific criteria, allowing a distribution on screen of the information of a particular distinctive type. Additional information such as photographs can be digitally stored within the GIS system, so that it is possible to access from a building or feature's graphic image a photographic image, thus providing an immediate assessment of its character and condition.

10. GENERAL RECOMMENDATIONS

Introduction

The final plenary session of the professional seminar entitled 'Innovative Conservation of Cultural Heritage in Nepal' held at the Summit Hotel, Kathmandu between 25th-30th September 1994, concluded with a discussion of the role of scientific documentation in the establishment of effective systems of planning control and in the implementation conservation projects. It was emphasised that apart from the palace buildings, the Patan Durbar Square Monument Zone also includes many hundreds of other structures of great importance to the integrity of the site, and that scientific documentation should play a primary role in the management and preservation of these buildings as well. The suggestion was also made that the computer-assisted recording system established for the Patan Durbar project could be utilised for the creation of a textual and graphical database for the Monument Zone and subsequently elsewhere in the Kathmandu Valley World Heritage Site. It was further emphasised that the creation of such documentation schemes should be linked to the creation of a Development Control Unit to monitor the World Heritage Site.

Role, Purpose and Function of Scientific Documentation

For the purposes of the World Heritage Site, scientific documentation may be defined as the collation and study of information leading to an understanding of the significance of historic buildings and sites. It is this understanding which allows for informed decision making within the planning system and, where necessary, serves as the basis for informed structural analysis and appropriate conservation techniques.

Achieving Documentation

Documentation of historic buildings may be achieved by:

1. Desk-based research into the historical and epigraphic sources (both written and pictorial) leading to the formulation of inventories.

2. Field recording of the visible fabric (using appropriate survey techniques) leading to the generation of archival drawings and photographs.

3. Analysis and interpretation of the desk-based information and field records leading to an understanding of historical significance.

In 1975, a protective inventory of sites and monuments in the Kathmandu Valley was published with the hope that this would form a legal document to assist in protecting cultural heritage (Pruscha 1975). Ten years later, the urgent need for the enhancement of this inventory as the basis for future conservation policy was being stressed (Sangachhe 1985). However, following a recommendation from the joint UNESCO/ICOMOS review mission to Nepal in 1993 (UNESCO/ICOMOS 1993), it is only recently that such enhancement work has begun. To date this has taken the form of a pilot project restricted to the Patan Durbar Square Monument Zone (DoA 1994; DoA forthcoming), though it is intended that the other Monument Zones will receive similar treatment in the future.

As far as fabric recording is concerned, various parties have been engaged in architectural survey since the 1970s but there has been no coordination of effort to set up an archive or to effectively link the information to the inventories.

A rudimentary computer database is being slowly created for the text of the Patan Durbar Square Monument Zone inventory but the software used is not designed for detailed interrogation or analysis. Nor is it capable of importing existing or future graphic and photographic archive data. It is therefore recommended that the option of using GIS software be explored, within which various levels of documentation information could be held.

Scope and Level of Documentation

The accuracy and amount of data held within any documentation system determines the quality of analysis and thus the overall value of interpretation.

For extensive documentation, a basic identification survey is the minimum requirement. Most of the existing inventories satisfy this minimum level but in their scope they require a more holistic approach to the gathering of information, rather than the initial biased concentration of effort afforded to those buildings and sites deemed to be of greater importance. For example, public and religious buildings are well represented in the records but extensive surveys of private houses have yet to be completed.

For intensive documentation, strategies need to be formulated to identify levels of field recording. Clearly not all structures need to be recorded in the same detail; different circumstances will demand different responses. Levels can range from comprehensive recording of complex buildings to selective recording of structures of more regular or repetitive construction. During opening up, recording should be sufficiently detailed to allow analysis and interpretation of the assembly and disposition of exposed features, to inform and justify, where appropriate, the rebuilding of as much of the original fabric as practicable. Survey methodologies and CAD systems must be compatible with each other to allow levels of recording to be increased as time and resources permit.

Prioritising work is another area for consideration. The establishment of a strategic programme could be achieved by using a scoring system to assess a building's uniqueness, authenticity or condition, and thereby the order and level for its recording. Where necessary, emergency recording would be targeted on those elements which are affected by development proposals or which are particularly vulnerable.

Resources for Documentation

As a result of the Patan Durbar project, survey and computer equipment have been purchased and personnel trained in its use. This resource could easily form the nucleus of a first-class recording arm of a future Development Control Unit. Since completing work on Patan Durbar, the team has undertaken a survey of all the monuments in the adjacent square, and through developing links with the Patan Conservation and Development Programme and the local municipality, has now embarked on documentation of additional parts of the Monument Zone. The continued and appropriate employment of the team and use of its equipment must be a high priority as they represent an investment of potentially enormous importance to future conservation of the Kathmandu Valley World Heritage Site.

Proposals for Future Scientific Documentation

Proposal 1

That the Department of Archaeology in cooperation with appropriate international agencies should build on the experiences of the Patan Durbar project and prepare a computerised inventory of the whole of the Patan Durbar Square Monument Zone as a pilot project and as an essential tool for the preservation of the historic built environment through development control.

Proposal 2

That the inventory should be enhanced by the acquisition of new material resulting from a rolling programme of proactive survey undertaken to agreed specifications and pre-defined recording levels.

Explanation

Proposal 1 would see the establishment of a computer database of existing records leading to a preventive inventory for the Patan Durbar Square Monument Zone in the first instance, possibly extending to areas outside the Monument Zone as a pilot for eventual implementation to other parts of the Kathmandu Valley World Heritage Site. Out of necessity, such an inventory would have to be linked initially to emergency repairs, and thence be used as a proactive research tool.

