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Raymond Lemaire Internationaal Centrum voor Monumentenzorg
Kasteelpark Arenberg 01, B3001 Heverlee (Leuven) - België

THE USE OF THREE-DIMENSIONAL TECHNIQUES OF DOCUMENTATION AND DISSEMINATION IN STUDYING BUILT HERITAGE

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Proefschrift voorgedragen tot het behalen van het doctoraat in de toegepaste wetenschappen door:

Mario Santana Quintero

Leuven, 10 januari 2003

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To Maite, Oriana, and Aiona
To Mariolga, Edgar and Luisa

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A B S T R A C T

THE USE OF THREE-DIMENSIONAL TECHNIQUES OF DOCUMENTATION AND DISSEMINATION IN STUDYING BUILT HERITAGE

'Article 2: The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage'.

'Article 16: in all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published' (Venice Charter, 1964)[1].

In the study of built heritage, the preparation of a '*precise documentation*' dataset of measured representations is of fundamental importance. This dataset can contribute to '*create a permanent record*' of its past and present. As well as, to the '*analytical report*' of its current condition and understanding of its authenticity, both of which encourage its future conservation.

The metric or measured set of representations could be seen as the most important and reliable source of information remaining of a monument that is either destroyed by natural phenomenon or by human action.

'Recording is the capture of information which describes the physical configuration, condition and use of monuments, groups of buildings and sites, at points in time, and it is an essential part of the conservation process' (Principles for the recording of monuments, groups of buildings and sites 1996, Sofia)[2].

This research presents a framework for the effective use and selection of three-dimensional metric survey tools in capturing and presenting '*information which describes the physical configuration, condition'* (geometry and texture)*, 'and use'* of a historic building's fabric.

The work presented here is based, on the one hand, the research is based on a series of important and recent publications dealing with the application of electronic and image-based metric survey tools in three-dimensional recording of monuments.

On the other hand, reports on five first-hand case studies, where recording and dissemination tools have been used for preparing the foundation 'dataset' of measured representations are presented: al-Baleed archaeological park (Sultanate of Oman), roman theatre of Jebleh (Republic of Syria), training experiences, castle of Arenberg (Belgium), and emergency recording of the Mussalah complex Herat and the Minaret Jam.

'Article 2: The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage'.

'Article 16: in all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published' (Venice Charter, 1964)[1].

In het onderzoek naar architecturaal erfgoed zijn representaties, gebaseerd op het samenbrengen van gedetailleerde opmetingen van fundamenteel belang. Deze dataset kan bijdragen tot de creatie van een permanent record over het verleden en de toekomst van dit architecturale erfgoed, evenals tot de analytische beoordeling van de huidige toestand en tot een begrip van de authenticiteit. Dit alles bevordert de toekomstige conservatie van het architecturale erfgoed.

In zekere zin kunnen deze opgemeten representaties beschouwd worden als de belangrijkste en meest betrouwbare bron van informatie die overblijft van monumenten die door natuurfenomenen of menselijke acties werden verwoest.

'Recording is the capture of information which describes the physical configuration, condition and use of monuments, groups of buildings and sites, at points in time, and it is an essential part of the conservation process' (Principles for the recording of monuments, groups of buildings and sites 1996, Sofia)[2].

Dit onderzoek levert een kader voor het effectieve gebruik en de selectie van driedimensionele metrische opmetingsinstrumenten voor het bekomen en presenteren van 'information which describes the physical configuration, condiction' (geometrie en textuur) 'and use' van historische gebouwen.

In het hier gepresenteerde werk wordt enerzijds gebruik gemaakt van recente en prominente publicaties met betrekking tot de toepassing van elektronische en beeldverwerkende metrische instrumenten voor het opmeten van het architecturale erfgoed. Anderzijds is het werk gebaseerd op nieuwe casestudies waarbij hoger genoemde technieken werden gebruikt: al-Baleed archeologisch park (Sultanaat van Oman), Romeins theater the Jebleh (Syrië), training ervaring, Arenbergkasteel (België), en de urgentie opmetingen voor het Mussalah complex en de minaret Jam (Afghanistan).

Notes:

[1] ICOMOS 'Venice Charter 1964', Petzet, M. Ziesemer, J. Ed. 'International Charters for Conservation and Restoration', Monuments and Sites I ICOMOS, Munich 2001. Pp. 13-14

[2] ICOMOS 'Principles for the recording of monuments, groups of buildings and sites, Sofia 1996', Petzet, M. Ziesemer, J. Ed. 'International Charters for Conservation and Restoration', Monuments and Sites I ICOMOS, Munich 2001. Pp. 107.

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INTRODUCTION

INTRODUCTION

The essence of this research deals with the acquisition, understanding, and communication of knowledge, specifically in the use of recording techniques in capturing the geometry and texture of built heritage for the production of measured representations, which will be used as the foundation for understanding the '*structure's construction history and the planning and building process; dating of individual building phases; reconstruction of a building's function, how it originally appeared and how it was altered; and identification of building technology issues and possible damages*' (Schuller, M., p.7, 2002)[1].



Figure 01: Great Buddha, Bamiyan Valley, Afghanistan, photograph Jul. 2002, actual state of conservation after explosion. Author.

The measured plans, being digital and/or plotted in paper not only contribute to the creation of a permanent record of its past and present, but to the analytical assessment of its current condition and understanding of its authenticity, both of which encourage its future conservation.

In a sense the metric or measured set of representations, which is the product of the documentation process could be seen as the most important and reliable source of information remaining of a monument that is either destroyed by natural phenomenon or by human action. This statement is illustrated by the vast amount of documentation material available for the pre-Islamic figures of the Buddhas in Bamyan[2], Afghanistan, which were destroyed by the Taliban in March 2001 (see figure 01-02).

These historical records along with current efforts for understanding the actual state of the remaining material will be used for preparing and implementing an emergency conservation plan with immediate effect to safeguard the monument, which is still suffering from last year's explosions. They can also support eventually 'Anastylosis' study that can help to partially reconstruct the statues using the remaining material[3].

In addition, the work presented here is inspired by the need to safeguard built heritage. It is based, on the one hand on the contribution

of real field examples, where recording and dissemination tools have been used for preparing the foundation 'dataset' of measured representations.

Furthermore, this 'dataset' (see clarification, p.) aims to set the foundations for preparing other specialized assessments, dealing with mapping and understanding the history, weathering processes, structural behaviour, and other studies to understand the authenticity and actual state of conservation of a subject and its context.

Subsequently, the results of these assessments or 'core data' (see clarifications) will be used to prepare an 'Analytical report', which can be used in conservation projects, as well as for preparing historical researches or to present the information to a broader audience in museums and expositions.

These examples were developed using methods and tools adapted to the needs of the specific area and locally available resources, emphasising in the use of procedures with optimal and sustainable attributes and which have in turn been effectively used in developing countries.

At the same time, this research is based on a series of important and recent publications dealing with the application of Electronic and Image-Based Metric Survey Instruments for the documentation of the geometry and texture of built heritage.

CRITICAL STATEMENTS IN STUDYING BUILT HERITAGE

Nowadays many research groups are creating impressive visualizations of built heritage items whilst tending to forget the fundamental principle that adequate recording leads to protection. In certain cases large amounts of money are invested without first considering the purposes and aims of a project at hand. Subsequently large amounts of records are produced, which may end up stored in an archival room and forgotten.

Moreover, many of these initiatives tend to concentrate on objects that have already been carefully studied and are already well protected. While in other parts of the world endangered monuments exist that have hardly been studied or on which local initiatives are working with very limited resources.

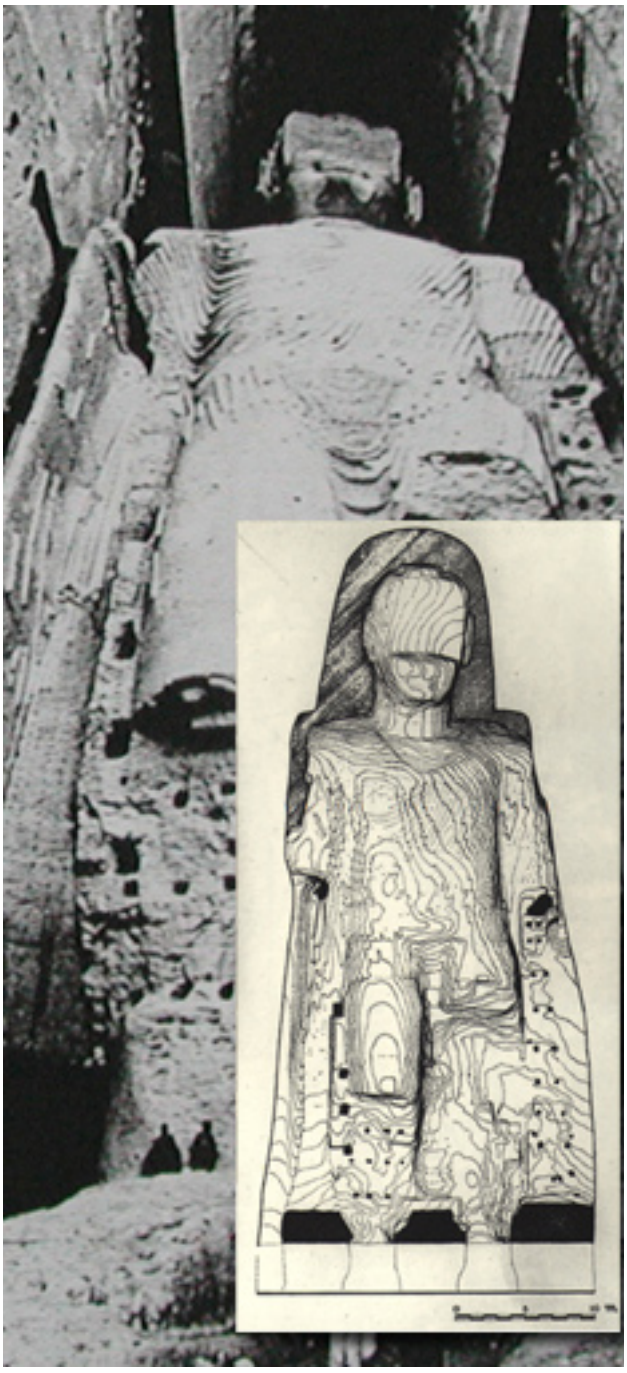

Figure 02: Great Buddha, Bamiyan Valley, Afghanistan, Photogrammetric Survey, M.D.A.F.A., 1928[5].

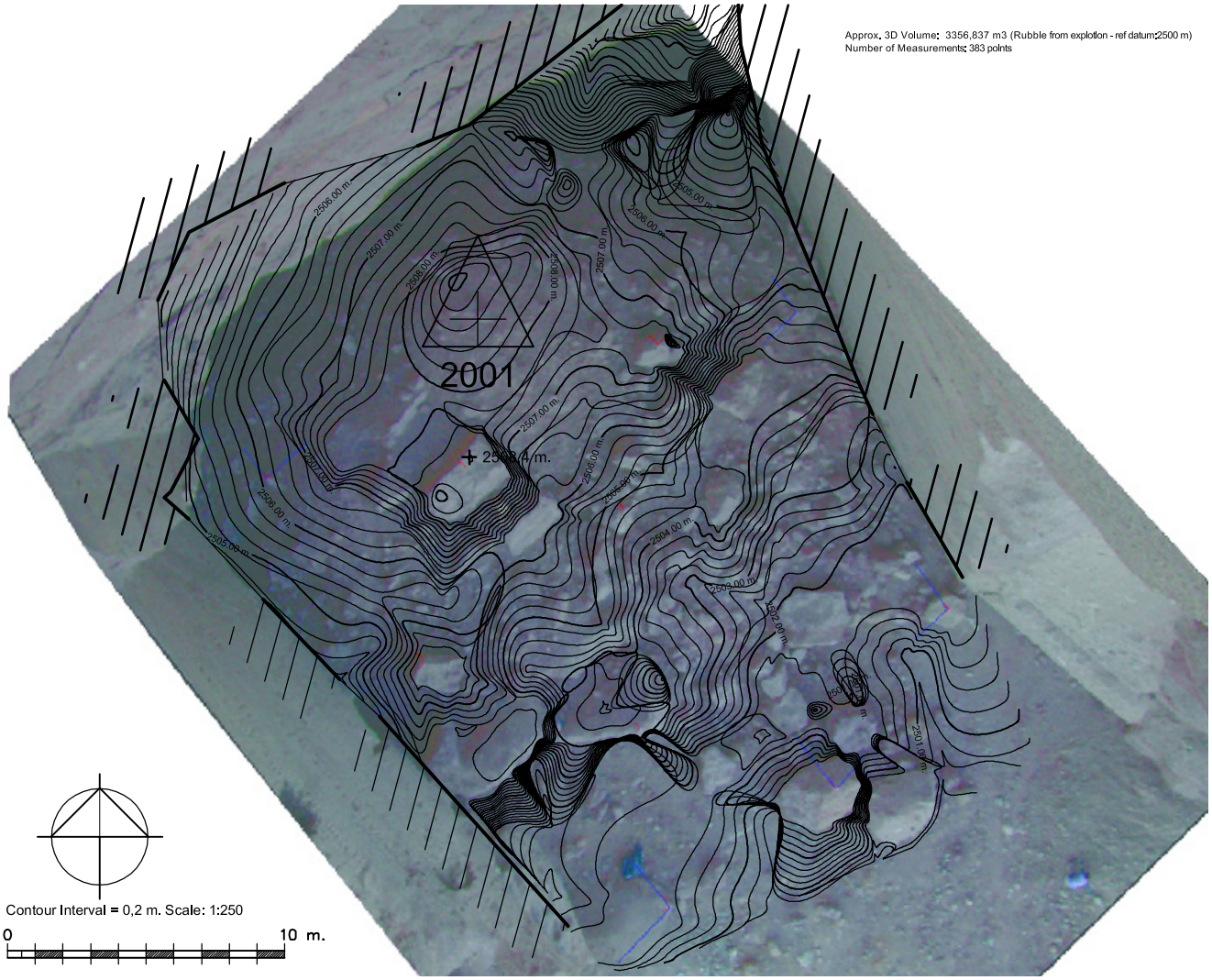

Figure 03: Great Buddha, Bamiyan Valley, EDM total station survey to prepare a digital terrain model of the remains of the explosion, this map will be used to predict the approximated amount of material to be studied and classified. ICOMOS-UNESCO Mission to Afghanistan 2002. Author.

