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Remote sensing, GIS and electronic surveying: reconstructing the city plan and landscape of Roman Corinth

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26.1 Introduction

Since 1988 a research team from the Mediterranean Section of The University Museum of the University of Pennsylvania has been involved in making a computerised architectural and topographical survey of the Roman colony of Corinth. Known as the Corinth Computer Project, the field work has been carried out under the auspices of the Corinth Excavations of the American School of Classical Studies at Athens, Dr. Charles K. Williams, II, Director[1]. Although the excavations at Corinth by the American School have been underway for almost a century, aspects of the study of the layout of the Roman colony have remained incomplete due to the size and complexity of the site as well as its complicated history. Our original objectives were to study the nature of the city planning process during the Roman period at Corinth; to gain a more precise idea of the order of accuracy of the Roman surveyor; and to create a highly accurate, computer generated map of the ancient city whereby one could discriminate between and study the successive chronological phases of the city's development[2].

It is important to acknowledge that during the course of the six years of the project to date, the nature of the research has evolved from a fairly straightforward consideration of the location and orientation of the excavated roadways of the Roman colony, to a more complex topographical and architectural consideration of various elements of the colony, including the rural as well as the urban aspects of planning and settlement. The project now utilizes a number of methodologies, simultaneously, in the overall study of the ancient city. At the time of writing, one aspect of the project is a regional landscape study of a portion of the Corinthia, with the city of Roman Corinth as the focus. Another aspect of the project is the effort to include information from the city of

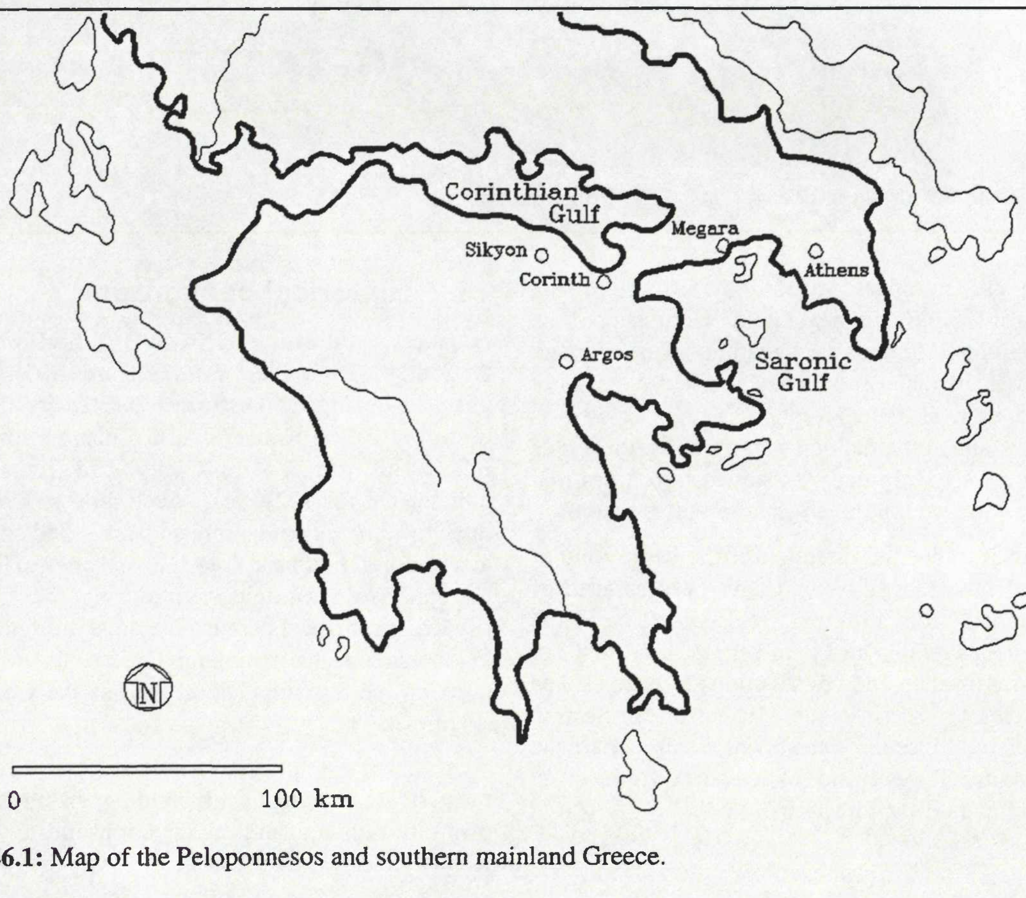

Figure 26.1: Map of the Peloponnesos and southern mainland Greece.

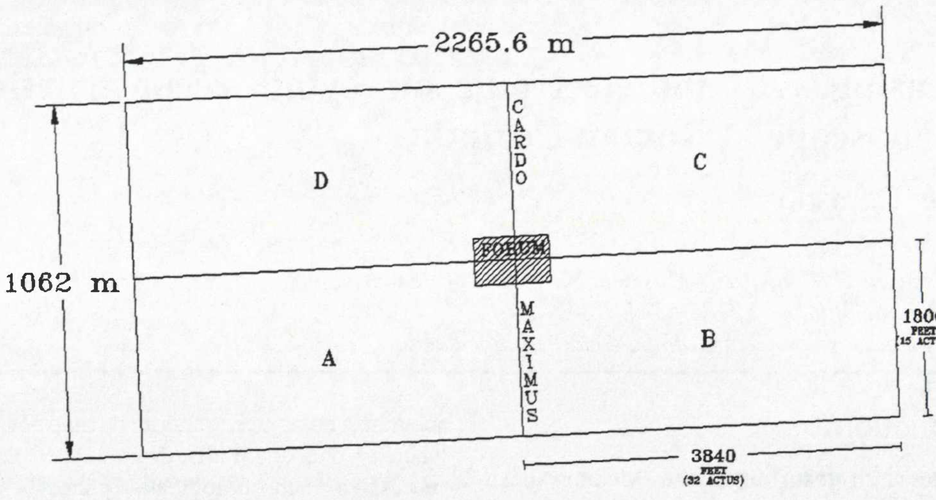

Figure 25.2: Schematic drawing of the four quadrants of the urban colony, labelled A,B,C,D, each of which is 32×15 actus, with centrally located forum and cardo maximus.