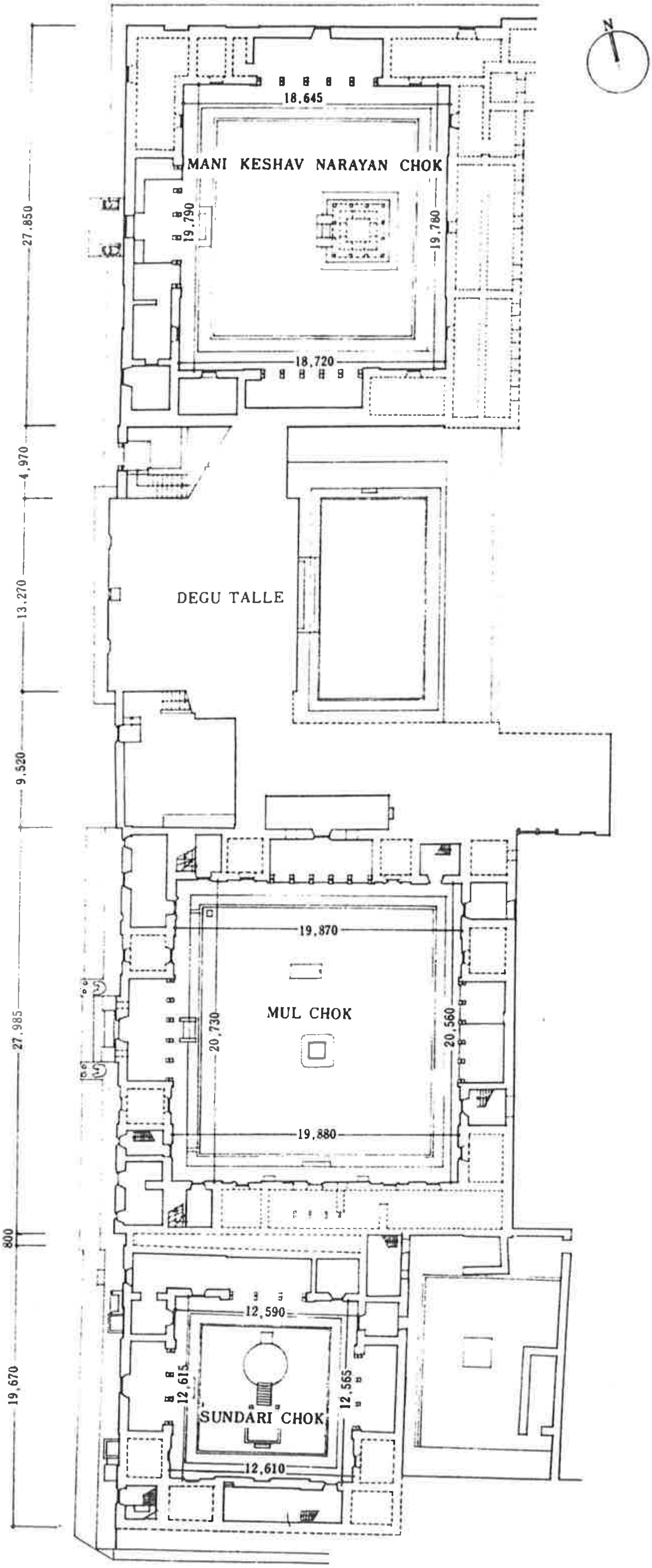
Proposal 2 would see prioritisation being dictated by a scoring exercise and undertaken by a field team employing a combination of survey methodologies appropriate to local conditions and to standards laid down by the Department of Archaeology. Information from the field would be fed back to the inventory to maintain the central database record.

Resources

Proposal 1 would require GIS computer software and appropriate hardware. As well as training in the use of the database, staff will be required to have some experience in development control and research.

Proposal 2 would require training of staff in the draughting of specifications for proactive and emergency recording and in the definition of levels of recording. Depending on the software chosen for the inventory, some training would also be required on loading new information into the database.

LIST OF ILLUSTRATIONS



N
MANI KESHAV NARAYAN CHOK
18,645
19,790
19,760
18,720
27,850
4,970
13,270
DEGU TALLE
9,520
19,870
MUL CHOK
20,730
20,560
19,880
27,985
800
12,590
12,615
12,565
SUNDARI CHOK
12,610
19,670