It seems that there is an incorrect assumption among several specialists in the field of recording heritage about the exact meaning of the acquisition and virtualised architectural representations of the geometry and texture of historic structures. As a result their fundamental role to carry the 'true-to-scale' measured information as a foundation for the preparation of assessments aimed at performing interventions that can ensure their protection, or indeed to spread the knowledge embedded in their history. In addition many scientists use documentation cases for purely political reasons or as a case study to test a recent development.

The natural increasing '*human impetus to understand and transmit an understanding of buildings and structures, whether for intellectual curiosity or pleasure*' (Cox, J., 1996, p. 119)[4] could endanger the conservation of historic buildings due to the uncontrolled exploitation of these historical sites.

Moreover, several of these representations are lacking in consistency and quality. The resulting digital and/or paper representations for the desired dissemination tool, produce impressive and often misleading computer graphic visualizations that temper the real values of what is relevant or necessary in studying monument.

It is important to mention that three-dimensional representations have always been a powerful tool for the scientific analysis and synthesis of studying built heritage.

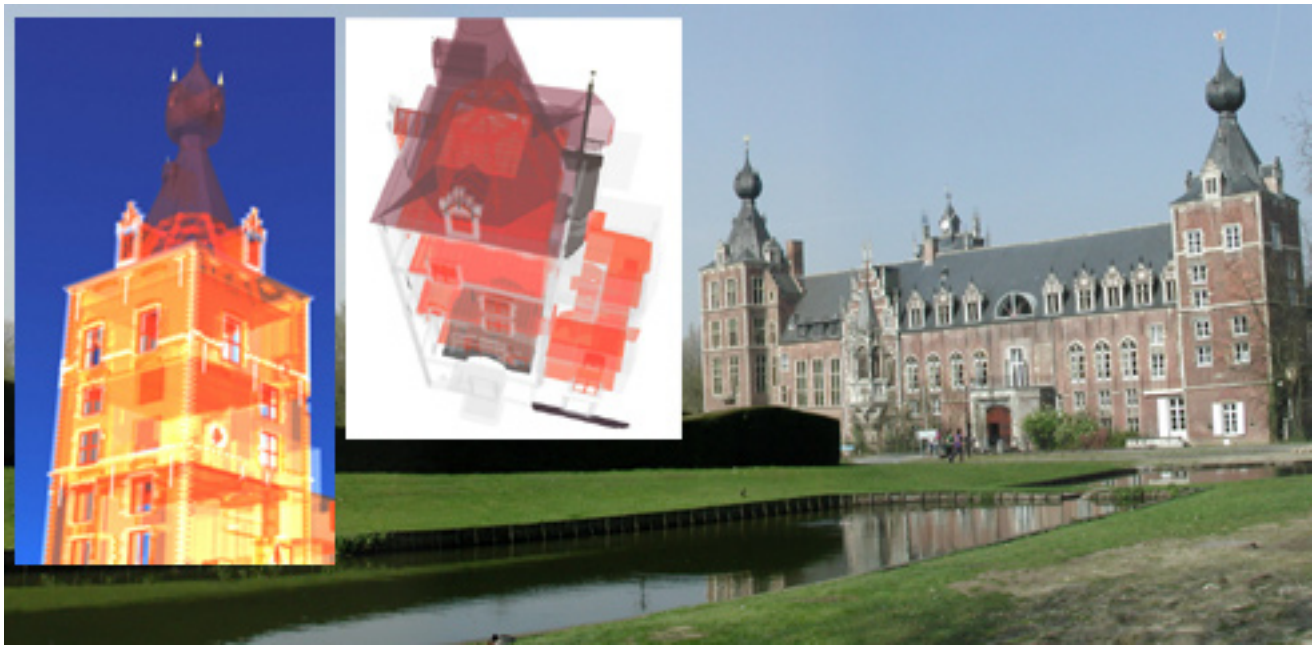

Figure 04: a CADR Three-dimensional model based on hand-measurements, East Tower, Castle of Arenberg, Leuven - Belgium. Author.

Today, more advanced three-dimensional techniques for acquisition, processing, and visualization enable results that conventional use of hand-drafted representations would never be able to produce in a short timeframe. In recent times, their adequate adaptation and application in the field of measuring buildings for conservation has been a matter for discussion.

On the other hand, many conservation researchers are sceptical of the potential of these more advanced three-dimensional capturing systems to fully and correctly simulate, as well as manage metric information used in the study of historic building. It '*seems that a detailed model is too large for current computing systems but it is also beyond current human ability to determine*' (Van Scoy, F., 2000)[5].

The use of 3D visualization tools for the purpose of built heritage, however, could be justified as a perception method '*for seeing the unseen, it enriches the process of scientific discovery and fosters profound and unexpected insight*' (Domik G., 2000, p.17)[6].

These tools can enhance the understanding of built heritage by their advantage in the acquisition of information: they make it possible to prepare a hypothesis based on the collection of very large amounts of measured data. A second advantage is the discovery of new historical phenomena through the correlation, combination and exploration of visual (3D Geometric-Texture models) and non-visual data (Historical documentary sources).

On the other hand, if the virtualised representations are not properly referenced and explained, they can lead to misunderstanding the values of the monument: a common error is only focusing on the preparation of a photo-realistic representation that everybody likes, which really lacks enough scientific evidence to support it.

The nature of studying heritage deals with understanding the interpretation of '*complex aesthetic and functional cultural questions, such as beliefs, convictions and emotions*' in this respect '*Science helps but should not create absolute meaning*'.

Thus, in documenting cultural heritage, the processes of capturing, processing, and finally visualization should be considered as instruments for aiding those responsible



Figure 05: measuring the Stupa 01, Satdhara, India during a workshop organized by the RWTH Aachen in the use of Reflectorless Electronic Distance Measurements Total Station device and CADR applications with the support of UNESCO. An example of the optimal and sustainable use of advanced techniques of documentation in developing countries. Author.

for making decisions to assess the future of a historic landmark.

This work aims to tackle the critical issues of three-dimensional registration and representation techniques in documenting built heritage as based on the grounds of more conventional (or traditional) tools of recording. These techniques can help in preparing a digital and/or printed information system by combining different sources of information in studying monuments, whilst emphasising the Measured Dataset of the geometry and texture of the fabric and context.

This research is based on reviewing and applying basic principle set down in international charters dealing with the protection of built heritage, and concepts used in the application of conventional hand-survey recording techniques in documentation. The purpose is to approach this electronic and image-based registration instruments using similar guidelines and to review their potential constraints, as well as their advantages in specific fields of research and action, such as conservation works (standing structures and archaeological sites), Historical publications, and broader-audience presentations (Museums and specialist expositions).

In addition, this investigation aims to present a methodology and a tool for the researcher in the selection of an adequate combination of instruments and applications for recording, disseminating, and managing measured information about the subject and its context.

Secondly, a methodology will be developed that can respond to the specific objective (scopes and target audiences), different activities or tasks, and the associated level of quality required in the desired Measured Three-dimensional dataset.

IMPORTANT CLARIFICATIONS IN THE FRAMEWORK OF THIS RESEARCH

Computer Aided Drafting (CADR): this research replaces the definition of ‘D’ for Design with Drafting, dealing with the use of these type of applications to in recording and representing the actual state of the subject instead of a conceptual tool to prepare a measured representation of an architectural design.

Measured Dataset: the result of the metric survey study of the subject and its context, consisting of a set of analogue (plotted) and digital measured representations, including orthogonal projections (sections, plan sections, etc) and three-dimensional models.

Core data: the result of the thematic assessments prepared of the subject using the Metric survey study as a mapping instrument to acquire and record the actual state of conservation (weathering forms,

structural analysis, etc), and historical chronology (historical documentary research, stratification, etc); as well as, other assessments adapted to the specific needs and situation of the subject. These 'core data' is used to prepare the Analytical and critical report.

Analytical and critical report: term used in the Chapter of Venice, in this research it is described as the resulting product of the Non-thematic (Metric Survey) and thematic studies (Condition assessment, historical assessment and other assessments required) aimed at accessing and analysing the information embedded in the subject and context and relevant for its conservation.

Geometry: this concept is widely used in constructing and modelling the subject in Computer Aided Drafting; it describes 'the properties of CADR objects that determine their shape, such as their construction in terms of point, lines and angle values' (Szalapaj, P., 2001, p. 221)[7].

In addition, this concept describes the current irregular shape of the subject.

Texture: this term is associated to the fabric of the subject, indicating the colour resulting from the type of construction material and weathering forms present.

For further consultation, it is recommended to review the Glossary (see appendix), which explains to a greater extent Computer-Aided Drafting, conservation, and other relevant concepts used in this research.

RESEARCH FRAMEWORK

Part 1: The Contribution

Chapter I: 'Fundamentals in Studying Built heritage: the role of Documentation' reviews a number of important principles and presents the current state of the art in relation to studying historic buildings and the application of recent developments in Electronic and Image-based recording tools.

This part is based on the review of basic concepts dealing with the study and protection of monuments, such as charters and other statements in the study of built heritage and the use of documentation methods.

The description of the State of the art has been developed by direct field experience with documentation projects. As well as, by most recent literature from conferences, journals and books. It is important to mention that recent literature deals with this part more effectively than the older one due to the rapid advance of digital applications and electronic instruments.

Chapter II: "Documentation of Built Heritage: Authenticity as the concept defining the Measured 'Dataset'" depicts the requirements of a measured 'Dataset' of representations in the context of recording Built Heritage and its relation with the concept of Authenticity to evaluate the relevance of the subject making it justifiable for protection.

Moreover, it analyses the different types of sources providing information about a historic building and setting.

Chapter III: ''Preparing the Measured Dataset: Bauforschung and the 'State of the Art' Metric Survey Techniques': this part presents an overview of the existing Metric Survey instruments available for recording the geometry and texture of the building's fabric and context, grouping them using a conventional classification, as well as applications for processing and preparing representations.

The evaluation of these techniques has been based on Bauforschung or Building Archaeology principals, first-hand case-studies and recent literature.

Moreover, a part of this chapter is devoted for

emerging tools, instruments and applications that have been developed recently, explaining their advantages and attempts to adapt them to the needs of recording of architectural heritage for its protection.

Chapter IV: 'The Methodology: documentation and dissemination of Built Heritage: The Non-Thematic Measured Dataset: Metric Survey' combines concepts studied in Chapter I and their application in the fieldwork, presenting a methodology that provides alternatives to the critical issues exposed in Chapter I when dealing with the current state of the art.

Moreover, the Measured 'Dataset', as a non-thematic set of metric information is defined in order to make clear the use of this type of study in understanding of the building and its context. The issues dealing with the quality required of this set for historic buildings is also described.

This methodology is divided in three phases of work: Data-Collection, Data-Analysis and Data-Synthesis.

Data-Collection describes the definition of the purpose and needs of the Measured representations, and the evaluation of internal and external variables in the selection of the techniques for acquiring the measured data and further organization and classification.
Data-Analysis deals with the processing through the modelling of the classified information.
Data-Synthesis deals with the preparation of the output, related to tools used for preparing digital or plotted information systems to communicate the data gathered and processed in previous phases.