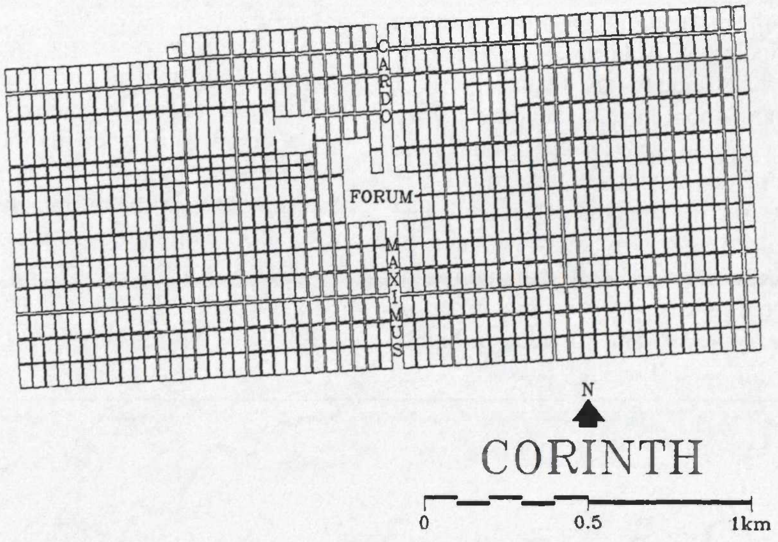

Figure 25.3: Restored 'drawing board' plan of the Roman colony.

Corinth from chronological periods other than Roman, specifically Archaic and Classical Greek, Hellenistic, Late Roman, Byzantine, Frankish, Venetian, Turkish and modern. As will be discussed briefly below, by means of low level and high altitude air photography, as well as satellite images and some balloon photographs, the limits of the project have been greatly expanded into areas that had not been considered in the original research design.

This project is under the direction of the senior author of this paper. In the past six years I have been assisted by numerous students from different fields of study at the University of Pennsylvania and I am very grateful to all of them for their assistance and contributions[3]. Osama Tolba has been a Research Intern in the Mediterranean Section of The University Museum since 1992, assigned to the Corinth Computer Project and with special interest in remote sensing and GIS applications.

25.2 Historical background

Founded by Julius Caesar in 44 BC, the Roman colony of Corinth, *Colonia Laus Iulia Corinthiensis* was laid out virtually on top of the former Greek city that had been destroyed by the Roman consul Lucius Mummius in 146 BC The former Greek city had remained largely uninhabited for 102 years. According to literary sources, the Greek male population had been killed and the women and children had been sold into slavery[4]. The location of Corinth had been important during the Greek period, situated near the Isthmus, the land bridge between the Peloponnesos and mainland Greece, as well as having ports on the Saronic Gulf as well as the Corinthian Gulf (Figure 25.1).

In the new foundation of 44 BC the Romans utilized many of the existing Greek buildings in the design of their own city although the organization and city plan of the Roman colony was different than its Greek predecessor.

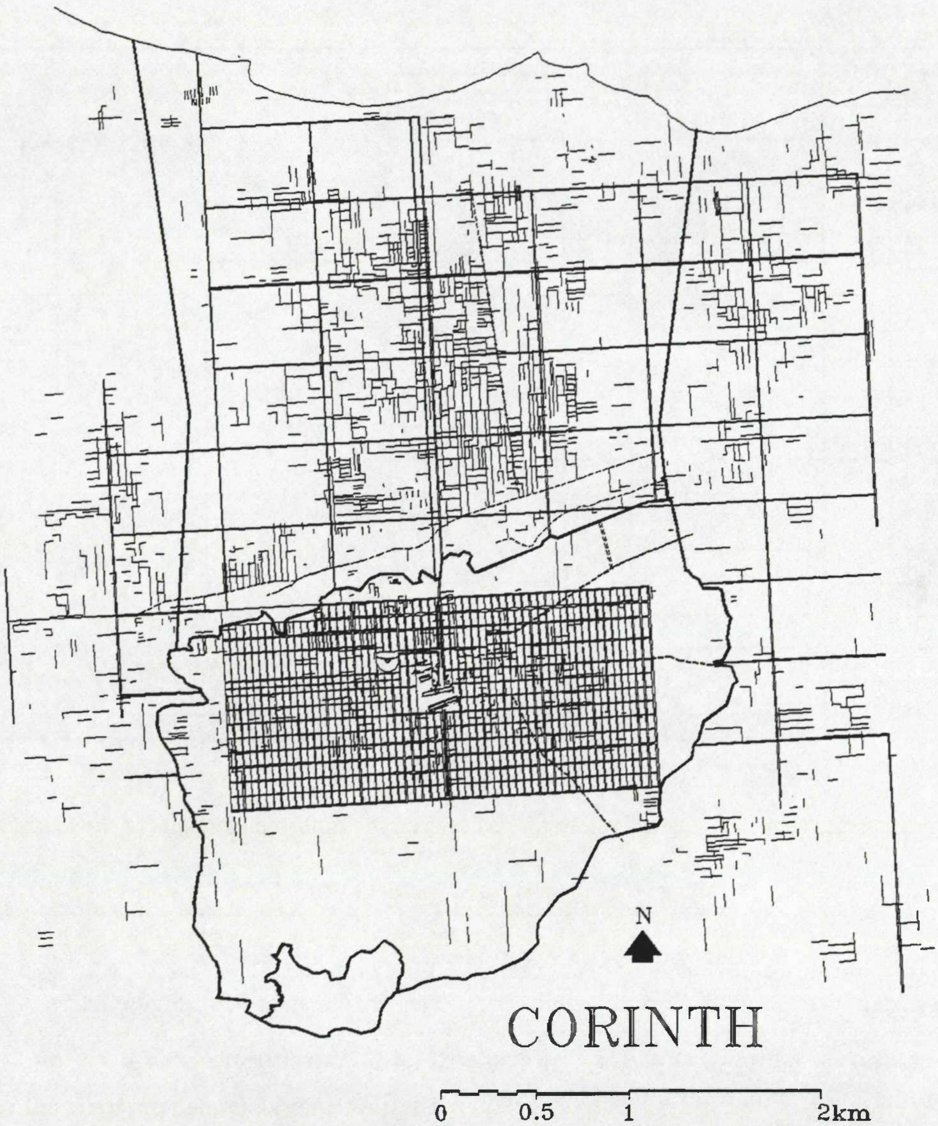

Figure 25.4: The evidence for Roman centuriation of 44 B.C. from all sources of information, including the city grid within the Greek circuit walls, and the rural 16×12 actus system of centuriation.

At this time, at the end of the sixth year of the project, we have succeeded in defining a detailed plan of the urban Roman colony as well as having evidence for what is likely to be several phases of Roman agricultural land division, centuriation, of the *territorium* surrounding the colony.