Fig. 1

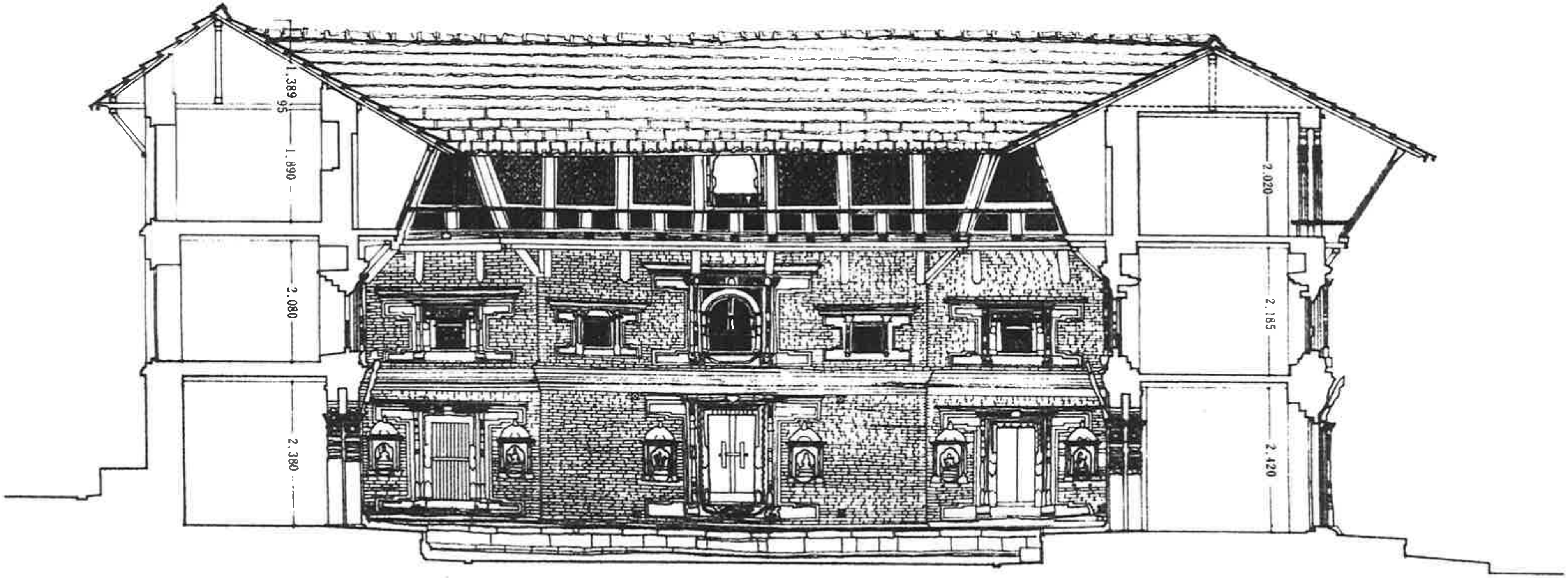


Fig. 2

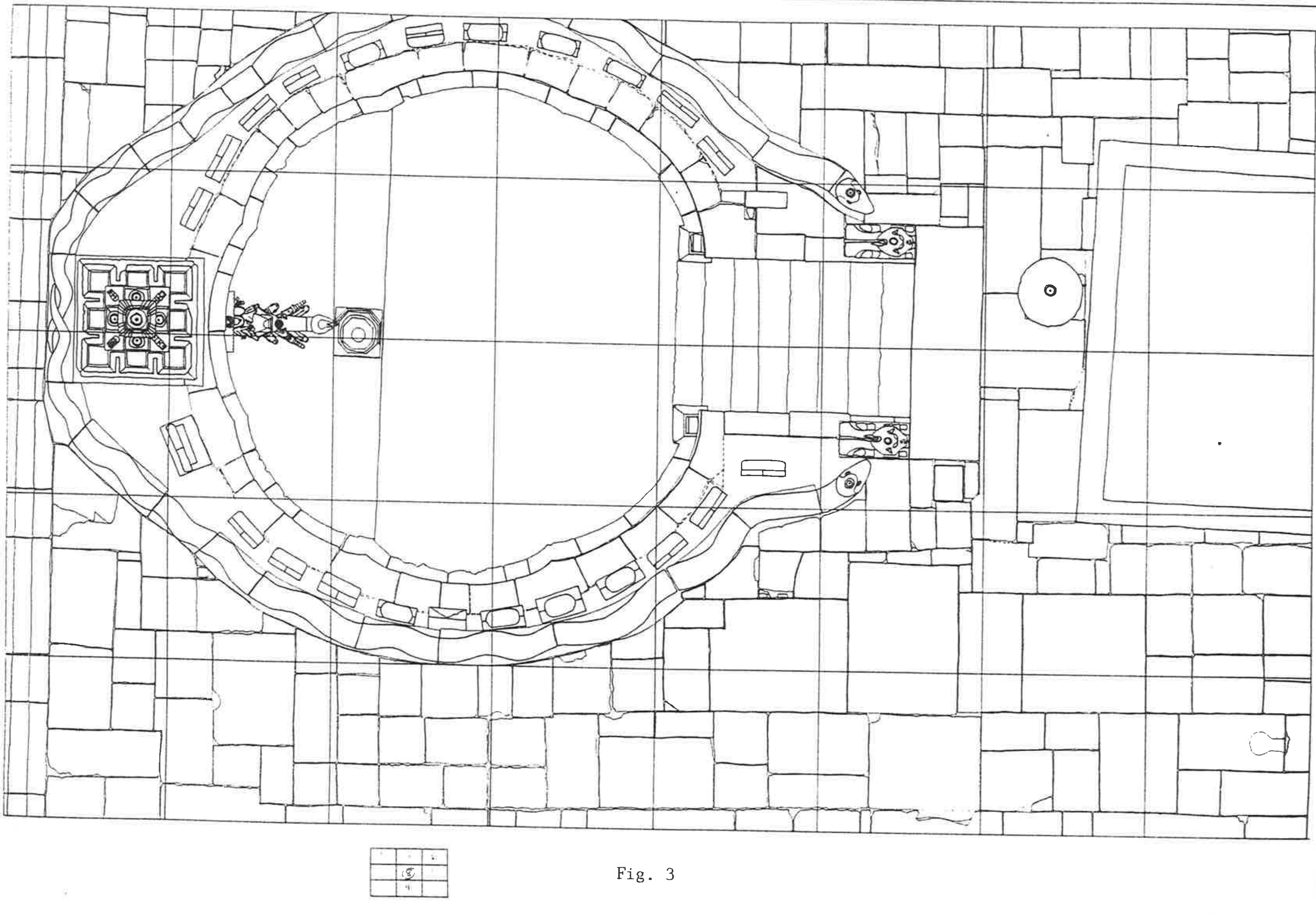
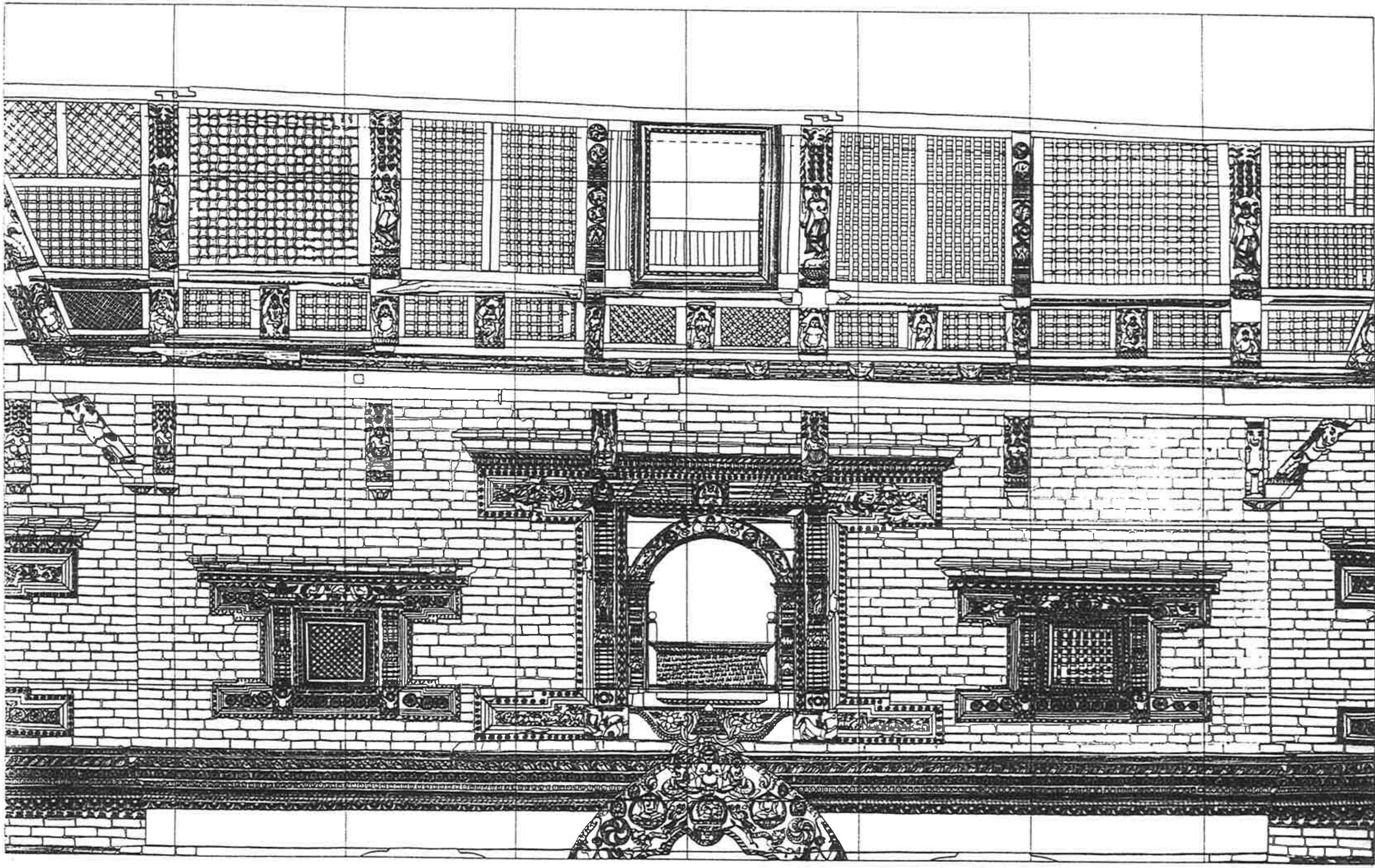