Chapter V: 'Applications: Framework for the selection of Metric Survey Tools for 3D Documentation and Dissemination of Built Heritage' is based on the methodology described in chapter IV.

Furthermore, this part presents a number of applications in studying built heritage, providing guidelines for the Metric Survey Study in the selection of three-dimensional documentation and dissemination tools.

In this respect, a Metric Survey Study is part of the 'core data', which involves the process of collection and mapping of the sources describing the monument's geometry and texture that can yield information to carry out other studies, such as Spatial-Typological analysis, condition assessment, historical assessment, and other relevant investigations to the analysis.

This research leads to the following applications, which are classified in:

- Historical Research of Built Heritage
- Conservation of Built Heritage
- Broader audience presentation

Furthermore, other applications, such as Monitoring and inventorying of Built Heritage are briefly mentioned for referential purposes.

Chapter VI: 'Epilogue: research tendencies and perspectives' finally, this part summarizes the innovations and ideas developed in current research. Collecting information from each trend and presenting recommendations for the future, as well as to reviewing research perspectives in this field and other related applications.

Appendix: Glossary of terms

Part II: The Practice: Case Studies:

Chapter I: Case Study: Conservation and Broader Audience presentation of Built Heritage: al-Baleed Archaeological Park, Sultanate of Oman.

Presenting an example of the General Use and specific use (Great Mosque, Courtyard House, Citadel, and City wall) of Metric Survey Methods, such as EDM Point Collection and Plane Parallel Rectified Photography.

Chapter II: Case Study: Conservation of Built Heritage: Preparing a proposal for the Restoration of the Roman Theatre of Jebleh, Republic of Syria.

Presenting examples in the preparation of the Metric Survey Study dataset for condition and historical assessments using the REDM Point Collection method.

Chapter III: Case Study: Experiences in Training Architectural-Conservators in the use of Metric Survey Methods: Master Students at the R. Lemaire International Centre for Conservation, Almaty Workshop (Republic of Kazakhstan), Sanchi Workshop (India), and Université d'été in Chinon (France).

This case study describes the incorporation of digital three-dimensional recording techniques in short- and long-term educational programmes, destined for international and interdisciplinary group of professionals active in conservation and restoration of built heritage.

The incorporation of these techniques consists in the combination of a theoretical approach and a number of practical exercises.

The theoretical approach consists of providing knowledge about principles in recording and the presentation of recent tools in the documentation of the built heritage.

Furthermore, the practicał framework of the training programmes deals with applying the concepts and principles explained in the theoretical course in a real examples of conservation projects.

Chapter IV: Case study: Historical research of built heritage: Castle or Arenberg, Leuven, Belgium

This example explains the use of measured representations in the preparation of a Three-dimensional model to explain the different construction phases of the building and the advantages and disadvantages that this technique has.

Chapter V: Case study: The use of metric survey tools in urgent recording: Mussalah Complex Site in Herat and Minaret Jam, Afghanistan.

This case study illustrates the use of metric survey tools for the documentation of monuments with possible imminent risk of damage. Where the tools are used to measured important features that can yield important information about the stability of the structure.

Notes:

[1] Schuller, M. 'Building Archaeology' Monuments and Sites VII ICOMOS, Munich 2002. P. 7.
[2] The Valley of Bamyan and the wall of the Buddhas, Afghanistan: The Valley of Bamyan, lying north-west of Kabul, is one of the most famous sites in Afghanistan for its spectacular statues of Buddha and the numerous grotto-sanctuaries dug in the rock. Mastropietro, M. Ed.'Archaeology or: conservation and maintenance; Restoration and Beyond Architecture from conservation to conversion Projects and works by Andrea Bruno (1960-1995), Edizione Lybra Immagne, Milano 1996, p. 27.
[3] This is based on discussion among the participants of the ICOMOS-UNESCO Mission carried out in July 2002 to Bamiyan.
[4] Cox, J.'Assessment and Recording: A practitioner's view; Concerning buildings: studies in honour of Sir Bernard Feilden' Ed. S. Marks & B. Feilden, Architectural press Oxford, Oxford 1996.
[5] Van Scoy, F.; Documentation of Virtualized Architecture: A Proposal; Proceedings VSMM2000 Conference, Gifu 2000.
[6] Domik, G. 'Do We Need Formal Education in Visualization' IEEE Computer Graphics and Applications; IEEE Computer Society, Vol 20/4, Jul.-Aug. 2000.
[5]M.D.A.F.A., vol II, Paris-Bruxelles, 1928 ; Amirian, G. 'I Buddha Colossali e il Complesso Monastico di Bamyan' 'ANA IKH 32, Dec. 2001, Alinea, Milan, p. 67.
[7] Szalapaj, P. 'CAD Principles for Architectural Design: analytical aproaches to computational representation of architectural form' Architectural Press, Oxford 2001, p.221.

PART ONE

THE CONTRIBUTION

CHAPTER I

FUNDAMENTALS IN STUDYING BUILT HERITAGE: **THE ROLE OF DOCUMENTATION**

CHAPTER I:

FUNDAMENTALS IN STUDYING BUILT HERITAGE: THE ROLE OF DOCUMENTATION

Studying Built heritage involves the participation of different experts in gathering and selecting information from a variety of sources. This acquisition process is called documentation, which is based on investigating the present and past of the subject and its context, interpreting and understanding its attributes.



Figure 06: Conventional Hand-Survey techniques in preparing a measured representation of an architectural element for the understanding of the remains. Roman Theatre of Jebleh, Syria Author

Moreover, historic buildings are great sources of information for the analysis of architecture, which can serve for the training of professionals dealing with the conception of new structures and conservation of monuments.

> *'In effect a historical building represents the most complete full-size experimental laboratory that one can conceive. Where a real building is concerned structural systems, building materials, connections, human interventions and naturally occurring phenomena' (Croci, G., 2000, p. 191)[1].*

This first part intends to immerse the reader in a series of important concepts related to the study of built heritage. These have been carefully selected from different institutions working in the protection of monuments.

In this sense, the challenge of this chapter is to present, develop, and summarize important fundamentals as tools for the adequate interpretation of the knowledge offered by the subject.

In addition, simultaneously to the review of such fundamentals, it is important to devote some time to clarifying the need, objectives and process required to prepare adequate studies of historic buildings.

On the other hand, this chapter provides a critical overview of the current state of the art regarding the use of documentation tools in the study of monuments, emphasizing in those recording tools for preparing

three-dimensional geometric and texture representations of the object's fabric.

1.1 FUNDAMENTALS IN STUDYING BUILT HERITAGE

Fundamentals developed for the conservation of built heritage are very important tools. They provide instruments and foundations to interpret the significance and attributes embedded in historic buildings, and to make 'critical analysis' in the interventions required for their protection. These concepts have been developed through the participation of interdisciplinary groups of experts and are based on many years of experience.

In contrast to the universal aplication of these principals, it is of paramount importance to take into consideration local, regional, and international legal and scientific framework before starting to study a historic building in a particular place.

1.1.1 THE SIGNIFICANCE OF BUILT HERITAGE

> *'The preservation of a monumental heritage not as ranks of silent stone archives but as the still eloquent, fertile and living expression of those who came before us* ***confers an irreplaceable and incomparable dimension*** *to the constructed space in which contemporaries live, offering them a poetic dimension without equal' (Lemaire, R. 1996, p. 54)*[2]

Architectural heritage is a unique and irreplaceable source of information about our ancestors and the events of history that have shaped the present, and as a result, the future.

Subsequently, historic buildings and sites are important in our social context and identity. They are similar to evidences of our past that have made the region what it is today, as well as examples of a specific artistic movements or vernacular expressions.

1.1.1.1 A UNIQUE AND IRREPLACEABLE SOURCE

> 'Historic buildings are irreplaceable' (ICOMOS 1990, p. 1)[3] *sources of information, they are valuable works that represent (Charter of Venice Art 3)*[4] *specific events that have occurred in the past.*

Moreover, they have an 'original significance (e.g. "first of its kind")' that expresses its contemporary uniqueness (e.g. "last surveying example"' Fitch, J.M. 2000: p.89)[5].



Figure 07: an electronic instrument to record the building and context geometry of an archaeological site, starting with the documentation of the landscape. Otrar Archaeological site, Kazakhstan. Author

Therefore, the process of recording built heritage plays a vital role in any conservation project. It is the foundation that enables one to understand the importance of the subject and to investigate the processes required to interpret the values embedded in it; as well as to understand the actual state or condition of conservation enabling to make adequate assessments of the interventions needed to implement an effective conservation.

1.1.1.2 REINFORCEMENT OF CULTURAL AND SOCIAL IDENTITY

A Cultural symbol provides identity to a region and pride to its people increasing their knowledge of, and popular interest in cultural heritage (Thornes, R., 1994: p.89)[6].

'Stalin demanded the implementation of the idea – if you relieve the nation of its monuments, then the nation will disapear in some time' (Kukharenko, R., 2001)[7]

The former Soviet nations are a clear example of the revival of national identity based on the search for and care of monuments that aim to renew religious and social ideology.

1.1.2 OBJECTIVES IN STUDYING ARCHITECTURAL HERITAGE

> *'Why do we make records of old buildings? The answer must surely be to document our understanding of the building(s) in question. An understanding of the importance of an historic site or structure is followed by its conservation, which results in further understanding, and, thus, further conservation' (Stocker, D., 1994: pp. 2-3)[8].*

The main objective of studying built heritage is to enhance the knowledge of the subject. This knowledge can be used for its protection, perhaps through the use of publications devoted to providing information about the relevance of the building and its context, and/or carrying out interventions for its conservation.

1.1.2.1 Create a permanent record

A permanent record capable of being communicated from generation to generation that could be available in case of destruction and/or alterations.

1.1.2.2 Protection leading to Conservation

Documentation is a strategic tool for identification, interpretation, and classification of monuments enhancing the understanding of the subject. The resulting record enables the implementation of interventions required to provide protection and therefore its conservation.

1.1.2.3 Promotion leading to Participation

The heightening of knowledge about a historic building can be seen as a tool for



Figure 08: The building's fabric and a workman, confronting study and tradition. Remains of a medieval Islamic Citadel, archaeological site al-Baleed, Sultanate of Oman

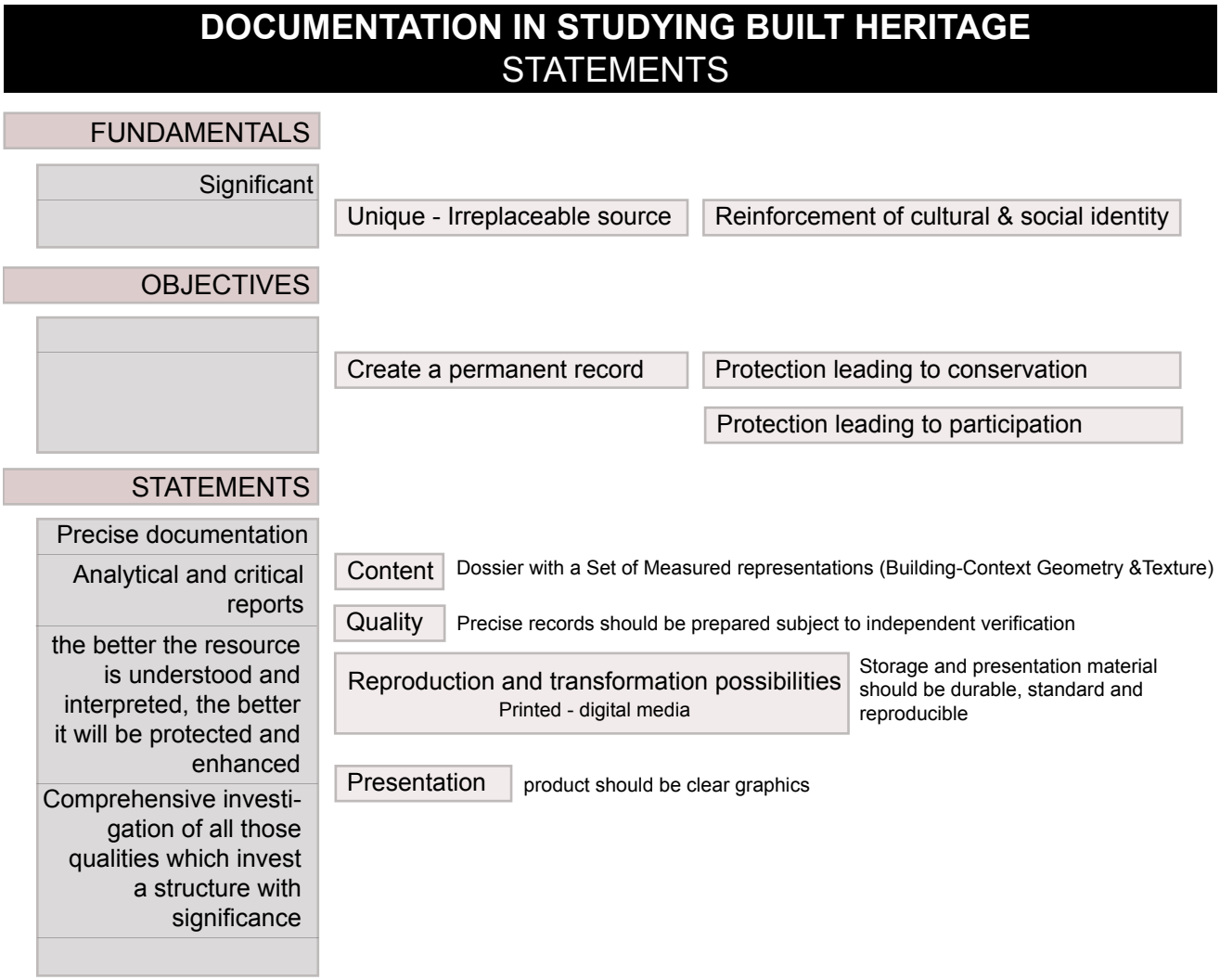

Chart 01: documentation in studying built heritage

promoting the participation of society in its conservation, as a tool of 'cultural tourism and regional development' (Thornes, R. & Bold, J. 1998, p. 3)[9].