25.3 Project result summary

25.3.1 Urban Colony

Based on the combined evidence of the site survey as well as information from air photographs and 1:2000 topography maps, which will be discussed below, we know that the Roman colonial plan was based on four quadrants (centuries), each 32×15 *actus* or 240 *iugera* (Figure 25.2). The colony was laid out *per strigas* with a total of 29 *cardines* and 29 one actus wide *insulae* in each of the four centuries. There would likely have been six *decumani* per century (Figure 25.3). The original plan for the urban colony existed almost entirely within the Greek circuit walls of the city.

It is likely that the *forum* of the colony was originally designed to occupy an area of 24 square actus or 12 iugera, comprising the topographical center of the colony. Some of this space was already occupied by significant Greek and Hellenistic structures, including the South Stoa. We also know now that probably simultaneous with the laying out of the urban colony, the Roman *agrimensores*, land surveyors, measured out rural land surrounding the colony for agricultural purposes.

25.3.2 Territorium

As a part of our work to date, a widespread pattern of centuriation has been identified of 16×12 *actus*, possibly parts of a larger 16×24 system to the north of the colony as far as the Corinthian Gulf (Figure 25.4). In fact, several systems of centuriation have been identified in and

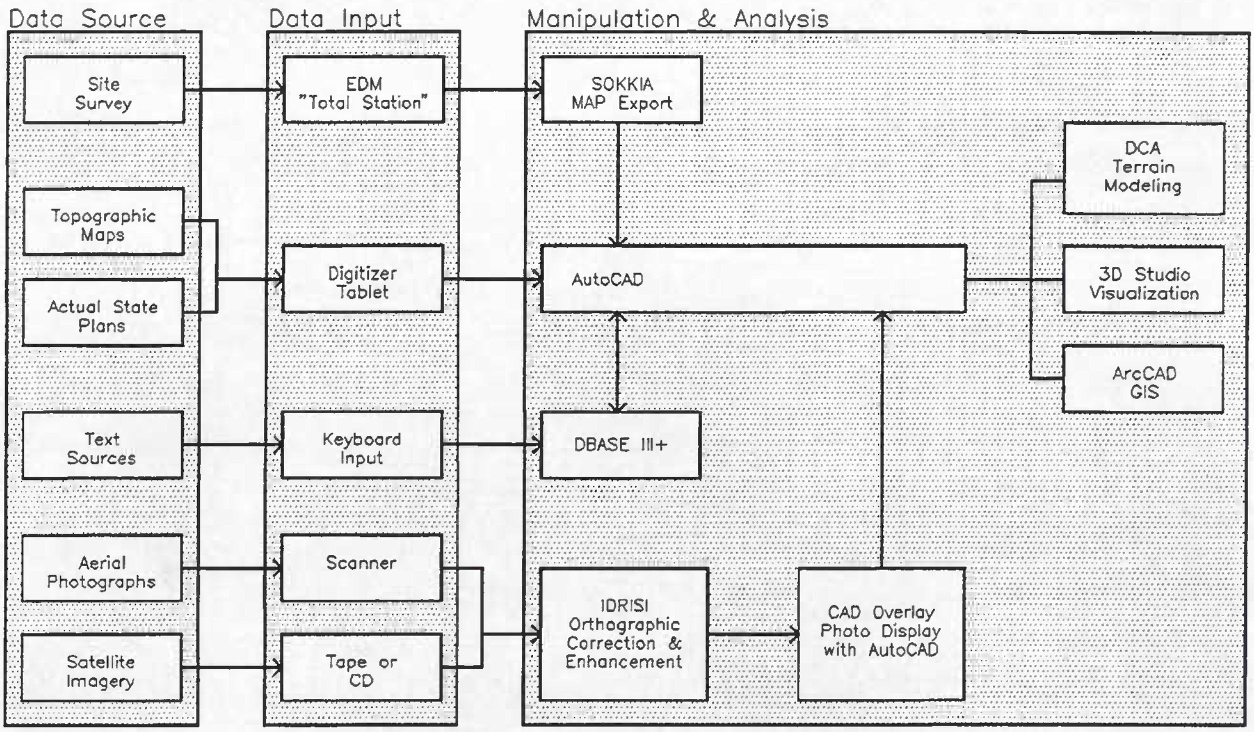

Figure 25.5: Schematic diagram showing the relationship between the multiple elements of the Corinth Computer Project.

around Corinth as a result of this study. For years, scholars had suggested that Roman Corinth could not have been founded on an agrarian base since no centuriation was present in the area[5]. Since this is now proven not to be the case, a new examination of the evidence is presently underway.

25.4 Methodology

25.4.1 Computer hardware

The project, both in Corinth as well as in Philadelphia, employs fast IBM type personal computers (Zeos 486 machines, 66 MHz.) with hard disk capacities up to over 1 gigabyte. Because each of the topographical drawings can be so large, up to 12 megabytes each, the large disk capacity is a necessity. The computers currently have 16 MB RAM. The air photographs as well as the satellite imagery are stored permanently on optical disks with 1 GB capacities. Compact disk players have also proved useful for acquiring SPOT satellite data, discussed below under Satellite Imagery. The input devices are of two types. First, digitiser tablets are used for tracing maps and plans in AutoCAD drawing format. These are relatively small tablets, no larger than 12×18 inches (Summasketch and Hitachi). Secondly, a flatbed scanner (Hewlett-Packard ScanJet IIc) with an area of 8.5×14 inches is used to digitise air photographs and smaller drawings. Plots may be made by means of an E-size eight pen plotter (CalComp 1025) as well as a laser printer (Hewlett-Packard LaserJet IIIp) (Figure 25.5).

25.4.2 Computer software

The principle computer program utilised in this project and the vehicle with which the other computer programs work is AutoCAD (AutoDESK, Inc). All maps and drawings are digitised and managed using AutoCAD; we currently use versions 11 and 12. In addition, the field survey data is directly translated from the hand-held computer to the personal computer, from survey software (Sokkia MAP) to AutoCAD using the DXF format. Air photographs are scanned and viewed behind the drawings using CAD Overlay GSX (Image Systems Technology Inc.) which allows us to enhance image contrast and trace selected features. We are also currently using IDRISI (Clark University) for various GIS functions. For instance, IDRISI is employed to rectify the air photographs and to maintain the raster geographic database, which includes SPOT and LANDSAT satellite images as well as a variety of aerial and balloon photographs. IDRISI also includes limited capabilities to import AutoCAD's 'poly-lines', which we used to translate the elevation data in order to generate a digital terrain model (see below under simulations). We have used 3D Studio (AutoDESK, Inc.) to generate renderings and animations of the digital terrain model of the topographical region under study.