Fig. 3



8		7
6	5	4
3	2	1

Fig. 4

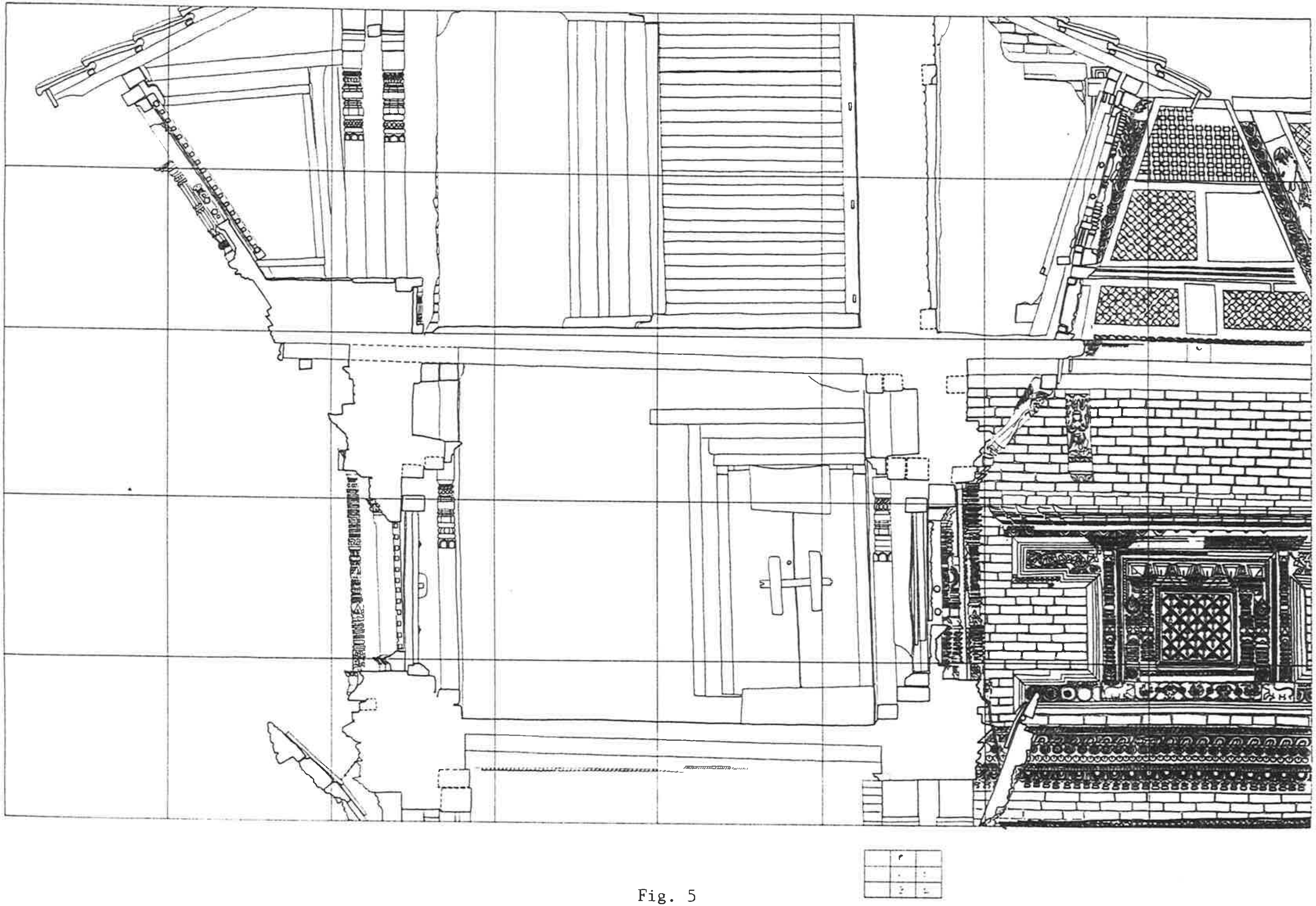
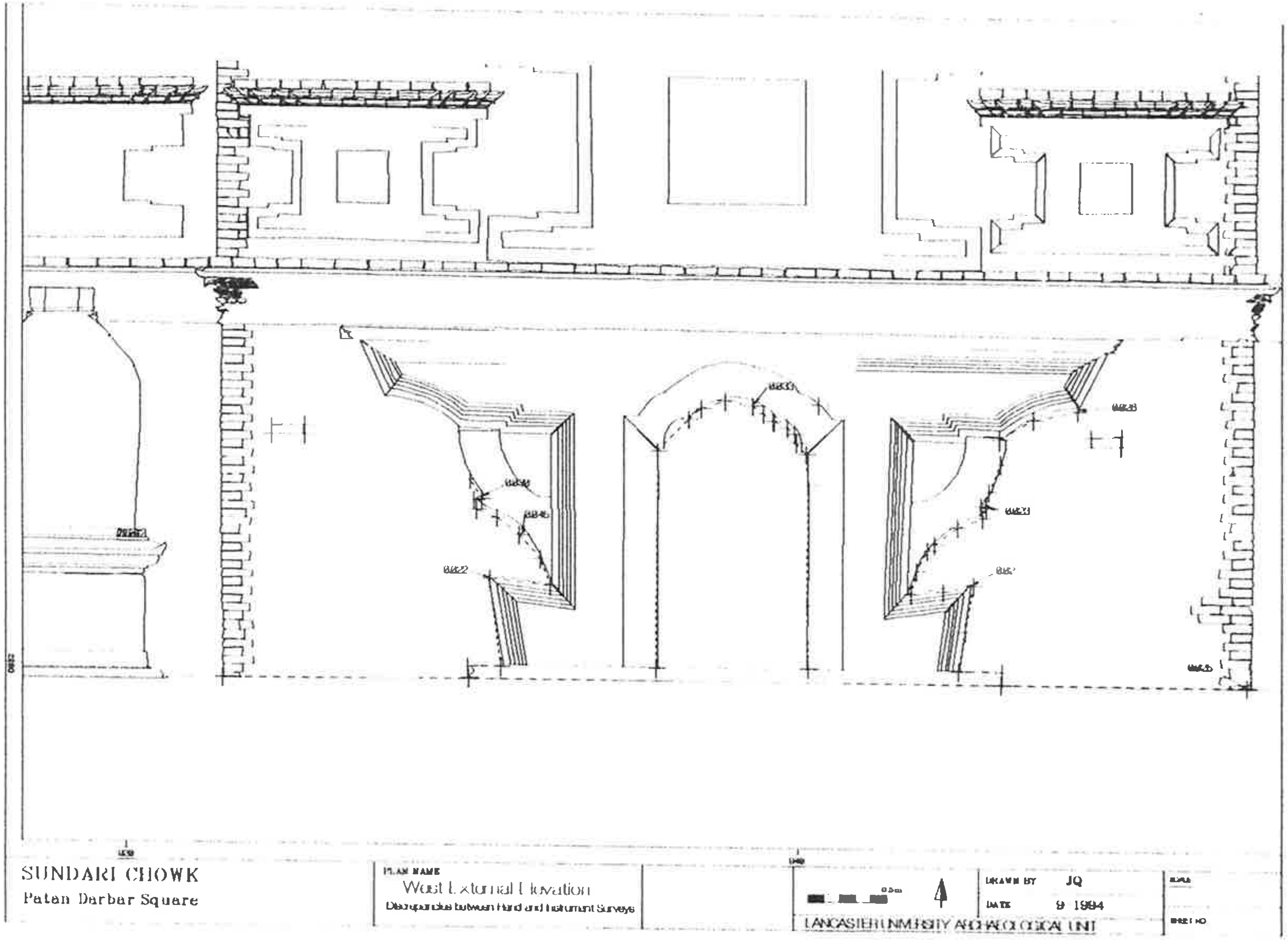


Fig. 5


SUNDARI CHOWK
Patan Darbar Square
Plan discrepancies between hand survey and instrument survey
1m
Date
Sheet No
1

Fig. 6



SUNDARI CHOWK
Patan Darbar Square
PLAN NAME
West External Elevation
Discrepancies between Hand and Instrument Surveys
0.5m
DRAWN BY JQ
DATE 9 1994
LANCASTER UNIVERSITY ARCHAEOLOGICAL UNIT
SCALE
SHEET NO

Fig. 7


Sundari Chowk
Patan Darbar Square
PLAN NAME
South Internal Elevation
L.U.A.U. Copyright 1994
0.5m
DRAWN BY
JQ
DATE
5-1994
LANCASTER UNIVERSITY ARCHAEOLOGICAL UNIT