Moreover, it serves to protect it from destruction due to lack of public awareness of its importance and to help in combating 'the theft of and illicit in cultural property on a global scale' (Thornes, R. & Bold, J. 1998, p. 3)[10].

1.1.3 STATEMENTS DEALING WITH DOCUMENTATION

The documentation of monuments requires a high level of quality ensuring a precise reproduction of the subject and its context. These statements have been already ascertained in diverse charters dealing with the conservation of historic buildings.

The Precision requirements and type of reports is stated by the Article 16 of the Charter of Venice 1964:

> *'In all works of preservation, restoration or excavation, there should always be* ***precise documentation*** *in the form of* ***analytical and critical reports****, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course*

of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published'.

'Precise documentation' in conservation works deals with the use of techniques that can acquire with precision and integrity the building and context geometry and texture.

Furthermore, the 'analytical and critical report' deals with the production of assessments about the actual condition of the subject, especially in the adequate quality of the measured dataset of geometric and texture for the thematic mapping.

The Charter of Venice explains in Article 2 and 10 the need of recourse to all techniques and modern technology where traditional techniques **proved to be inadequate**; these concepts can thus be applied to the need of exploring recent developments in recording tools to document and disseminate built heritage. In this manner can be supplemented insufficient or ineffective results from conventional techniques, when dealing with complex three-dimensional structures:

'Article 2: The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage'.

'Article 10: Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modem technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience'.

Moreover, the Practice in the Apleton Charter, Canada 1983 deals with the requirements dealing with the interpretation and quality of the records being prepared:

*'The **better a resource is understood and interpreted, the better it will be protected and enhanced'**.*

*'In order to properly understand and interpret a site, there must be a **comprehensive investigation of all those qualities which invest a structure with significance'**.*

Such work must precede activity at the site. Work on site must itself be documented and recorded.

In addition, the HABS/HAER[11] Standards (Washington 1990, p.1-2)[12] prepared by the National Park Service in the U.S.A. provides adequate guidelines for preparing this consistent, precise, and quality record for

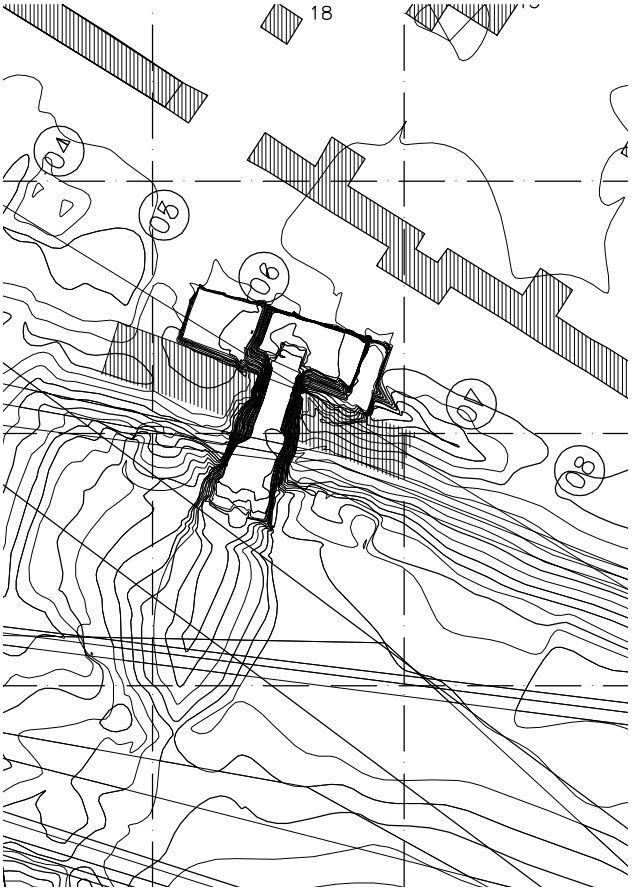

Figure 09: a DTM Model - Using a CADR application to represent the landscape of the site, using the electronic instrument, Later Mosque - Citywall, Otrar, Kazakhstan Author

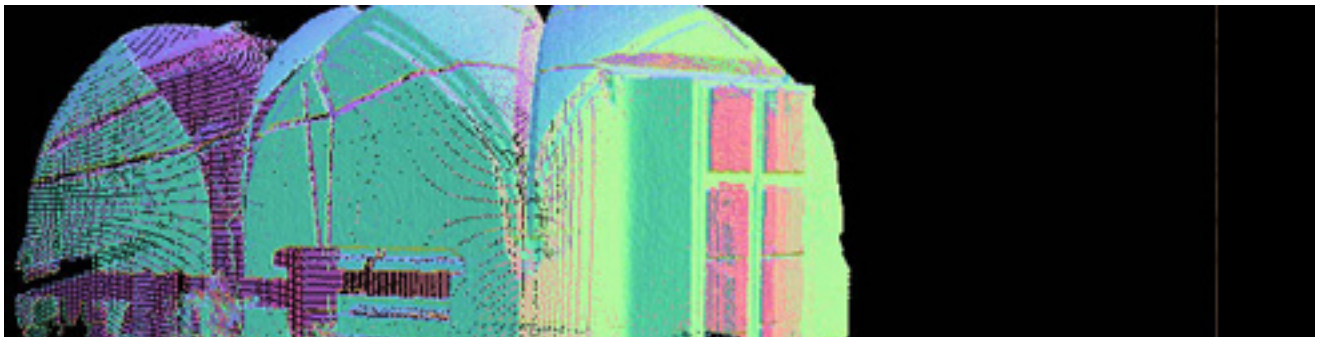

Figure 10: the geometry of a historic space is represented with a high density of points measured with a Terrestrial Laser Mapping Scanner (Callidus). Salle Heraldique, Castle of Arenberg

the preparation of analytical reports. These standards are explained below and they have been enhanced with contributions from the Author.

1.1.3.1 CONTENT

> *Standard I: 'Documentation Shall Adequately Explicate and Illustrate What is Significant or Valuable About the Historic Building, Site, Structure or Object Being documented'.*

The documentation dossier should explain the relevance of the building based on a number of thematic studies, such as the metric survey study (measured representations, including the acquisition of the geometry and texture from subject's appearance, landscape and urban emplacement), historical assessment (phases of constructions, including modifications, missing parts and additions), spatial and typological study, and condition assessment, and, as well as other important elements adapted to the specific case and context of the subject.

This document should consist of a set of graphical representations and photographic record; as well as, relevant historical documents gathered during the investigations.

1.1.3.2 QUALITY

> *Standard II. 'Documentation Shall be Prepared Accurately From Reliable Sources With Limitations Clearly Stated to Permit Independent Verification of the Information'.*

The sources and method of collection, analysis and subsequent dissemination product, consisting in an information system in the form of printed and/or digital representations should be explained, in order to permit verification of its reliability.

1.1.3.3 REPRODUCTION AND TRANSFORMATION POSSIBILITIES: PRINTED AND DIGITAL MEDIA

> *'Standard III. Documentation shall be prepared on materials that are readily reproducible, durable, and in standard sizes.*
>
> *The size and quality of documentation materials are important factors in the preservation of information for future use. Selection of materials should be based on the length of time expected for storage, the anticipated frequency of use and a size convenient for storage. Basic durability performance should be discussed according to needs and media used'.*



Figure 11: a hand-sketch is prepared prior to use of the Electronic device to be used for control and referencing purposes, Stupa 01, Sanchi, India. Author.

This part is discussed in detail in Chapter IV dealing with the implementation of a methodology in the use of metric survey studies in the documentation of built heritage.

1.1.3.4 PRESENTATION

> *'Standard IV. Documentation shall be clearly and concisely produced'.*

The product of the documentation process should be presented using clear types of graphics, photographs, and other visualization tools that can provide quantifiable data (e.g. the use of graphic scale in maps and orientation in photographs) in order to make them both permanent and useful for future investigations.

1.2 CRITICAL ISSUES: STATE OF THE ART

Studying built heritage involves dealing with the values embedded in the object and its culture based on its present physical condition and history.

Recently developed electronic, image-based surveying tools and computer applications play an important job as a tool for acquiring, processing (modelling) and disseminating (visualizing) those values.

Moreover, the widespread acceptance of these documentation tools in the use of technology in studying built heritage and in particular their use for projects of conservation presents new trends. To be more specific their capacity to deliver consistent and quality results adapted to the objectives of graphic representations in studying built heritage, be they digital or plotted on paper.

1.2.1 THE OBJECT OF STUDY: BUILT HERITAGE

> *'For built architecture, the object is nothing but perfect; admittedly, reflection of a previous abstraction, more or less elaborated, the action to build fits in the uncertain and passes, sometimes through centuries, by modifications, revisions, depredations imparted by time and/or men. Representation will follow two antagonistic ways: one will attempt to erase imperfection and redeem, in a thought's ripening, the object and his perfection actual or supposed; endeavour once more' (Saint-Aubin, J.P. 1992, p.15)*[13]

The action of weathering processes affecting the building's fabric, construction faults; as well as, the non-existence of factory manufactured architectural elements makes its fabric not ideal in shape, irregular and

incomplete (e.g. in a façade representing a stone using straight and regular lines).

Buildings are not static objects, they are constructed with imperfections, they are altered and the ageing process affects their fabric.

1.2.2 BUILT HERITAGE: AN INCOMPLETE AND HETEROGENEOUS SUBJECT

Historic buildings do not posses an ideal state; they have suffered alterations caused by the ageing; as well as, additions and modifications to their original fabric. Or parts might have simply disappeared.

1.2.3 COMPLEX CULTURAL QUESTIONS AND VALUES

The study of built heritage is based on interpretations of 'complex cultural questions of beliefs, convictions, and emotions, as well as of aesthetic, material and functional significance, 'Science helps to interpret, but it cannot and should not create absolute meaning or singularly represent one truth'(Matero, F. 2000, p.8)[14]. These matters are explained in more detail in Chapter II dealing with the definition of the measured 'dataset' of representations in the study of built heritage.

1.3 LIMITATIONS OF ELECTRONIC AND IMAGE-BASED TOOLS FOR ACQUISITION AND REPRESENTATION IN DOCUMENTATION OF BUILT HERITAGE

> *"A long-standing barrier to widespread adoption of computer aids in architecture has been the challenge of getting the discipline's highly graphical data into digital form" (Addison, A., 2001, p.177)[15].*

Recent attempts to adapt advances in electronic and image-based acquisition and processing tools in documenting and disseminating of architecture has brought new trends to its aplication in the field of studying built heritage.