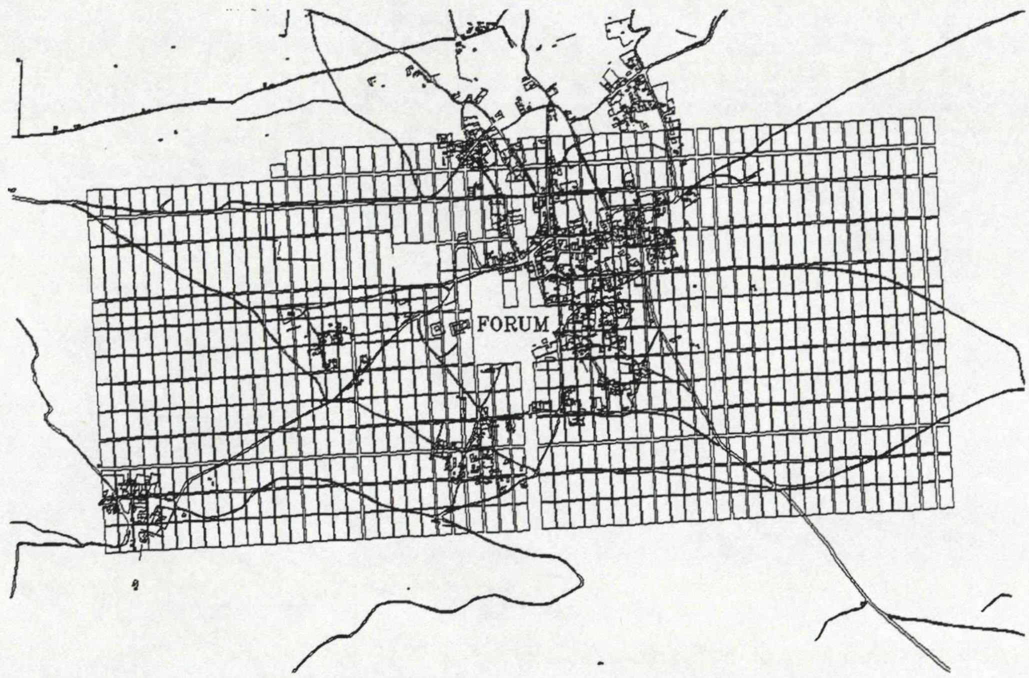

Figure 25.6: 'Drawing board' plan of the Roman colony superimposed on the map of the modern village, including village roads (1963).

Figure 25.7: 'Drawing board' plan of the colony superimposed on the modern village, village roadways and modern field lines and property lines.

25.4.3 Field survey

During the past six summers, the physical survey of virtually all of the above-ground monuments and structures of the site of Ancient Corinth has been accomplished with a Sokkia electronic total station linked to a compatible hand-held computer for data storage and retrieval[6]. The visible monuments of the city and surrounding area have been surveyed and recorded by the director of the project aided by small teams of students. The intent of the survey has not been to create an actual-state drawing of the buildings and monuments of the city, but rather to make measurements in three dimensions of the exact location and orientation of the diagnostic elements of the monuments and structures of the city. Each day the survey data from the hand-held computer is transferred to a PC in the field house where it is edited and the drawings are created in the Sokkia Survey program MAP, and then exported in a DXF file to AutoCAD. Each of the individual survey jobs from all

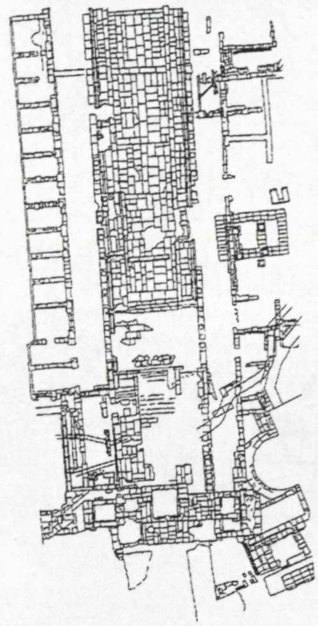

Figure 25.8: Actual-state drawing of the Roman Lechaion Road as it leaves the Roman forum to the north.

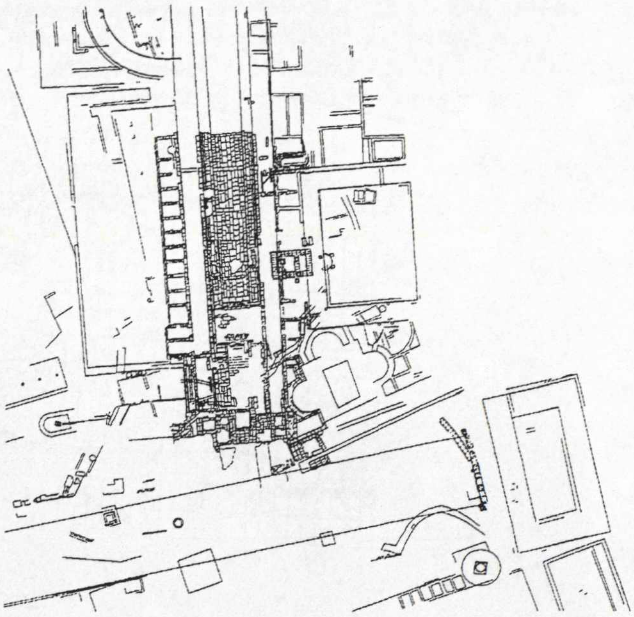

Figure 25.9: Actual-state drawing of the Lechaion Road (same as Figure 25.8) as it is scaled to fit the survey drawing of the same area.

around the ancient city has created a separate drawing. All of the season drawings have created the city survey for each summer and all the summer survey drawings have created the cumulative project drawing.

The framework for the entire study has been the precise survey and measurement of 16 different roadways of the Roman city, excavated at different times during the course of the Corinth excavations. These 16 roadways that provide the basis for the reconstruction of the regular colonial city plan have laid the groundwork for the further study of the urban and rural planning and organization of Roman Corinth. From the beginning we have tied our work into the local Greek geodetic coordinate system so that all of our site surveys, as well as the actual-state drawings, notebook drawings, photographs, and satellite images as well as the digitized topographical maps, are geographically registered with the same system. Using as a base the four permanent Greek geodetic markers that are within the range of our survey instrument, we have over the past six years installed a series of secondary reference points which we use in our day to day work.