Fig. 8

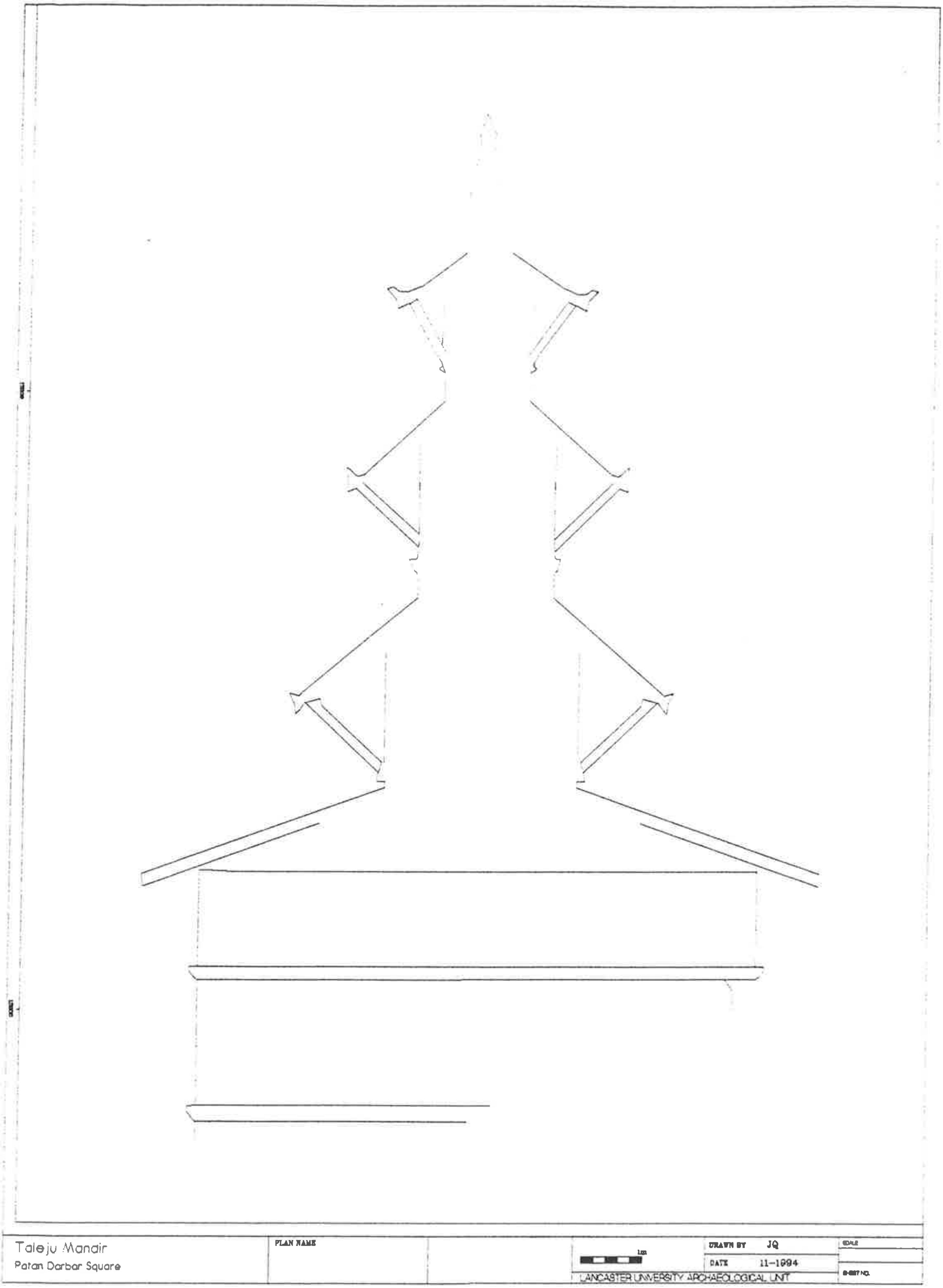

Taleju Mandir
Patan Darbar Square
PLAN NAME
1m
DRAWN BY JQ
DATE 11-1994
LANCASTER UNIVERSITY ARCHAEOLOGICAL UNIT
SCALE
SHEET NO.