1.3.1 INTEGRATION OF CONVENTIONAL HAND-SURVEY TECHNIQUES WITH RECENT ELECTRONIC AND IMAGE-BASED DOCUMENTATION TOOLS

The process of adapting the long-developed concepts and applications used in conventional hand-survey techniques for recording the building and context geometry and texture of built heritage to recent

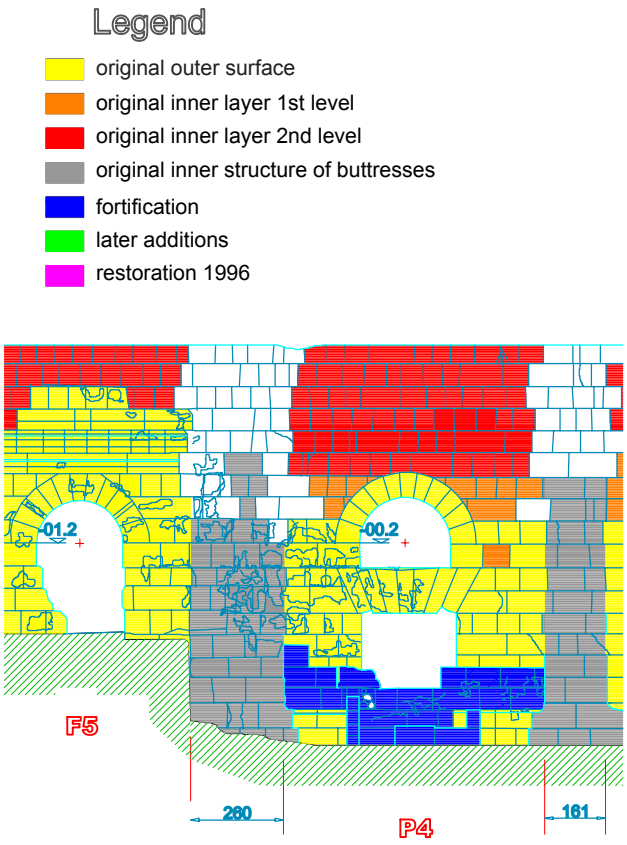

Figure 12: a CADR elevation prepared with photogrammetry for mapping purposes. condition assessment of the main facade of the roman theatre of Jebleh, Syria (Al-Murri, T., Patricio, T. et al, 2001).



Figure 13: virtual reality display instrument. Virtual Systems and MultiMedia Conference, Gifu 1998, Japan Author.

developments in electronic and image-based tools for recording and presenting measured representations of structures, has been very difficult and not always successful.

Although the limitations of conventional techniques are widely known, they are still generally used because they offer multiple adapted solutions to needs associated in recording the fabric of built heritage.

On the other hand, new electronic and image-based tools are available in a very large range of prices, associated with their characteristics and field operability options provided; they are generally classified in low-, mid- high-end applications.

These classifications directly impact their adaptation to recording built heritage, because more trends are added to the problem of selecting an optimal tool(s), such as cost-effectiveness in terms of speed, field operability restrictions, and other variables.

Furthermore, these applications and electronic and image-based systems have been conceived to execute functions that are not directly associated with the needs of recording built heritage (e.g. CADR developed for Architectural design basically).

1.3.2 A VAST AMOUNT OF AVAILABLE DOCUMENTATION TOOLS AND METHODS

There are a vast number of computer applications available; many of them can be useful to professionals studying built heritage. However, they have been predominantly created for other purposes.

Moreover, most of the specialized documentation tools designed for conservation are only useful to perform a specific task. Furthermore, these techniques have different procedures and syntaxes that do not enable them to interact together.

Interventions in built heritage require one to gather a range of different information, ranging from historical to physical, improvement in the communication and management of different acquired data and interaction among them.

For instance; the University of Leuven in cooperation with other institutions has developed the MDDS (Masonry Damage Diagnostic System) (Van Balen, K.) aimed at helping conservationists in classifying the range of weathering processes present in brick masonry. It is an expert system conceived as a knowledge base system and developed using the "decision table" model structure. This system is a good example of global systems integrating available tools. However it is specialized, allowing only for brick damage reporting.

1.3.3 QUICK OBSOLESCENCE OF DIGITAL TOOLS AND LACKING OF ADEQUATE ADAPTATIONS TO STUDY BUILT HERITAGE

> *'Technologies evolve more quickly than the social and psychological adaptations needed to make effective use of them' (Henry, W., 2000, p.13)*[16]

Complex calibration procedures tamper with the adequate adaptation of modern techniques in built heritage. Techniques, then, should use more intuitive procedures adapted to the specific needs of historic buildings.

In recent years a debate has emerged around the velocity of the further development of new and current technologies, and the complex and problematic manner, in which the adaptation of these techniques have been achieved in heritage. The disorganized adoption of them has caused serious misleading attempts that are limited to offering only a few perspectives from a reduced amount of information from monuments (e.g. idealized visualizations of the state of conservation exalting only the geometric representation of the shapes).

The only solution to avoid incompatible or obsolete equipment is the careful study of the different technologies available and the consultation of experts.

They can generate records of the built heritage that can be stored in reduced spaces, avoiding the use of big storage rooms.

1.3.4 CURRENT ELECTRONIC AND IMAGE-BASED INSTRUMENTS ARE NOT INTUITIVELY DESIGNED AND TAILORED FOR THE STUDY OF BUILT HERITAGE

Available tools have been developed without the active contribution of specialists in conservation of built heritage.

Multidisciplinary teams should take an active role in the development of CADR and virtual systems to improve their capabilities for acquiring and processing information from historic buildings.

On the other hand, the investment required to purchase and aply these techniques continues to be a limiting factor in spite of the aparent decrease in price, the relative speed needed, and the small amount of personnel required.

Most of '*the devices are often very expensive, require careful handling and complex calibration procedures and are designed for a restricted depth range*' (Pollefeys, M., 1999, p.)[17].

Moreover, instruments and software applications are often obsolete and/or incompatible with each other. These problems have increased in recent years where the speed technology is developed, which is related with the adequate selection and investment.

A long time might be required to learn specific operations and parameters of applications and instruments to be able to operate them correctly and effectively. Due to lack of knowledge the user is forced to use applications with already defined parameters and expensive hardware whiles '*effective programming is more important than powerful*' (Sutherland, J. et al, 1998, p.432)[18].

The use of electronic and image-based techniques of recording where certain

procedures are automatic, meaning that there is no direct contact, that previous knowledge of the subject of study, can temper with the main fundamentals in recording built heritage, which consists in experiencing the building by observing, measuring and finally representing in measured maps its geometry and texture, therefore, understanding its quality and values.

In this sense, the danger of overlooking important knowledge is increased when the operator becomes more concerned with mastering the tools and the composition of the space and not with experiencing, and therefore learning from, its unique and irreplaceable characteristics.

1.3.5 A COMMON LANGUAGE FOR SHARING THE PROCESSES IS REQUIRED

A lack of conventions, standards and adequate sharing of protocols to deal with the information gathered by studying built heritage creates serious problems, such as '*compatibility*' (Thornes, R. & Bold, J. 1998, p. 3)[19] that could lead to the creation of platforms and aproaches with a '*common access possible*' (Fink, E., 1998, p. vii)[20]. Especially in 3D visualization tools.

There are several efforts to establish standards in studying heritage, one of them is the "Core of Architecture" developed by the Getty Trust, which has been very successful in the world of inventories to catalogue information about historic buildings in digital databases. However, in the field of preparing measured representations using digital or plotted three-dimensional acquisition, modelling, and dissemination tools have been vague or non existent. There has been a huge production of all types of measured three-dimensional models, orthogonal projections, and other maps of historic buildings spread all over the world. Most of these efforts are lacking the essential concepts dealing with the reliability of information and proper use of tools of representation.

On the other hand, common basic types of conventions, such as orthographic, paraline, and perspective projections are not adequately integrated in the representations.

These problems have been discussed by different groups of researchers that have gathered and organised workshops and conferences about the subjects. These presentations have been very effective in spreading the word about using these types of technology to disseminate values and knowledge about historic buildings, but at the same time they have been very naïve in establishing guidelines for the adequate dissemination of standards for the application of technology.

This could be compared with the need of having a kind of Charter of Venice for the use of these type of instruments, in which certain guidelines can be provided as basic concepts and to adapt them to each case around the world.

Most of this problem is based on an inadmissible approach, which lacks interdisciplinary groups interacting together to produce convincing guidelines.

Perhaps, different levels of quality and visual approaches are required, providing a specific level of detail adapted to specific needs and scientific approaches.

These levels should assume that '*some users want to visualize simple information with minimal effort, while others want to customize and experiment with the entire visualization and interaction process in order to understand complex information*' (Hibbard,B. 1999)[21]. This part is further discussed in Chapter II in Target Groups.

Powerful simulation tools that can enhance human perception offer both a challenge to and immense opportunities for communicating, however, they can also lead to incorrect decisions and actions.

'Where all electronic information is accessible' (Hibbard,B. 1999)[22].

One solution could be the implementation of fundamentals associated with the use of traditional documentation techniques of built heritage.

1.3.6 'MISLEADING CONSISTENCY' - ABSENSE OF PRECISION

1.3.6.1 Dealing with simulating the present state of conservation of the subject

Digitally produced measured three-dimensional, orthogonal, and other representations are idealized often disregarding the aging process, missing parts, and conditions of the object.

The physical appearance of the building in terms of decay, additions, subtractions, and missing parts is '*accumulated physical evidence that can be viewed as a prime historical resource*' (Fitch, J.M. 2000, p.89)[23] Therefore, the representation of each of these tracks is important in the definition and analysis of the subject.

Moreover, modelling techniques tend to idealize the attributes of the subject (e.g. a cylinder is inserted instead of a decayed and deformed column), making the process very labour intensive to achieve acceptable results.

1.3.6.2 Dealing with the simulation of all the components

Misleading consistency or 'Misleading accuracy', as mentioned by Chalmers (1996)[24], is based on the disregard of the precise simulation of all the attributes and components of the subject, context geometry and texture as independent entities with specific relations, history and physical conditions. This can create misleading representations (e.g. represent different types of stone using the same colour or description). All the components are resources, providing the historical picture of the monument.

Thus, to avoid confusion and to create control points it could be convenient to attach information about the interpretation process behind the creation of a three-dimensional model (e.g. the use of metadata in Internet pages).

Moreover, the development of systematic protocols and structured methods adapted to each case; bearing in mind those monuments are unique, could be useful.

The use of these procedures of documentation could help in avoiding confusion or misunderstandings (e.g. making control measurements in surveying).

1.3.6.3 Dealing with hypothetical virtualised reconstructions

'In essence, the process of 3D modelling has made virtual reconstructions appear realistic whether or not they accurately reflect how the architecture really appeared in the past' (Kantner, J., 2000, p.47)[25].

Virtualised models of built heritage are powerful tools of visualization, making it possible to visualize real scenes. However these models often do not show to what extent scientists have interpretated the existing 'measured dataset' gathered to create the model and how the missing elements are modelled and could be differentiated from the existing parts.

Up to a certain point therefore, the user and/ or audience could misinterpret the actual geometry and texture of a building and its context during a particular phase of the building construction.

1.3.7 LACK OF INTERDISCIPLINARY APROACHES

The work of studying architectural heritage is a multi-faceted and interdisciplinary task. It requires the expertise of different fields. Mainly historical, urban, and architectural and engineering analysis is required to produce good dissemination records.

In recent years, many research groups around the world have produced such representations from monuments, using advanced electronic and image-based tools, mainly for testing emerging documentation and visualization aplications. These attempts are certainly valuable for scientific research in fields relating to computer graphics, often however they are simply lacking the background to be useful to other professionals working with heritage.

1.4 CLOSING REMARKS

The information acquired from historic buildings is unique and irreplaceable; it serves for the identification and classification of objects for the development of adequate policies for their conservation and maintenance, as well as to promote identity and cultural tourism.

Documentation is one of the most important phases in the process of study towards the protection of a monument; it plays an important role as base-data for deciding the types of intervention to augment the life and promotion of a monument.

Technology provides new tools for speeding up and making more effective the documentation and dissemination of information from historic buildings, but it should be used wisely, meaning that it should also be adapted to the needs of the process and the reality of the field of studying monuments.

Furthermore, to achieve this, it is important to take into account the condition of the fabric, its history and other components.

This research is related to the use of 'Plane Survey' (R.E.A., 1993, p. 1)[26], which assumes that the surface of the earth is plane. It is important to remember that this type of survey is used for relatively small areas. When the survey size is increased, the precision will drop considerably.

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[10] Ibid 9.
[11] HABS/HAER: Historic American Buildings Survey/ Historic American Engineering Record.
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[13] Saint Aubin, J.P. 'Le Relevé et la Représentation de l'Architecture', Service de l'Inventaire Général, Paris 1992. Original text in french: Dans le cas de l'architecture construite, l'objet n'est riens moins que parfait; certes, reflet, d'une abstraction préalable, plus ou moins élaborée, l'acte de bâtir s'inscrit dans l'aléatoire et passe, a travers parfois plusieurs siècles, par des modifications, des remaniements, des

déprédations que lui impriment le temps et/ou les hommes. La représentation va suivre la deux voies antagonistes : L'une tentera de gommer l'imperfection et de réhabiliter, dans la maturation d'une réflexion, l'objet dans sa perfection réelle ou suposée.

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CHAPTER II

DOCUMENTATION OF BUILT HERITAGE:
AUTHENTICITY AS THE CONCEPT DEFINING THE ‘MEASURED DATASET’

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DOCUMENTATION OF BUILT HERITAGE:

AUTHENTICITY AS THE CONCEPT DEFINING THE 'MEASURED DATASET'

'In the case of the documentation (heritage) values have to be recognised and the information should be considered valuable enough to justify the effort of documentation' (Van Balen, K, 2001)[3].