25.4.4 Topographical maps

Sixteen 1:2000 topographical maps from the Greek Geodetic Survey have been digitised to create the topographical foundation for the immediate area of Roman Corinth, roughly 35 square kilometres. The topographical maps include information such as modern roads, paths, ledges, property lines, field lines, houses, as well as topographical contours. It has been noted, for instance, that several modern village roads still have as their orientation the Roman roads of the colony (Figure 25.6). In addition some modern house and lot lines still respect the ancient Roman insulae and, in the areas surrounding the city, it has been noted that aspects of the modern field boundaries still reflect vestiges of the ancient Roman land division, with some lots retaining the original colonial orientation as well as maintaining widths of 1 Roman *actus* of 120 Roman feet (Figure 25.7). As will be discussed below, from the contour lines of the topographical maps, it has also been possible to utilise other engineering and GIS programs to create digital terrain models of aspects of the site, general three dimensional computer images of the landscape as well as to run three dimensional GIS functions. (See below, Simulations).

25.4.5 Actual-state plans

As the Corinth Excavations of the American School of Classical Studies at Athens have been underway since 1896 there exist a great number of excavations from in and around the Greek and Roman cities. Each excavation has produced an actual-state plan or a stone for stone drawing. One of our current objectives is to digitise many of these actual-state plans and to scale or rotate them, where necessary, to fit the precisely surveyed monuments. In this way it has been possible to recreate, literally block for block, the excavated remains of the successive phases of the city. Each of the actual-state drawings is retained as an independent entity in our drawing archive and then can be imported into the larger survey drawing, when needed. In this way, a very precise physical site survey is combined with accurate stone for stone actual-state drawings of the site. There exist now over 50 actual-state plans that have been carefully digitised, representing different structures and buildings throughout the ancient city (Figures 25.8 and 25.9). The goal will be to complete the stone for stone drawings of the entire excavated city. Needless to say, the availability of the actual-state drawings from a computer aids a great deal to the ongoing study of the successive cities of Corinth.

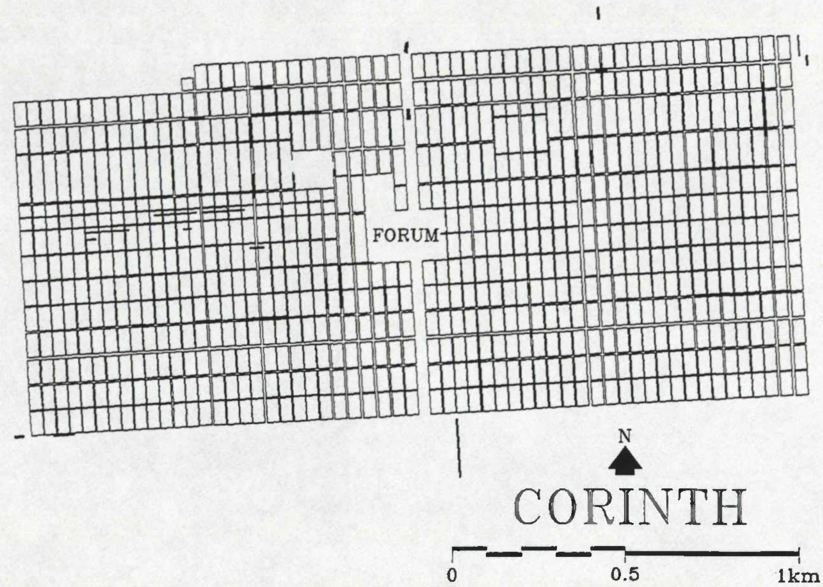

Figure 25.10: The evidence from air photographs relating to the Roman city grid high-lighted against the 'drawing board' plan of the colony.

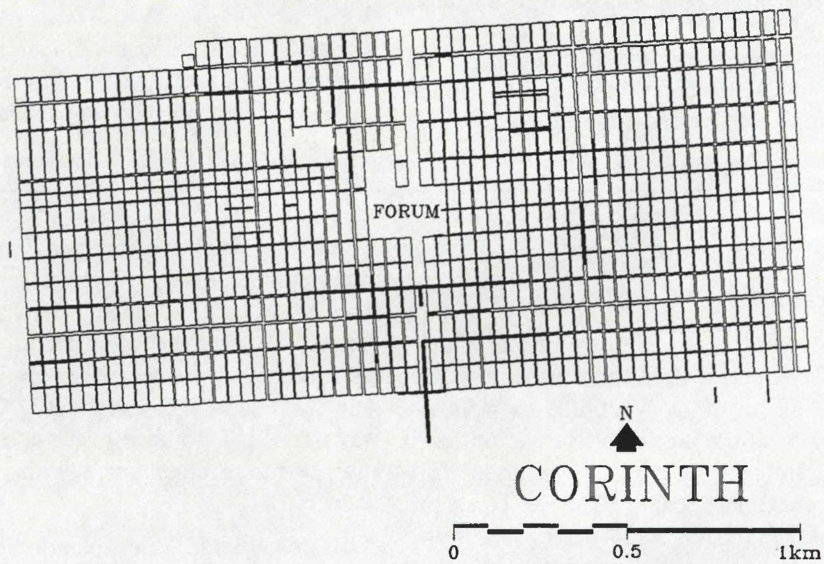

Figure 25.11: The evidence from modern roadways, property lines and field lines relating to the Roman city grid high-lighted against the 'drawing board' plan of the colony.

25.4.6 Database

We have begun to create a database (using dBase III+) of all of the identifiable structures and monuments included in the map of the successive ancient cities of Corinth. At the moment the database includes information about the name of the building or structure, its date of construction and up to three bibliographic references to the publication. We are currently exploring different ways of linking the database with the various completed AutoCAD drawings. For example, we have associated most of the forum buildings' drawing entities (lines) with their respective dates and references through AutoCAD's SQL extension. The objective was to automate the generation of consecutive period plans of the Roman city. However, this task has been hindered by the difficulties of assigning a discrete number to the date of construction, primarily because these dates are usually specified in ranges. Additionally, most buildings in the forum were subjected to modification and addition, and it was not always clear when the buildings were abandoned.