Fig. 9

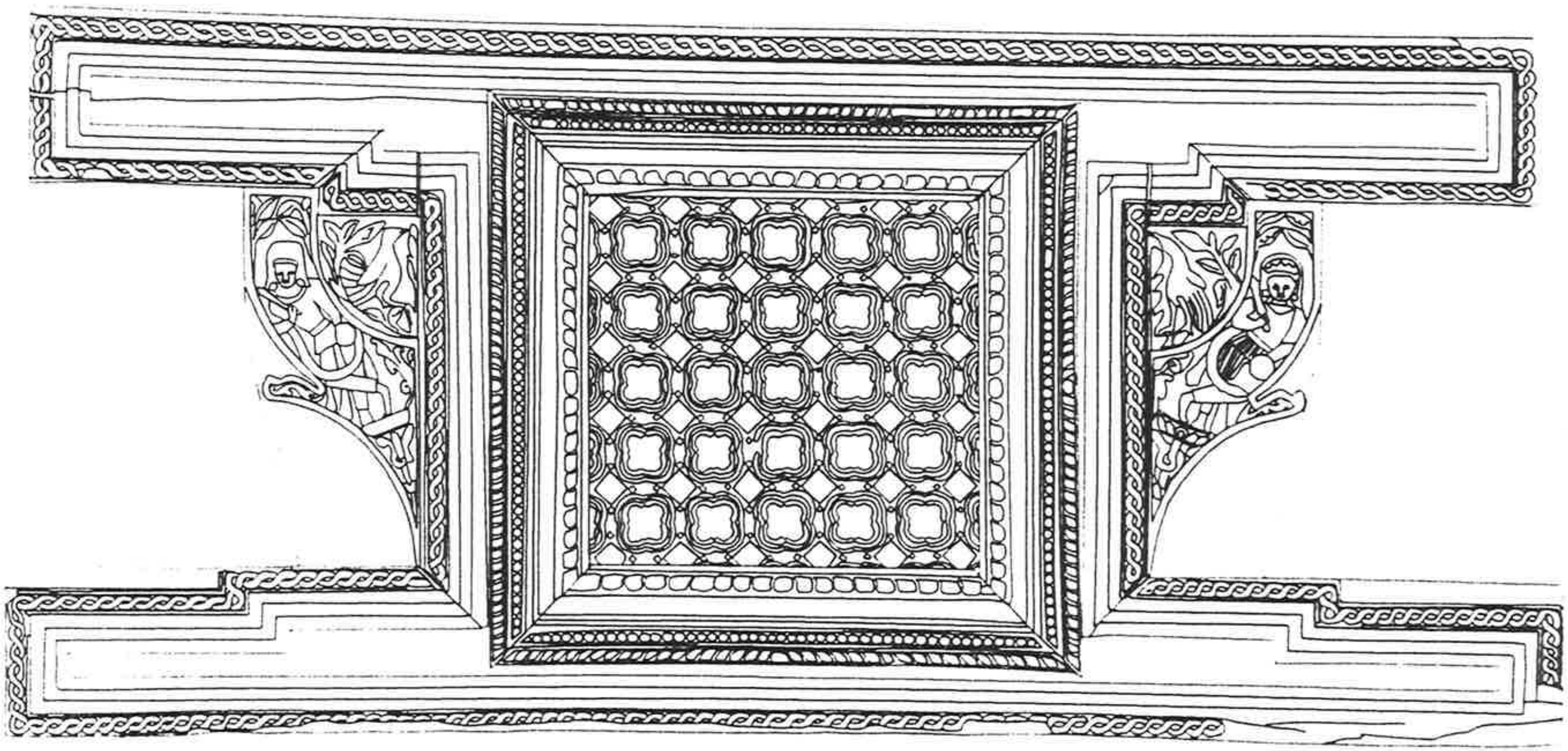


Fig. 10

APPENDIX 1

Scientific Documentation Training Workshop

Programme
Tuesday 20th September - Sunday 2nd October 1994

Tuesday 20/9	am	Establish survey control and coordinate information
	pm	Commence verification of plan
Wednesday 21/9		Bhaktapur
Thursday 22/9	am	Introduction to *Elementary Training Course* (all 12 trainees)
	pm	Complete verification of plan and courtyard south facing elevation
Friday 23/9	*Elementary Training Course 1* (4 trainees)	
	am	Verification of exterior west facing elevation
	pm	Commence instrument survey of courtyard north facing elevation (outline)
Saturday 24/9	Rest day	
Sunday 25/9	*Professional Seminar: Inauguration*	
Monday 26/9	*Elementary Training Course 2* (3 trainees)	
	am	Complete instrument survey of courtyard north facing elevation (outline)
	pm	Commence instrument survey of courtyard north elevation (features)
Tuesday 27/9	*Elementary Training Course 3* (3 trainees)	
	am	Complete instrument survey of courtyard north elevation (features)
	pm	Commence instrument survey of courtyard north elevation (detail)
Wednesday 28/9	*Elementary Training Course 4* (2 trainees)	
	am	Complete instrument survey of courtyard north elevation (detail)
	pm	Complete instrument survey of sample panel of brickwork

Thursday 29/9 — *Professional Seminar: Scientific Documentation*

Friday 30/9 — *Advanced Training Course 1* (3 trainees)
am Instrument survey for rectified photography
pm Instrument survey for first floor plan
Introductory CAD Training Course 1 (2 trainees

Saturday 1/10 — Rest day

Sunday 2/10 — *Advanced Training Course 2* (3 trainees)
Instrument survey for cross-section profile
Introductory CAD Training Course 2 (2 trainees

List of Participants

Elementary Training Course 1

Mr Yogendra Agrahari - *Architect, Department of Archaeology*
Mr Hiranya Baidya - *Archaeologist, Department of Archaeology*
Mr Jai Charana Kastee - *Senior Divisional Engineer, Department of Archaeology*
Mrs Sarala Manandhar - *Senior Archaeologist, Department of Archaeology*

Elementary Training Course 2

Ms Sirish Bhatt - *Trainee Conservation Architect*
Mr Suraj Pradhan - *Trainee Conservation Draughtsman*
Mr Satya Prasad Prajapati - *Conservation Draughtsman*

Elementary Training Course 3

Ms Elina Bajracharya - *Trainee Conservation Draughtswoman*
Ms Jharna Joshi - *Trainee Conservation Architect*
Mrs Sarita Shakya - *Trainee Conservation Draughtswoman*

Elementary Training Course 4

Mr Kiran Chalise - *Trainee Conservation Architect*
Mr Deepak Pant - *Project Conservation Architect*

Advanced Training Course 1

Ms Elina Bajracharya - *Trainee Conservation Draughtswoman*
Mr Suraj Pradhan - *Trainee Conservation Draughtsman*
Mr Deepak Pant - *Project Conservation Architect*

Advanced Training Course 2

Ms Elina Bajracharya - *Trainee Conservation Draughtswoman*
Mr Suraj Pradhan - *Trainee Conservation Draughtsman*
Mr Deepak Pant - *Project Conservation Architect*

Introductory CAD Training Course 1

Ms Sirish Bhatt - *Trainee Conservation Architect*
Ms Jharna Joshi - *Trainee Conservation Architect*

Introductory CAD Training Course 2

Ms Sirish Bhatt - *Trainee Conservation Architect*
Ms Jharna Joshi - *Trainee Conservation Architect*

Nepalese Computer-assisted Recording Team

Ms Sirish Bhatt - *UNESCO Team Leader*
Trained in Beijing as an architect and has AutoCAD experience. Very conscientious, with good organisational abilities and good CAD skills. Speaks English very well.

Ms Jhana Joshi - *UNESCO Assistant*
Trained in Beijing as an architect and has considerable CAD skills. Also has a good understanding of the instrument survey process and a good manual surveyor.

Mr Suraj Pradhan - *UNESCO Assistant*
Very proficient at the use of the total station, with a good understanding of the overall instrument survey process. Conscientious and very eager to learn new methodologies.

Mr Shaligram Kattel - *DoA Representative*
Keen to learn from the outset and developed fairly well in the course of the instrument survey. Manual draughting skills are fairly good.

Mr Amrit Shakya - *DoA Representative*
A worthwhile member of the team, particularly effective as a negotiator for access and liaison with the DoA.

APPENDIX 2

Professional Seminar

The programme and press release are enclosed.

"INNOVATIVE CONSERVATION OF CULTURAL HERITAGE IN NEPAL "

HMG / UNESCO Professional Seminar 25th - 30th September 1994.

Seminar organizers (leaders) :

Mr Khadga Man Shrestha, Director General, Department of Archaeology
Mr Tara Nanda Mishra, Deputy Director General, Department of Archaeology
Mrs Riddhi Pradhan, Chief Exploration Officer, Department of Archaeology
Dr Hideo Noguchi, UNESCO.
Professor Dr Hans C. Bjønness, UNESCO CTA
Mr David Michelmore, UNESCO Consultant
Mr Jason Wood, UNESCO Consultant
Professor Dr Chikaosa Tanimoto, UNESCO Consultant
Professor Dr David Yeomans, UNESCO Consultant

Sunday 25th of September

First day	<u>Inauguration</u>
10 AM	Inauguration of the seminar by Dr Iswar Upadhaya, Secretary of the Ministry of Education, Culture and Social Welfare.
10.15 AM	"Goodwill message" by His Excellency , the Ambassador of Japan to Nepal, Mr Yoshida.
10.30 AM	Opening address by Mr Khadga Man Shrestha, Director General, Department of Archeology (DoA): *"Issues of Conservation and their Solutions"*
11.00 - 11. 20 AM	Tea / Coffee
11.20 AM	Mr Tara Nanda Mishra, Deputy Director General, DoA. : *" Archeological Conservation Principles and Collection of Evidence".*
11.40 AM	Mrs Riddhi Pradhan, Chief Exploration Officer, DoA.: *" Historical Introduction to the Kathmandu Valley World Heritage Site - with special reference to Patan Monument Zone".*
Noon - 12.30 PM	Plenary discussion
12.30 - 2 PM	Lunch
2 - 4 PM	Outline of seminar content and professional introductions on site (Sundari Chowk) by Hans C. Bjønness, Jason Wood, David Michelmore, Chikaosa Tanimoto, David Yeomans.

The seminar is organized under the UNESCO / Japan Trust Fund Project
for Patan Darbar Square, Nepal
A project under agreement with
HMG Ministry of Education, Culture and Social Welfare, Department of Archaeology.

Monday 26th of September

Second day Masonry restraint and earthquake techniques.