The 'measured dataset' is defined as a set of metric representations, which is a product of a '*mapping process*' of the building - context geometry and texture that is digitised and transferred to a '*computer-readable format*' (Domik, G., 2000, p. 17)[1].

Furthermore, this measured dataset can be complemented with the digitalisation of other thematic sources of information, such as historical accounts, condition assessments, and other studies aimed to produce a 'core data'. This is subsequently used for preparing a 'critical and analytical report' about the authenticity inherent to the object of study.

The role and application of the concept 'authenticity' (Nara Conference on Authenticity, 1994)[2] in this case is relevant to improve the selection and interpretation of the sources of information embedded in a historic building, understanding that 'authenticity' is a multi-layered concept, which relates to the evaluation of the building and reasons for justifying its conservation.

In this sense, authenticity in recording the building-context geometry and texture in heritage aims to establish whether a historic building is credible and truthful. This concept is based on the study of a series of values and dimensions inherent to the subject and its context.

Subsequently, these values are based on aspects relating to these layered concept, in terms of values dealing with the form and design, materials, function, construction techniques, location, as well as the 'spirit' and



Figure 14: a simple plan parallel photograph can be rectified in order to record the forms and materials presented in the fabric. In this case this photograph displays the various colour patterns representing a different type of stone and carving technique. Angkor 1999, Cambodia. Author.

AUTHENTICITY
DEFINING THE DIMENSIONS OF THE MEASURED DATASET IN BUILT HERITAGE

	DIMENSIONS	Artistic	Historic	Social	Scientific
ASPECTS	Form - Design	✓	✓	✓	✓
	Location - Setting				
	Materials - Substance	✓	✓	✓	✓
	Tradition, techniques workmanship	✓	✓	✓	✓
	Use - Function	✓	✓	✓	✓
	Spirit - Feeling	✓	✓	✓	✓

Chart 02: definition of the 'measured dataset' using multi-layered concept of Authenticity in studying built heritage, relation between aspects and dimensions (Van Balen, K., 2001)

'feeling' and 'other internal' and 'external factors' of the subject (Nara Conference on Authenticity, 1994)[4].

> *'Moreover, documentation methodology plays a vital role in the investigation and preparation of reports aimed at understanding the authenticity of a building, the evaluation of these sources relates to the study of 'direct and indirect sources' (Feiffer, C., 2000, p. 160)[5].*

> *'This approach proposes that the phase of documentation is limited to the acquisition, analysis and dissemination of the information necessary to prepare reports that aim at evaluating the authenticity of a building as the base camp for further understanding and protection.*

The study of the authenticity in built heritage is used to '*establish the significance of the building or site*' (Clark, K. 2001, p. 73)6.

> *Authenticity is, in fact, in continual flux, its defining criteria subject to ceaseless change (Lowenthal, D., 1999, p. 5)[7]*

Finally, it is important to bear in mind that authenticity is a dynamic concept integrating interdisciplinary and intercultural approaches, and therefore subject to changes according to these properties.

2.1 AUTHENTICITY: A LAYERED CONCEPT (ASPECTS - DIMENSIONS)

A study aiming to protect, promote or conserve a monument is based on the identification and evaluation of the values inherent to it. In this field '*authenticity' performs an important role that should be seen as a layered concept of values*' (Van Balen, K, 2001)[8].

That is to say, that the concept is structured in different aspects:

> *Form and design, materials and substance, use and function, traditions and techniques,*

> *workmanship, location and setting, and spirit and feeling, and other internal and external factors (Nara Conference on Authenticity, 1994)*[9] .

Furthermore, those aspects are understood according to various dimensions: artistic, historic, social and scientific (Nara Conference on Authenticity, 1994)[10]. These dimensions are interpreted in the study of built heritage through appropriate interdisciplinary approaches.

Moreover, the evaluation should also take into account other aspects dealing with the '*cultural diversity in terms of space and time*' (Van Balen, K, 2001)[11].

> *Authenticity, once focused on performance and possession, has given way to authenticity of materials and form, of structure and process, and of aim and intent, moving from exclusive concerns with buildings and artifacts to broader considerations of landscape and nature, folklife and folklore, ideas and beliefs (Lowenthal, D., 1999, p.5)*[12].

These statements are translated into the need to define 'data' in relation to the study of the actual state of the fabric, as well as with its history in terms of the modifications suffered in the aging process and natural development of the subject in its setting.

2.1.1 FORM AND DESIGN / LOCATION AND SETTING

2.1.1.1 Form and Design

Form and design are directly linked to understanding the geometry in the study of the subject's and context's shape. It is the critical assessment of the spatial and typological attributes of the building, and while it is normally part of the first phase of study, it requires a relatively long time to achieve. The results acquired in this phase serve as 'dataset' to perform other studies. In some cases it is the only aspect studied and thus, it is incorrectly assumed as the only factor to evaluate the relevance of a monument.

This aspect is recorded in the Metric Survey Study of the fabric of the building in terms of understanding the geometry and texture of the subject and its context, which is evaluated with the help of thematic assessments and the resulting typological analysis. This on-site survey is fundamental and is complemented by comparing and verifying records found in the historical archival investigation that describes modifications in the fabric of the structure with the aim of establishing a chronology of works, modifications and other interventions, for the purpose of which is to interpret the current state of the monument.



Figure 15: a 3D model (right) representing the use of new columns following the original type of structures found in this particular site, left: Courtyard Great Mosque of al-Baleed; Right: digital representation, Salalah 1997, Sultanate of Oman. Author.

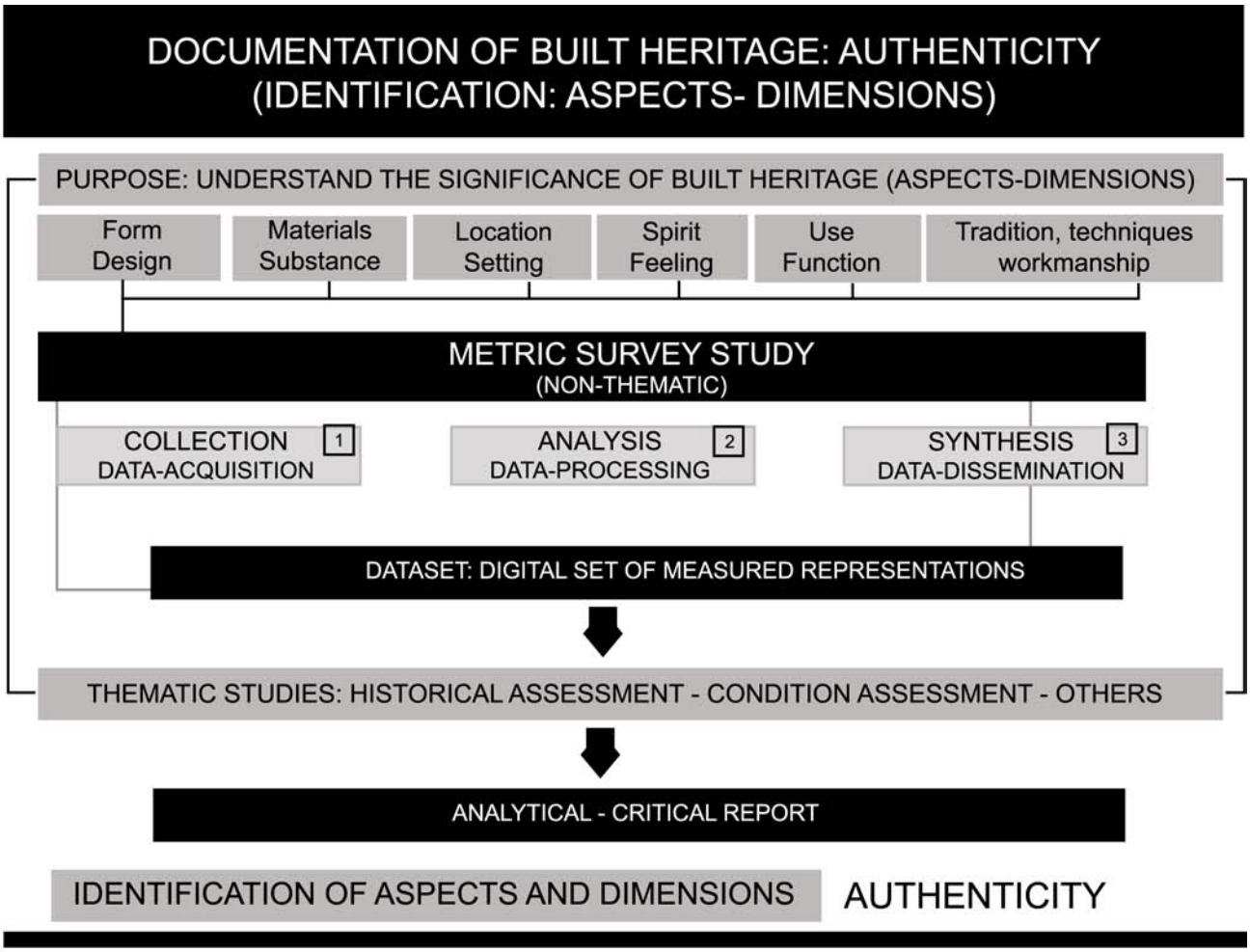

Chart 03: documentation: using Authenticity as basis for recording the building-context geometry and texture to evaluate the significance of built heritage

2.1.1.2 Location and Setting

These aspect are related to the study of the context, consisting in the urban location and landscape characteristics of the objects surrounding the subject and their interaction.

Moreover, the study of the context involves the examination of the characteristics of the vegetation and environmental conditions of that specific area.

2.1.2 MATERIALS AND SUBSTANCE

Although the assessment dealing with 'form and design' is very important to determine the subject's authenticity. This study should be followed by studies mapping the condition and determination of the material comprising the fabric.

The nature of the materials used in buildings is very diverse and requires detailed study. This information can contribute to an evaluation of the quality of the masonry and a determination of the general condition of the structure and weathering processes affecting the masonry; as well as in identifying traditional methods of construction contributing to the '*understanding of science and to the history of technology*' (Van Balen, K, 2001)[13].

This aspect not only evaluates a monument from '*the moment of its presumed beginning but at every stage of its development, including its attrition and decay*' (Lowenthal, D., 1999, p.7)[14], meaning that material and substance are evaluated on a broad range of forms, from the type of material used to the external and internal causes of deterioration.

Material and substance is part of the 'Condition assessment study' to understand the actual state of conservation, which maps information about the structure and fabric of the building; as well as the research for physical evidence.

On the other hand, complementing what has been previously been expressed in other aspects, this source is supported by intensive historical research, related to determining the type of materials used, in order to investigate its composition and physical characteristics and the sources of extraction.

2.1.3 USE AND FUNCTION

The study of these aspects aims at understanding the different changes though history of the buildings and all the traces that these modifications have produced in the fabric of the subject.

This aspect is related to the validity of the function of the building in terms of structure, state and current situation.

In addition, it allows the validation of an existing function and use of specific elements of the fabric in the current state of the building.

2.1.4 TRADITIONS, TECHNIQUES AND WORKMANSHIP

The study of this aspect is based on an evaluation of the techniques used for designing and constructing the building, in terms of material treatment, moulding, and structural properties of the form.

This part is related to the study of other values, such as form-design, material, and substance; as well as, location and setting as related to social and environmental characteristics, in terms of available material and advance of techniques of construction.

2.2 DIMENSIONS

The authenticity of the subject of study can be understood by analysing the values inherent to it through the interpretation of the artistic, scientific, historical, and social dimensions.

These dimensions reveal the importance and significance of the historic building, as well as providing the tools needed to adequately proceed with its conservation. In this case, documentation plays a very important role as the tool capable of providing the necessary information to understand these dimensions.

Furthermore, at this stage, metric survey



Figure 16: In this case, the concept of authenticity is aims can record the different aspects and dimensions of this temple, which are complex. This example shows a scientific and artistic achievement with a specific social function. Fathepur Sikri 2001, India. Author.

is limited to provide evidence and facts about the subject, leaving the work to other specialists of classifying, interpreting and justifying the actions required for its protection.

2.2.1 ARTISTIC DIMENSION

This dimension is based on the artistic aspect of the subject and significance. Related to the style, origin, modifications, and other artistic attributes of the monument.

2.2.2 HISTORIC DIMENSION

Apparently the historic dimension is the most relevant and comprehensive parts of the analysis. This dimension can be characterized by the '*significance of the artifacts*' (Fitch, J.M., 1998, p.1)[15] and their uniqueness and importance on a specific time and place. All of them having an impact in the understanding of the perpetuation of a monument.