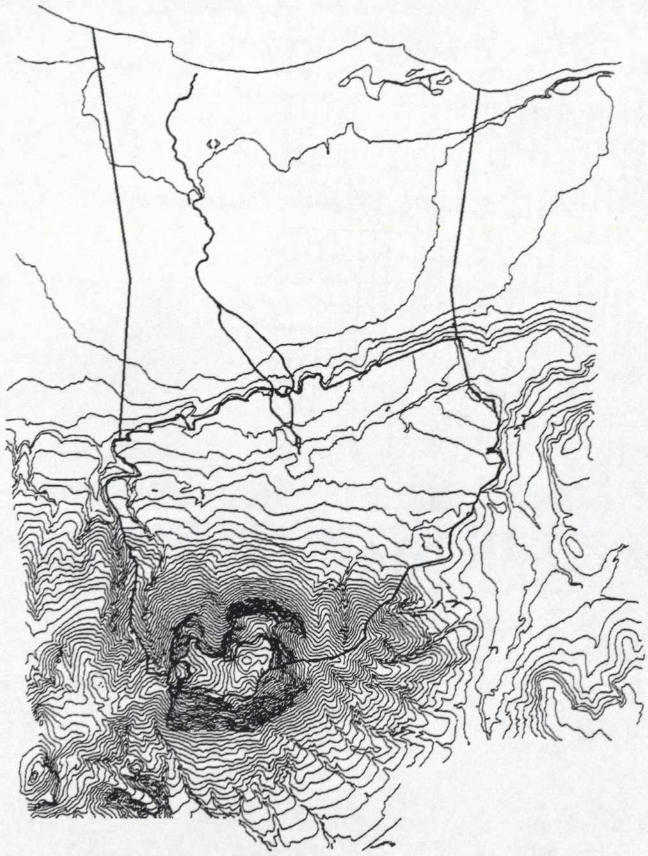

Figure 25.12: A vector-based topographical map of Corinth showing contours at 10 metre intervals, and illustrating the least slope path from the Greek agora to the Gulf of Corinth.

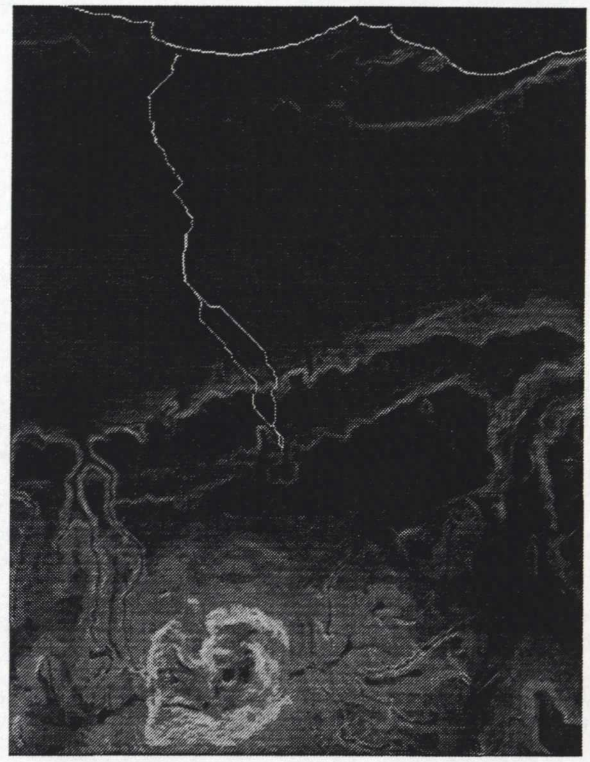

Figure 25.13: A raster-based map of the same area, illustrating the least slope path from the Greek agora to the Gulf of Corinth. (Lighter shades of gray indicate steeper slopes).

25.5 Remote sensing

25.5.1 Air photographs

We have used several types of air photographs to study Greek and Roman city planning and land organisation in the Corinthia. There exist both low altitude as well as high altitude photographs of the area as well as some very low level balloon photographs. Low altitude air photographs, at an approximate scale of 1:6000, taken in 1963 by the Hellenic Air Force, correspond very well with the 1:2000 topographical maps, which were made in the same year using the air survey[7]. The air photographs have been useful for a number of reasons. Shadows and vegetation or soil markings high-lighting unexcavated underground features in the landscape, such as roads, ditches or structures are visible. These features can be helpful when put together with other forms of information, such as the surveyed and excavated roadways (Figures 25.10 and 25.11).

Before performing any analysis of any of the photographs it is necessary to first rectify its geometry in calibration with the existing maps and surveyed data. Therefore, each photograph is scanned at the resolution of 400 dpi (dots per inch) using a desktop flatbed scanner (Hewlett-Packard ScanJet IIc) and rectified using the resampling program included in the IDRISI package, (discussed below under GIS applications). The control points needed for this operation are taken from the topographical maps. The corners of buildings or the intersection of field boundaries have proven to be most precise. Once the photograph has been successfully rectified, it is possible to display it as a backdrop to the AutoCAD drawings using CAD Overlay GSX. In this way one is able to trace over the crop and soil marks and study them in conjunction with other surveyed or map data.

High altitude air photographs at a scale of approximately 1:37,500, taken in 1987 by the Greek Army Mapping Service, have helped us to understand the overall pattern of the roads and field boundaries in the larger terrain surrounding Ancient Corinth. Control points necessary to rectify these photographs are taken from the topographical maps or satellite images, where we do not have a detailed map of the entire area covered by the photograph.

A series of low level balloon photographs at an approximate scale of 1:1750 taken by Dr. and Mrs. J. Wilson Meyers in 1986 have greatly assisted in the identification of details in the landscape at the Roman harbor of Lechaeum. What may be an earlier (pre-44 BC) Roman agrimensorial survey of the harbor, possibly to be associated with the Lex Agraria of 111 BC or alternatively an aborted colonization attempt of the late second century BC, has been noted.

26.5.2 Satellite imagery

During 1993 we have added two satellite images of the Corinthia to our data set; a panchromatic scene from SPOT, the French satellite agency, and a multi-spectral scene from LANDSAT, the US satellite company. The image from SPOT is a single spectral band scene, gray scale, acquired in May 1991 at the resolution of ten metres (per pixel) and covers an area of 60×60 kilometres. The LANDSAT scene, on the other hand, is an EOSAT archive image acquired in June 1987 with a resolution of 28.5 metres. It covers a larger area of 185×170 kilometres and is a Thematic Mapper (TM) scene with seven coloured spectral bands that can be displayed individually or in combination with others. The different nature of the two satellite images has dictated very different uses for them. One can see roads and agricultural field boundaries clearly on the SPOT image and, therefore, we are using it to analyse the patterns in the landscape along the southern coast of the Corinthian Gulf between Corinth and Sikyon. We have been able to identify uniform grid systems conforming to the practice of Roman centuriation. This particular study has been carried out using AutoCAD and CAD Overlay GSX by measuring road and field spacing on the image and testing against various hypothetical grids of Roman land division. The grid systems are created in AutoCAD and can be superimposed on the satellite image using CAD Overlay GSX. The preliminary success of this investigation has lead us to purchase an additional SPOT image, a 15 minute by 15 minute window to the east of Corinth so that we may in the future study the land organisation to Corinth's second port of Cenchreai on the Saronic Gulf.