10 AM	Dr. Chikaosa Tanimoto: *"Earthquake performance of masonry"*.
11 AM	Dr. David Yeomans: *"Monitoring and restraining masonry"*.
Noon - 12.30 PM	Discussion
12.30 PM	Lunch
2 PM	On site at Sundari Chowk. Mr. Hari Ratna Ranjitkar: *"The effect of the 1934 earthquake and the subsequent reconstruction. The evidence of the building"*.
2.30 - 4 PM	On site examples at Sundari Chowk and discussion on remedial action.

Tuesday 27th of September

Third day. Timber conservation.

10 AM	Dr. Khedar Ranjitkar, Chief Conservation Laboratory: *"Chemical conservation of timber"*.
10.40 AM	Mr. David Michelmore: *"Timber repairs"*.
11.20 AM	Dr. David Yeomans: *"Assessing timber structures"*.
Noon - 12.30 PM	Discussion
12.30 - 2 PM	Lunch
2 - 4 PM	Mr. Wayne Kirkby: Demonstrating timber joining techniques on site. Site to be announced.

Wednesday 28th of September

3rd day. Strategies of World Heritage Sites Conservation / Masonry, lime mortars and renders.

10 AM	Dr Hideo Noguchi : *"Strategies to conservation of World Heritage Sites"*.
11 AM	Mr David Michelmore: *"The use and performance of lime conservation"*.
Noon	Discussion.
12.30 PM	Lunch
2 - 4 PM	Mr Wayne Kirkby: *"Demonstration and discussion of craft techniques"*. Site to be announced.

Thursday 29th of September

4th day. Scientific Documentation.

10 AM	Dr Hans C. Bjønness: *"The architectural recording of Sundari Chowk".*
10.40 AM	Mr James Quartermaine: *"Instrument survey and digital recording systems".*
11.20 AM	Mr Jason Wood: *"Photographic survey and computer aided modelling".*
Noon	Discussion.
12.30	Lunch
2 - 4 PM	Discussion on scientific documentation and monitoring at Sundari Chowk.

Friday 30th of September

5th day. Conclusions.

10 AM	Summary of previous discussions by seminar leaders.
11.15 AM	General discussions
12.30 PM	Lunch
2 PM	Continuing discussions
3 PM	Concluding remarks by seminar leaders
4 PM	Closing address by Mr Khadga Man Shrestha, Director General, Department of Archaeology.

Press release.

Seminar on
"INNOVATIVE CONSERVATION OF CULTURAL HERITAGE IN NEPAL "

The Department of Archeology is, with the assistance of UNESCO, making efforts to establish standards for conservation practise and documentation which are appropriate for local conditions and in accordance with international standards for conservation of the architectural cultural heritage. This is of particular importance in relation to the World Heritage Site of the Kathmandu Valley and its seven Monument Zones.

As a part of this effort is the Department of Archeology and UNESCO from 25th to 30th of September arranging a professional seminar in Patan. The seminar will, on the 25th of September, be inaugurated by the Secretary of Ministry of Education, Culture and Social Welfare, ***Dr Iswar Upadhaya.***
His Excellency, the Ambassador of Japan to Nepal, ***Mr Yoshida***, will give a "goodwill message".
The opening address will be by ***Mr Khadga Man Shrestha***, the Director General of Department of Archeology (DoA), who will speak on " Issues of Conservation and their Solutions". ***Mr Tara Nanda Mishra***, the Deputy Director General of DoA, has given his introduction the title "Archeological Conservation Principles and Collection of Evidence". Finally,.during the inaugural session, ***Mrs Riddhi Pradhan***, Chief Exploration Officer of DoA, will give an " Historical Introduction to the Kathmandu Valley World Heritage Site - with special reference to Patan Monument Zone". Later in the seminar ***Dr Hideo Noguchi***, UNESCO,will lecture on "Strategies for the Conservation of World Heritage Sites". In addition local and international experts will lecture and there will be on - site training workshops at Patan Darbar for traditional craftsmen and on scientific recording .

The seminar is organized under the UNESCO / Japan Trust Fund Project for Patan Darbar Square, Nepal. This is project under agreement with HMG Ministry of Education, Culture and Social Welfare, Department of Archaeology. The project is a part of the significant commitment of the Government of Japan multilaterally, through UNESCO, to contribute to the conservation of World Heritage Sites.

The purpose and contents of the professional seminar can be outlined as follows:
The ***purpose*** of the workshop is to enable discussion to take place between local and international specialists on conservation issues in Nepal. The Department of Archeology, is through the workshop discussions on timber construction and masonry and its earthquake resistance, mortars, and requirements for scientific documentation, taking an important initiative to establish standards for conservation practice and documentation which are

appropriate for local conditions and in accordance with the International Council for Monuments and Sites (ICOMOS) Charter of Venice (an international standard for conservation).

The architectural and cultural heritage of any country may have unique characteristics and present particular problems. The architectural heritage of the Kathmandu Valley is no different in this respect. It has extraordinary high quality of architectural expression and craftsmanship, but also its problems. The composite nature of bricks and timber used together has parallels in brick and timber used elsewhere, but the extensive use of decorative timber within brick facades is unique. This workshop has been designed to bring together both craftsmen and professionals involved in conservation to develop approaches for in-situ repair of the fabric using traditional skills augmented by the application of appropriate technologies, including advanced building technological survey methods.

Proper conservation of historic structures is impossible without an adequate understanding of their anatomy and their detailed behaviour. We need to know both how they were originally constructed and how the materials have changed with the passage of time. We also need to get insight into how this has affected the performance of the structure. In the region we also need to understand the dynamic characteristics of a building to be able to assess its response to earthquake loading. We are therefore involved in the exploration of the anatomy of building, the condition of both the masonry and timbers and the movements that have occurred over time. This will enable us to understand the way in which loads are transmitted within the structure, Measurements of vibrations at several parts of the building will determine the relative stiffness of different parts.

The seminar will also take up advanced architectural and archeological recording and building survey methods and discuss these methods application in the Nepalese context. In recent years, social awareness of the conservation of the historic built environment has increased, and the role of the architect and archeologist and employment of modern architectural and archeological survey techniques and associated computer applications has been extended. Today, the production of detailed scientific documentation in advance of, and during, major works of repair and conservation of historic buildings is seen as paramount, as well as controlling changed historical design by modern development.

The importance of architectural recording as a part of actually preserving the building is essential. "As it is" recordings can in the future serve important functions in the effort to rebuild if the monuments are destroyed in natural disasters. In the context of Nepal, there are skilled architects, archeologists and draftsmen who should be trained to take interest and contribute to the conservation of the built, architectural, heritage. The actual detailed recording is enriched through the skilled eye, and dedication and cultural and religious insight of the Nepalese professional. It also is a process of learning the construction techniques and "language" of the historic building and trying to comprehend the thinking of the masters who designed and constructed these monuments with extremely high architectural and craft skills. This insight is essential when the same group of professionals later will make the preservation design and recommend on the difficult aspects of level of intervention. A diversified standard of architectural and archeological recording should be established which takes into consideration the significance of the monument, its appropriateness for the different techniques, its conservation need and the scale of the recording or inventory to be implemented. It will for example be a different approach to make an inventory of the monuments and urban spaces and structure of the World Heritage Site, Monument Zone of Patan Darbar compared with the detailed recording being done at the very significant monument of Sundari Chowk, Patan Darbar.