> *We call historical all things that once were and are no longer. In keeping with the most modern conception, we include therein another view as well: that everything that once was can never be again, and that everything that once was forms an irreplaceable and inextricable cable link in a chain of development. Or, in other words: everything that succeeds was conditioned by what came before and would not have occurred in the manner in which it did if not for those precedents. (Riegl, A., 1996,p.70)[16].*

> *The Architectonic or aesthetic integrity of the building in purely formal terms. Here the present physiognomy is compared to its initial state to determine if its appearance has been strengthened or weakened by "the slings and arrows of outrageous fortune": in other words, whether its current state helps or hinders our comprehension of the aesthetic intentions of the original builders. (Fitch, J.M., 1998, p.83)[17].*

2.2.3 SCIENTIFIC DIMENSION

The Scientific dimension in architectural heritage is related to the understanding of the subject as an example of the development of construction techniques, manipulation of materials, and other matters related to progress in this field.

On the other hand, it can be associated with failure, specifically when dealing with previous conservation interventions or mistakes in the design (e.g. The tower of Pisa. In this example the subject has only been protected by improving its stability and stopping is inclination, but it has been brought to its original leaning state of few centuries ago).

2.2.4 SOCIAL DIMENSION

The social dimension deals with the meaning of the subject in terms of its importance to a community on a local, regional or international level. These dimensions are associated with cultural identity

2.3 ANALYSING ARCHITECTURE: RECORDING THE FABRIC OF THE BUILDING AND ITS CONTEXT

Although analysing architecture is not a simple task, the purpose of this part is to define the geometry of the building in terms

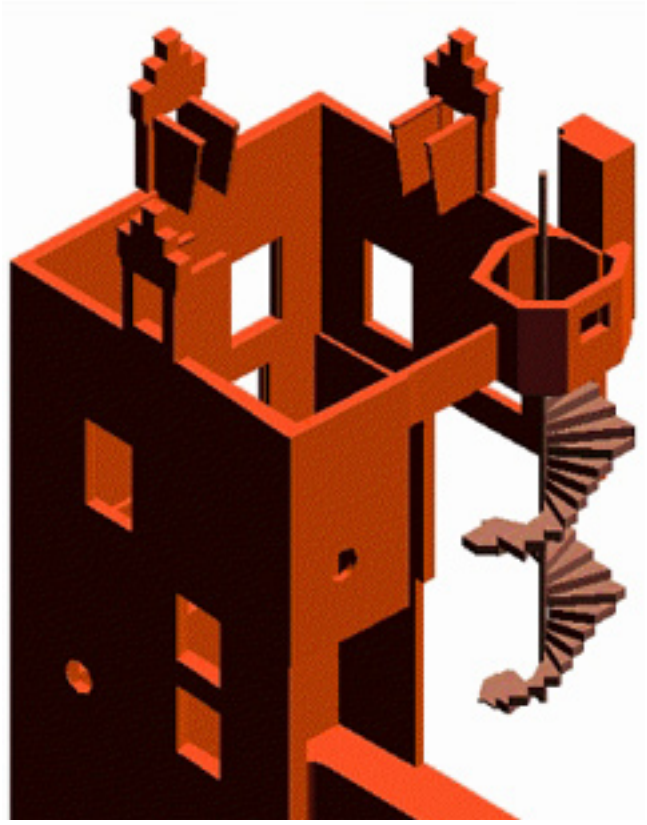

Figure 17: depicting components and entities in the geometry of this building using a CADR 3D modelling application: Castle of Arenberg 1997, Belgium. Author.

of elements for the understanding of this research. These elements are structured in entities and components, organized in hierarchies and sharing functional relations.

This definition of geometry aims to understand the use of abstractions and the level of detail that can be used to represent the subject's geometry and texture. These concepts should be applied in accordance with the requirements and type of applications produced.

Moreover, it is recommended that the process of modelling those elements using computer processing applications, especially CADR should be defined using an object-oriented approach, which in this case means studying components of the architectural geometry consisting of an entity (identity), 'a set of attributes (state vector) and a set of methods that describe its behaviour' (relations) (Hendricx, A., 1999, p.53)[18]. Subsequently, these entities are grouped in components (object class) and in a specific hierarchy.

2.3.1 BUILDING GEOMETRY: THE FABRIC

This research has reviewed the object oriented approach in defining geometry, as well as basic concepts presented in the 'conceptual elements of architecture' by Unwin (Unwin, S., 1999, p.19)[19], which goes beyond defining objects as the physical components of a building.

In terms of this analysis, the datum or height of the ground is defined as the space above that surface that has been modified by architecture.

2.3.1.1 Entities:

Entities are the units, individual features composing the geometry of a building (e.g. arch, window, door, beam…) taking into consideration that these are composed by a number of ingredients or materials (e.g. a brick, stone or wooden frame).

2.3.1.2 Components

Entities are grouped in components, having a specific structural, artistic and/or boundary function (e.g. walls).

On the other hand, in archaeology a component can be defined with a number or Locus, which relates to its position in space and with characteristics. This term can be used to define either a whole structure or ruin; as well as a single component of the building.

Vertical boundaries or barriers (walls)

A vertical boundary is a component dividing one space from another in a horizontal axe,

meaning a wall, or other type of barrier, such as a fence, or simply a psychological barrier (e.g. the elements of a façade).

Horizontal boundaries or barrier (Roof and the floor)

A horizontal barrier divides and makes use of the environmental conditions providing shelter to humans (e.g. the roof dividing the sky from the place)

Supporting posts (walls)

These components can be a wall, beam or other structural elements supporting the roof or other floors. A supporting post can also be a wall supporting the horizontal traction of the earth in a basement.

Path

A path is a horizontal or vertical component that routes across the ground, a surface avoiding obstacles (staircases, ramps, etc).

Openings

An opening is a doorway to move from one place to the other, or in the case of windows from where it is possible to look to another place.

2.3.2 HIERARCHIES

Hierarchies are associated to the location of the entities in a component and in the whole; this relation is associated with a functional or artistic character. Such as a set of columns that support a floor or that are part of a space called the entrance hall.

Components are grouped in hierarchies, meaning that a building is structured in levels and spaces. The modelling of historic buildings, as in other architecture related fields is associated with the identification

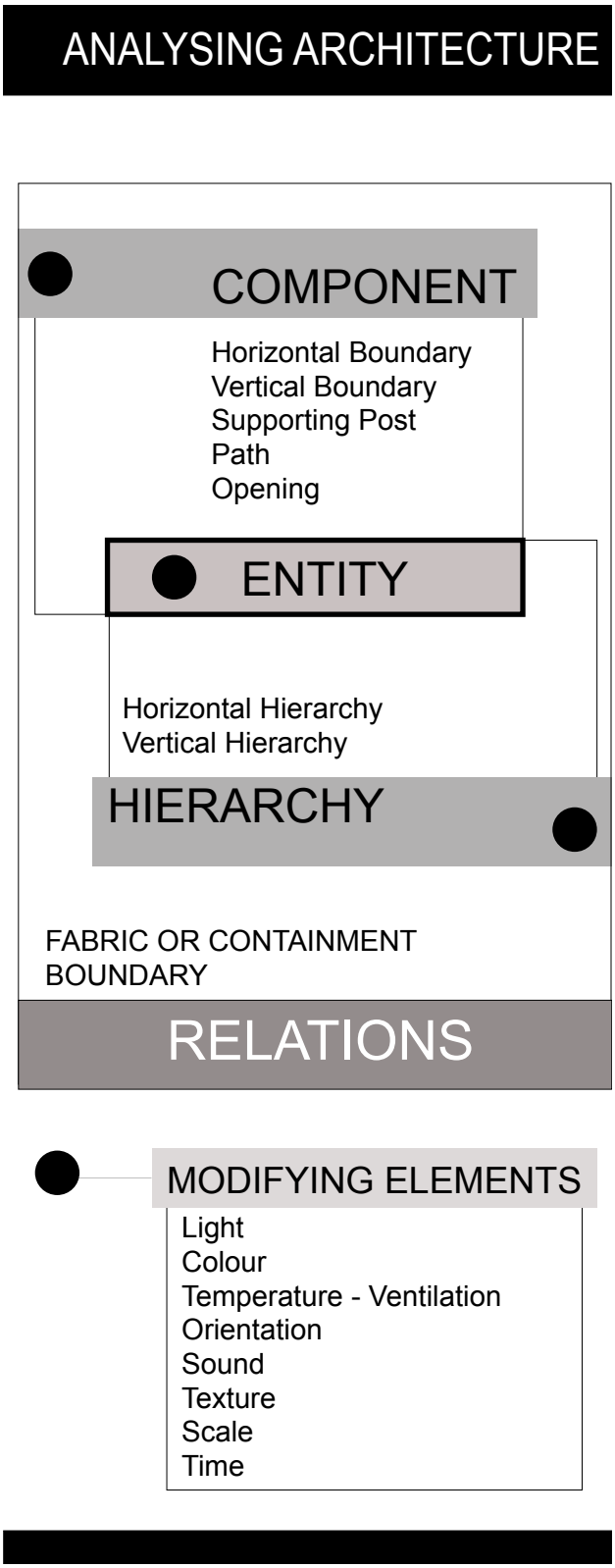

Chart 04 : analysing architecture, entities, components, hierarchies, and their relations; as well as modifying elements.

of these hierarchies in order to be able to implement definitions, classifications and descriptions.

The types of hierarchies described here

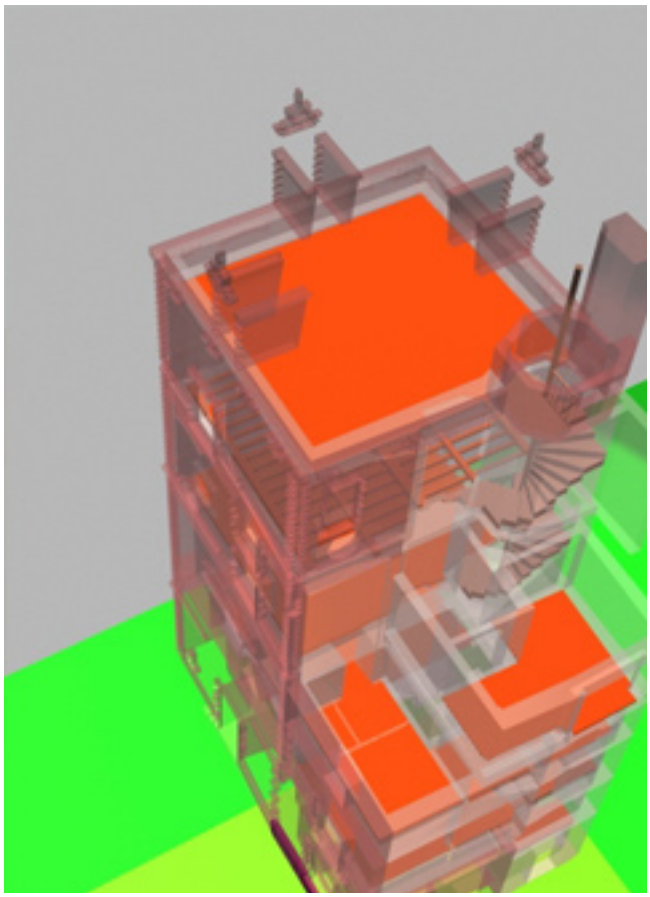

Figure 18: a CADR render showing the different components and hierarchies in a historic building. Castle of Arenberg, Leuven 2002, Belgium. Author.

are based on a two-dimensional reference system, but they can be applied for three-dimensional organization systems, as well as historical research studies. The emphasizing of this part is to encourage the development of something new, but to adapt existing systems to three-dimensional descriptions.

2.3.2.1 Horizontal hierarchies

Rooms or spaces are considered as the horizontal organization system, having different hierarchies according to the movement and functional relations of the building (e.g. the entrance hall, kitchen, living room…).

2.3.2.2 Vertical hierarchies

This vertical organization system is expressed in terms of levels (e.g. Ground Floor, first floor, mezzanine…).

On the other hand, vertical hierarchies can be used to describe the different components of a façade, in relation to different bodies.

2.3.3 RELATIONS

Geometric characteristics and relations between architectural entities: hierarchical structure of groups of components

2.3.3.1 Fabric or containment relationships (Rivard, H. & Fenves, S., 2000, p.153)[20]

Fabric or containment relationships, links and structural nodes between the elements composing an entity, such as the column and the entablature.

2.3.3.2 Boundaries relation

'Character and Articulation' (Koutamamis, A. 1996, P. 20.)[21], related to position and orientation in space.

2.3.4 MODIFYING ELEMENTS IN ARCHITECTURE

The use of elements to describe and model the components of the building morphology is very important; however it is also relevant to explain agents, i.e. elements that are used to modify the characteristics of a place. These factors, such as light, colour, temperature, orientation, ventilation, texture, scale and time are related not only to environmental conditions, but they are inherent to the shape and material of the building.

The designer might have recourse to these elements to actually modify the scenes in order to produce different perceptions and sensations. The physical study not only deals with the analysis of geometry, dimensions,

materials and state of conservation, it is also the study of the feeling and purpose of the designer, and in this sense these elements are very important.