The LANDSAT image is of coarser resolution (28 metres per pixel vs. 10 metres) and, therefore, is better suited to studying land use pattern, ground cover and geological interpretation. In the future we may consider these well known applications of the LANDSAT multi-spectral scene in this study.

The SPOT satellite image came in the BIL (band interleaved by line) format, which was imported into the various kinds of software that we use, e.g., IDRISI. The original SPOT image was shipped to us on a series of twenty-two 3.5 inch diskettes which proved to be somewhat of a challenge to download and decompress. The more recent 15 minute window from SPOT was shipped on a compact disk, which greatly facilitated its use. The total size of the larger SPOT image is approximately 50 MB while the total size of the LANDSAT image is approximately 360 MB. These large files are stored on an auxiliary optical disk (Panasonic Optical Disk Drive LF-7010) and parts of the scenes have been clipped for processing and analysis as necessary. The LANDSAT scene came on mainframe 'computer compatible tapes' (CCT), which necessitated the use of university facilities to download the files onto our PC's. This was accomplished by utilizing a 250 MB tape backup system (Colorado Jumbo Trakker).

26.6 GIS applications

The principal GIS program utilised to date has been IDRISI which was developed by the Graduate School of Geography at Clark University. IDRISI is a grid-based geographic information and image processing system whose purpose is to provide professional-level geographic research tools at a low cost. The program comes with excellent documentation, is easy to use, and one can buy, very inexpensively, a student manual. It is a raster based system and it includes over 100 program modules of which we have used a number, including those that handle database management, geographical analysis, image processing as well as statistical analysis.

We have utilized a number of features of IDRISI in our study of the landscape to the north of the Roman colony. For instance, by utilizing the elevation element of the topographical maps of the study area we have asked the IDRISI program to find the path of least effort between the proposed location of the Greek agora or city center of Corinth, with any point on the south coast of the Corinthian Gulf. The result is a line or lines that the program has created that represents the easiest route to follow to get to the shoreline (Figures 26.12 and 26.13). This information, together with other data, regarding possible Greek land organization and orientation, has suggested the location of the Greek port of Lechaion to be in a different location than that of the Roman port some 1–2 kilometres to the west[8].

We have also been using ArcCAD (ESRI, Inc.) in the study of the various agricultural field systems visible in the landscape to the north of the Roman city of Corinth. Since ArcCAD provides a link to existing AutoCAD drawings we could create ArcCAD coverages from selected CAD-generated maps. However, our maps had been digitized with great attention to detail and appearance, which led to two problems when we began the conversion to ArcCAD. First, there were too many vertices in the polygons defining the boundaries of properties and roads, more than the maximum allowed by ArcCAD. Second, while the lines looked right, they were not always continuous or closed. It is possible to correct these problems if we can afford the time overhead. Another application of ArcCAD in the Corinth project involves using its querying capabilities to separate lines, in a map or aerial photo, into groups having similar orientation. We were able to write a small AutoLISP program that calculates the angle of a line segment and stores it in a field in the respective database. We can then use ArcCAD or ArcView to high-light, display, or generate a new map of the group of lines which angle falls within a certain specified range (e.g., the angle corresponding to the Roman colony).

26.7 Simulations

Using the Digital Terrain Model component of Softdesk, Inc., a civil engineering program, we have been successful in transferring the elevation data (contour lines) from the series of 1:2000 topographical maps to create a simulated

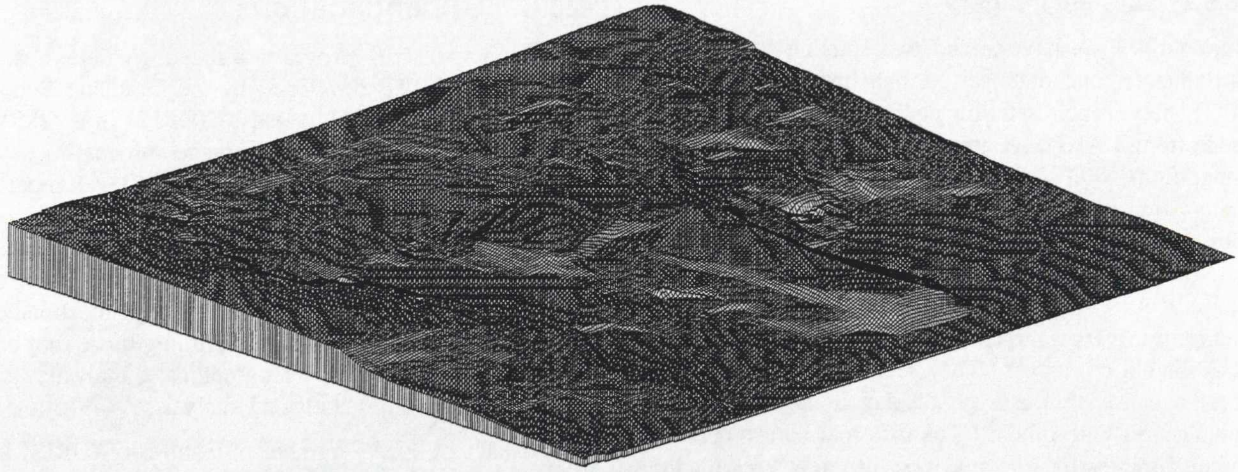

Figure 25.14: Digital terrain model illustrating a portion of the ancient city of Corinth and including the artificially constructed modern excavation dump, looking southwest.