However, the challenge faced is to make the survey techniques more accurate assisting the hand measurements with the application of specialised instrument and photographic survey techniques, and the development of Computer Aided Drafting (CAD) (and designing) programmes, for the digital recording and analysis of historic buildings and the interpretation of the their structural history. The relative merits of some of the various survey methodologies and software packages currently described, and the different levels of accuracy and detail which are obtainable in the production of two dimensional drawings, and the potential for the creation of three-dimensional computer models will be explained.

The application of these methods will be reviewed based on the specific needs of and application by professional Nepalese architects, archeologists and draftsmen and to the systematic inventory needs and efforts of the Department of Archeology.
It is essential that the national and international community work together for the conservation of the Architectural Heritage of the Kathmandu Valley.

As declared by His Majesty's Government of Nepal and approved by the World Heritage Committee (for which UNESCO is the secretariat), the World Heritage Site of the Kathmadu Valley, with its seven monument zones, indeed has significant importance for the preservation of the Culture of Mankind.

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APPENDIX 3

Project Archive

Photogrammetry: Item 1
29 x 1:20 elevation drawing sheets
12 x 1:50 elevation drawing sheets
3 x 1:50 vertical section drawing sheets
8 x 1:100 horizontal section drawing sheets
5 x 3.5" discs (MicroStation and DXF)
249 x black-and-white negatives
249 x colour negatives
249 x diapositives of black-and-white negatives
249 x black-and-white contact prints, annotated with control point positions
249 x colour prints enlarged to fit A4 paper
2 x diagrams showing photographic coverage
4 x diagrams showing traverses
13 x station record sheets
List of coordinates of control points and traverse stations
Camera calibration certificate

Photogrammetry: Item 2
1 x 1:2 sample window elevation drawing sheet
235 x black-and-white negatives
235 x colour negatives
235 x colour contact prints
5 x diagrams showing photographic coverage

For details of all photogrammetry diagrams, record sheets, coordinate lists, and certificates, see HMG/UNESCO/JTFP 1995c.

Instrument Survey
6 x 1:50 elevation and section drawing sheets
12 x 1:50 plan drawing sheets
4 x 1:400 plan drawing sheets
1 x 1:500 plan drawing sheet
6 x 3.5" discs (FastCAD)

For a list of all instrument survey CAD file names and layer descriptions, see HMG/UNESCO/JTFP 1996b.

Deposition Arrangements
On behalf of HMG Nepal and the Japan Trust Fund Project, one set of drawings and digital data, together with all original photogrammetric negatives, diapositives and prints, have been deposited at UNESCO headquarters in Paris. A second set of drawings and digital data is available for delivery to Nepal and will be placed in the custody of the Department of Archaeology. It has been agreed that a third set of

drawings and digital data will held by LUAU for security reasons and in order to provide technical support as may be required in the future.

APPENDIX 4

Instrument Survey at the Palace of Fifty-Five Windows, Durbar Square, Bhaktapur

Introduction

The Durbar Square in Bhaktapur is one of the seven Monument Zones that make up the Kathmandu World Heritage Site. The Durbar itself, known as the Palace of Fifty-Five Windows, developed from the Mul Chowk, begun in the fourteenth century, and attained its fully developed form in the fifteenth century. The palace's most outstanding feature, the upper storey gallery of fifty-five windows, was added in 1697 by the Malla king Bhupatindra.

Durbar Square suffered severely in the 1934 earthquake and many of the buildings have been reconstructed. The palace collapsed almost completely, but the gallery and roof were rebuilt using the original timber components salvaged from the earthquake. During the reconstruction, the width of the previously projecting gallery was reduced and the wide overhanging roof modified.

In recent years, the outward movement of the main and front facade of the palace below the second floor gallery has increased, and one of the terracotta cornices broke loose during the last earthquake in 1988. In response to the Nepalese government, a conservation proposal was commissioned by the German Foreign Office from Gutschow, Hagmuller and Associates (GHA 1993). The proposal recommended a two-stage approach: stage 1 involving the structural consolidation of the palace in view of the endangered condition of the front facade; stage 2, the restoration of the gallery and roof to their original shape and material.

The GHA report is primarily concerned with the conservation measures required for the implementation of stage 1, the basic principal of the proposal being to secure the external and load-bearing brick walls in their present position by means of steel rod anchors tied firmly into reinforced concrete slabs replacing the present clay floors.

At the instigation of the Department of Archaeology, a number of the UNESCO consultants in Nepal as part of the Patan Durbar project, were asked to make further investigations at the Palace of Fifty-Five Windows. The purpose of these investigations was to review the measures set out by GHA (1993), and assess the suitability of the proposals in the light new structural analysis and the need to conform to UNESCO guidelines for conservation of cultural property and the conservation norms which the Department of Archaeology is seeking to establish. As part of this initiative, it was necessary to undertake new instrument survey and digital recording of the front facade. The following report is concerned with this aspect of the work alone.

Aims and Objectives

The aims and objectives of the survey exercise were to establish:

- accurate vertical cross-section profiles of the external and internal wall faces of the front facade in order to measure the outward deflection of the elevation
- accurate horizontal cross-section profiles of the external wall face of the front elevation at ground and upper levels in order to measure the displacement of the elevation in plan.

Survey Methodology

The primary task was the establishment of an accurate control network followed by the accurate three-dimensional measurement of detail points against the internal and external faces of the wall.

The survey control was established using a closed traverse, which extended out from an accurate base line established parallel to the face of the palace. Accurate control stations were established outside the building and also within internal ground and first floor rooms to enable the recording of the internal faces. Control observations were made from both faces of the instrument to reduce instrument error and the distances were read using an accurate measurement mode to a tripod mounted prism. The accuracy of the traverse was checked by comparing the original and final coordinates and any error is reduced by mathematical adjustment of the original coordinates. The control accuracy was found to be accurate to +- 3mm.

The three-dimensional detail points were surveyed by EDM tacheometry involving the measurement of horizontal/vertical angles and distances to a hand-held prism. The raw digital data was transferred to the logging computer and stored with descriptive coding information. The small prism was traced along vertical profile lines extending over all significant detail, both internally and externally and the location of each prism position was established in three dimensions using the total station. The accuracy of the data was typically in the order of +- 8mm. The main source of error was normally from incorrectly positioning the prism on the architectural detail; however, as far as possible, these errors were kept to a minimum.

On completion of the survey the survey data was transferred to the desk-top computer to enable the editing of the raw data. By running a special vertical rectification programme the XYZ data was rectified to two-dimensional XZ data and thus provided an accurate profile. The rectified data was then transferred to the CAD system for analysis.

Survey Results

The survey provided accurate profiles through the walls, revealing the extent of the lean and also the amount of separation between the external skins and the wall core. Three vertical profiles were generated, one at each end of the facade and the third in the middle. The internal face of the ground floor section of the wall was found to be perfectly vertical; however, there is a slight lean on the external face: about 2.17°-1.36° deviation from the vertical. Thus there is a significant difference in wall thickness between the base of the wall (0.84m thick) and the top of the ground floor (0.91m thick). Such a deviation would suggest that the lower section wall core and internal face are broadly *in situ* and intact, but that the outer skin of the wall appears to have separated from the wall core.

The first floor section by contrast shows a dramatic lean on both the internal and external faces, by up to 4.72° suggesting that the whole 0.74m thick wall has started to rotate from the vertical about the first/ground floor interface. The top of the first floor section deviates by as much as 150mm from the vertical axis. The difference between the wall thicknesses between the top and the base of the wall section is only 30mm, which suggests a much lower separation of the external skin by comparison with the ground floor.

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