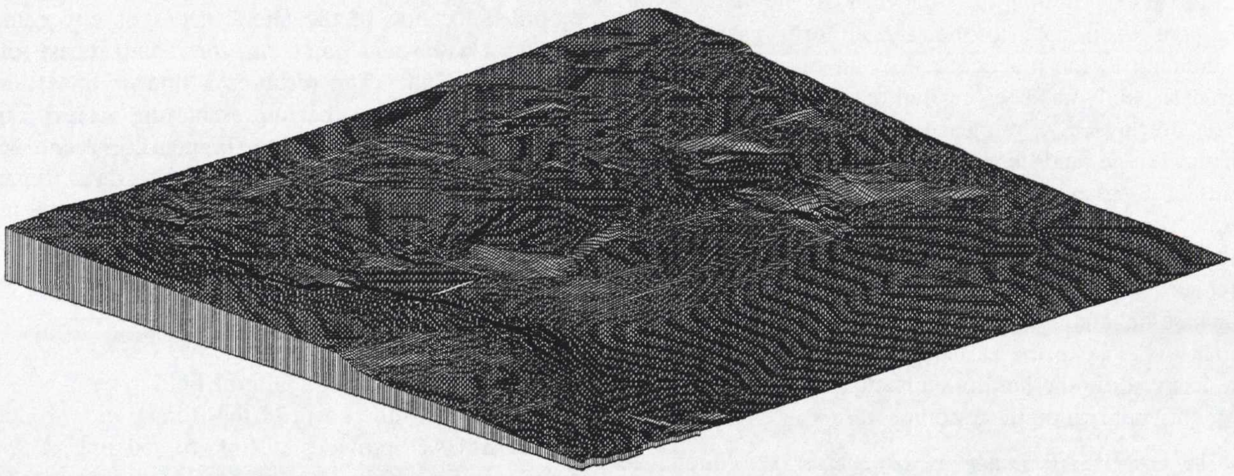

Figure 25.15: Digital terrain model of the same area as Fig. 14 above, eliminating the excavation dump.

landscape in three dimensions. We have done this for the entire area of the topographical maps, ca. 35 square kilometres, creating a large DTM based on a 20 metre square grid. For smaller DTM's we have chosen a square grid based on 5 metre segments.

An example of such a smaller DTM was created to assist us in the understanding of the topography of the ancient Greek and Roman city. In the late nineteenth and early twentieth centuries, during the early years of the excavations at Corinth, a huge excavation dump created an artificial peninsula of land that extended from Temple Hill out to the north. The total length of the artificial mound is approximately 200 metres and its maximum height approximately 15 metres. In the modern day, the excavation dump literally obscures a clear view of the nature of the topography of the ancient landscape. We created two DTM's to study the location. First we built a DTM from the contours of the topography map, reflecting the appearance of the area in the modern day (Figure 25.14). Then we connected the contour lines to the east and west of the artificial peninsula of land to create what may be a reasonable model of the landscape before the excavation dump was created (Figure 25.15). It is our hope to be able to study the modified landscape and DTM in order to better understand the ancient city.

We have used 3D Studio to generate renderings and animations of the digital terrain model of the 35 square kilometre area of Corinth, some including the colonial Roman grid and the Greek city walls and the area from Akrocorinth in the south to the Gulf of Corinth in the north. These images have assisted in the recreation of the landscape and are especially useful in demonstrating gross topographical features (Figure 25.16). Another kind of simulation is created simply by showing the contour lines of the topographical map from a distant three dimensional viewpoint (Figure 25.17). These visualization techniques, however, have so far had little influence on the outcome of our research serving mainly as presentation and communication tools.

25.8 Order of accuracy

We have been very much aware that the order of accuracy of each of these techniques varies greatly from one another. For instance, the architectural and topographical

Figure 25.16: Rendering, created from a digital terrain model, of a large portion of the study area illustrating Akrocorinth to the left and Penteskouphi to the right, looking southwest. The shoreline of the Gulf of Corinth is in the foreground.

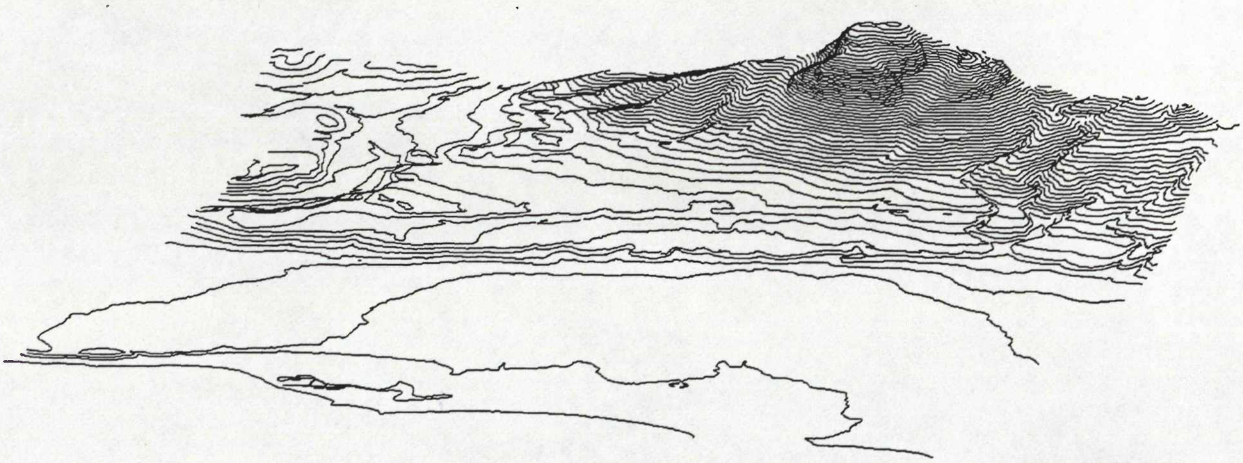

Figure 26.17: Three-dimensional view of Akrocorinth and Penteskouphi from the north.

survey by means of electronic total station produces a very high order of accuracy, usually within millimetres or centimetres. The topographical maps are generally accurate to 1-2 metres as are the air photographs from which they were made. The satellite images, of course, have far less accuracy. The pixel size in SPOT panchromatic image is 10 metres and in LANDSAT multi-spectral image is 28 metres. We are using each of these techniques for differing purposes. The backbone of the entire project is produced by the electronic total station survey of the roadways and structures of the ancient city. The other kinds of evidence is used in conjunction with the survey and is calibrated with respect to it.

Acknowledgements

The Corinth Computer Project was initiated by the Corinth Excavations of the American School of Classical Studies at Athens under the Direction of Dr. Charles K. Williams, II. We thank Dr. Williams and Dr. Nancy Bookidis, Assistant Director, for friendly and generous assistance in all aspects of this undertaking.

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Notes

1. During each summer season of the survey, the project has been carried out as a part of the architectural aspect of the Spring Training Seasons of the Corinth Excavations. The annual reports of the Corinth Excavations appear in *Hesperia*, the Journal of the American School of Classical Studies at Athens.
2. A brief summary of the methodology of the Corinth Computer Project is discussed in Romano (1989).
3. A preliminary report of an aspect of the results of the project has appeared in Romano (1993).
4. For a general discussion of the history of Corinth during this time period, see Wiseman (1979).
5. The latest interpretation of this type is Engels (1990).
6. A detailed discussion of the computerized field survey has appeared as Romano and Schoenbrun (1993)
7. Air photographs do not have a scale which is consistent all over the image due to lens distortion and terrain variation.
8. For a summary of the evidence see Romano (1994).

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