2.3.4.1 Light

Although this could be constructed as an external factor or condition, light could have been manipulated in order to provide clarity or darkness in specific areas to enhance the quality of a space. This part is very important in the application of digital techniques of the rendering of historic buildings, by using a fake condition can be misleading.

2.3.4.2 Colour

'Issues of colour are of inseparable from those of light. Light itself can be any colour' (Unwin, S., 1999, p.29)[22]. It can also be associated with the material used, decay, and the coding of the building.

2.3.4.3 Temperature and ventilation

The manipulation of temperature is related to the use of materials, ventilation and other modifying elements in order to reach a certain favourable condition (e.g. the use of mud brick to cope with dramatic changes of temperature through the day).

2.3.4.4 Orientation

The orientation of a building plays a vital role in its conception, this modifying tool could have been used either for religious or philosophical beliefs, or to make the most use of light, ventilation and other factors.

2.3.4.5 Sound

The properties of the design and the use of material are related to sound, the understanding and function of a space might be distinguished by its acoustic properties (e.g. a concert hall or a church).

2.3.4.6 Texture

> *'It relates to light and the sense of sight; but it is also a characteristic which one can feel – in this it relates to the sense of touch. In both ways, texture contributes to the identification of place' (Unwin, S., 1999, p.33)*[23].

Texture is related to the use of specific materials, colours, and other elements to modify the aspect of a building.

2.3.4.7 Scale

Scale is associated with the use of dimensions and sizes relative to specific objectives and elements of the design. The senses are manipulated by the use of scale.

2.3.4.8 Time

Time is related to modifications and alterations of the fabric, the creation of patina, ageing and weathering agents causing decay.

2.4 SOURCES OF INFORMATION: DIRECT AND INDIRECT IN RELATION WITH THE STUDY OF THE SUBJECT'S FABRIC

In this research, direct sources are defined as the study of the building-context geometry and texture through direct contact with the fabric.

This part is associated with a 'metric survey

study', consisting of a set of measured geometric and texture representations of the building and its setting.

Subsequently, this study involves the acquisition of the geometry and texture of the context (topography, urban survey) and building (standing and buried structures if required). This study can be achieved by 'Metric Survey' techniques, and the use of a referential 'photographic survey' (Feiffer, C., 2000, p. 110)[24]. This study is characterized by the absence of thematic content.

Furthermore, the metric survey is used for mapping the thematic content studies (Spatial and Typological analysis, the Condition Assessment, Historical Assessment of the object, and other studies), in order to ensure a useful set of information for the mapping, assessments, and further analysis.

On the other hand, there are the indirect sources, which deal with the study of sources found in written documents, iconographical sources, previously prepared survey or design drawings, old illustrations and other archival evidence.

The collection of these sources is associated with the Historical Assessment (Thematic study), a which reviews the study of historical documentary research, iconographical sources, and other relevant documents, which are complemented by the verification of the historical evidences found in the stratigraphical investigation (Feiffer, C., 2000, p. 110)[25]. This part is further developed in Chapter IV dealing with the introduction of a methodology in the implementation of documentation and dissemination.

2.5 ESSENTIALS IN DOCUMENTATION: AN INSTRUMENT FOR THE CLASSIFICATION AND INVENTORIZATION OF BUILT HERITAGE

The study of values aims at clarifying the requirements of classification and the inventorying of the information collected from the monument. However this research is not enough to protect a monument. Therefore, several guidelines have been prepared to classify and organize this material and thereby provide legal instruments for the protection of monuments in local, regional, or international arenas. It is important to apply simple and similar guidelines, in order to guarantee compatibility and to facilitate the exchange information between organizations.

Moreover, among the existing instruments this research has selected the notions and classifications developed in the 'Core Data Index to Historic Buildings and Monuments of the Architectural Heritage' (Thornes, R. & Bold, J., 1998, P. 27-32)[26] developed by the Council of Europe, the Getty Information Institute and the European Foundation for Heritage Skills, and which have been adopted as instrument for the application of the 'Convention for the Protection of the Architectural Heritage in Europe' (C.E., 2001)[27].

The Core data provides the following required definitions:

- Names and references
- Location
- Functional type
- Dating

Other definitions include: persons and organisations associated with the history of the building, building materials and techniques, protection/legal status, and notes are optional to this legal instrument. They vary 'according to the nature of the record held and to the individual organisational

requirements' (C.E., 2001)[28].

2.5.1 NAMES AND REFERENCES

Names and References contains information about:

- Name of building
- Unique reference number
- Date of compilation
- Compilation of the core data index record
- Recording organisation
- Cross-reference to related building records: qualifier of relationship, cross-reference to records of fixtures and fittings, cross-reference to documentation (photographic or reference, graphic reference, textual sources reference, and bibliographic reference)
- Cross-reference to archaeological records
- Cross-reference to environmental records

This part is used for simple identification of the building and cross-reference and exchange in various layers of information.

2.5.2 LOCATION

A combination of the fields defined in the sections below may be employed to identify the location of the building.

- Administrative location: state, geo-political unit, State administrative division(s) and Administrative sub-division.
- Address: postal name, number in the street/road, name of street/road, locality, town/city and postal code
- Cartographic references: X, Y coordinates, spatial-referencing system employed, and other international or regional coordinate systems (UTM, Lambert, GPS, and Ordnance Survey).
- Cadastral reference/land unit

2.5.3 FUNCTIONAL TYPE

This part is related to the classification of its style, function and category in terms of predefined zoning characteristics and other legal instruments.

- Building type
- Date
- Building category

2.5.4 DATING

This section allows for precise dating when it is known, or date ranges or periods when it is imprecise.

- Period
- Century
- Date Range (from – to)
- Absolute Date

2.5.5 PERSONS AND ORGANISATIONS ASSOCIATED WITH THE HISTORY OF THE BUILDING

The following sections are not mandatory according to this legal instrument. It is associated with the identification of persons and organisations participating 'either with the construction of the building, e.g. architects, or its function, e.g. the original proprietors. The fields may be repeated to accommodate persons and organisations associated with the buildings over a period of time. Detailed information may be held in related biographical files' (C.E., 2001)[29].

- Person or organisation
- Role in the history of the building (Date)

2.5.6 BUILDING MATERIALS AND TECHNIQUES

This instrument is used for basic identification of monuments; however, this research maintains that the knowledge of building materials and techniques is essential in any study of architectural heritage.

Components:

- Main materials and structural techniques
- Covering materials
- Physical condition
- General condition

2.5.7 PROTECTION/LEGAL STATUS

This part is certainly very important for protecting a monument in a legal framework, but it is secondary in relation to the implementation of a documentation and dissemination study.

- Type of Protection
- Grade of Protection
- Date at which protection was granted

2.5.8 NOTES

Notes is related to optional historical summary that briefly explains the historical development of the building and other facts that can not be identifiable in the dating or persons and organizations involved associated to its history.

2.6 CLOSING REMARKS

The definition of the 'measured Dataset' by way of 'Authenticity' is a very important issue, these concepts not only deal with the study of heritage in general, but with the diversity of cultures and multisdiciplinarity approaches required for its study.

The process of recording in documentation of historic buildings is associated with reviewing different sources about the subject of study; the simultaneous application and manipulation of both important fundamentals and recording techniques can be of great help for protecting the past inherent to our built heritage. This process of stewarding the information for future generations is a very complex task that requires preparing different types of dissemination instruments, based on flexible and compatible systems for producing legal instruments to guarantee their protection.

> *"Survey: methodical inspection, survey and documentation of the resource, its historical setting and its physical environment; Definition: critical-historical definition and assessment of the object and its thing, so giving it its significance; Analysis: scientific analysis and diagnosis of the material substance and associated structural system with a view towards its conservation" (Feilden, B. & Jokilehto, J., 1993, p.11)*[30].

Since a dissemination tool can be used for falsifying values that are not there through the use of attractive visualisation tools offered by current applications, these misleading results should be avoided at all cost. These instruments are crucial to the positive or negative impact of the public in relation with the truth and the credibility of a monument.

This chapter has dealt with authenticity as an evaluation concept for acquiring sources embedded in built heritage, and with the definition of the context and building depicted in entities and components that enable the adequate acquisition of its geometry and texture. These principles give foundations to tackle the real purpose of preparing a

measured dataset of representations of the subject, as the pillar for further evaluation of the significance of a historic building.

The use of adequate digital three-dimensional modelling and representation systems will enable the simulation of a complex structure and its relationship with other elements of the building. All these components should be included in the model although they might seem trivial or difficult to simulate by the computer.

Notes:

[1] Domik, G. 'Do We Need Formal Education in Visualization' IEEE Computer Graphics and Applications; IEEE Computer Society, Vol 20/4, Jul.-Aug. 2000, p. 17.

[2] Larsen, K.E. Ed. 'Nara Document on Authenticity', Proceedings of the Nara Conference on Authenticity, UNESCO-ICCROM-ICOMOS, Japan 1994.

[3] Van Balen, K. 'Mortar Characterization, from values to compatibility; Pointing Project Report Contribution', Leuven, 2001

[4] Larsen, K.E. Ed. 'Nara Document on Authenticity', Proceedings of the Nara Conference on Authenticity, UNESCO-ICCROM-ICOMOS, Japan 1994.

[5] Feiffer, C. 'La Conservazione delle superfici intonacate: il metodo e le tecniche', Skira, Milano 2000, p. 160.

[6] Clark, K. ' Informed Conservation: Understanding historic buildings and their landscape for conservation' English Heritage, London 2001. p. 73.

[7] Lowenthal, D. 'Authenticity: Rock of Faith or Quicksand Quagmire', Conservation, The Getty Conservation Institute Newsletter, Los Angeles 1999, p.5.

[8] Van Balen, K. 'Mortar Characterization, from values to compatibility; Pointing Project Report Contribution', Leuven, 2001.

[9] Larsen, K.E. Ed. 'Nara Document on Authenticity', Proceedings of the Nara Conference on Authenticity, UNESCO-ICCROM-ICOMOS, Japan 1994.

[10] Ibid 8.

[11] Ibid 7.

[12] Lowenthal, D. 'Authenticity: Rock of Faith or Quicksand Quagmire', Conservation, The Getty Conservation Institute Newsletter, Los Angeles 1999, p. 5.

[13] Ibid 7.

[14] Ibid 6, p. 7.

[15] Fitch, J.M. 'Historic Preservation', University Press Virginia, London 1998. p. 1.

[16] Riegl, A. 'The Modern Cult of Monuments: Its Essence and Its Development', Historical and Philosophical Issues in Conservation of Cultural Heritage, The Getty Conservation Institute, Los Angeles 1996. P. 70.

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[19] Unwin, S. 'Analysing Architecture', Routledge, London 1999. P. 19.

[20] Rivard, H. & Fenves, S.; A Representation for Conceptual Design of Buildings; Journal of Computing in Civil Engineering, Jul. 2000. P. 153.

[21] Koutamis, A. 1996, P. 20.

[22] Unwin, S. 'Analysing Architecture', Routledge, London 1999. P. 29.

[23] Ibid 22. P. 339.

[24] Feiffer, C. 'La Conservazione delle superfici intonacate: il metodo e le tecniche' Skira, Milano 2000, p. 110-111.

[25] Feiffer, C. 'La Conservazione delle superfici intonacate: il metodo e le tecniche' Skira, Milano 2000, p. 110-111.

[26] Thornes, R. & Bold, J. 'Documenting the Cultural Heritage', Council of Europe, Getty Information Institute and the European Foundation for Heritage Skills. Los Angeles 1998. P. 27-32).

[27] Council of Europe 'Recommendation No. R (95) 3 of the Committee of Ministers to member States on co-ordinating documentation methods and systems related to historic buildings and monuments of the architectural heritage'
http://culture.coe.fr/infocentre/txt/eng/econ121.html
(Last visited: 31/05/2002)

[28,29] Ibid 26.

[30] Feilden, B. & Jokilehto, J. 'Management Guidelines for World Cultural Heritage Sites', ICCROM UNESCO ICOMOS, Paris 1993, p.11.

CHAPTER III

PREPARING THE MEASURED DATASET:
BAUFORSCHUNG AND THE ‘STATE OF THE ARTS’ IN METRIC SURVEY TECHNIQUES

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PREPARING THE MEASURED DATASET:
BAUFORSCHUNG AND THE 'STATE OF THE ARTS' IN METRIC SURVEY TECHNIQUES

The use of the term 'bauforschung' is highly relevant to the documentation of built heritage. It is the process which 'involves the first investigative phase of architectural historical research, combining the analysis of archaeological, historical and iconographical source material with the **complete recording of a building's appearance and pathology**' (RLICC, 1996)[1].

Furthermore, in bauforschung, the '**complete recording of a building's appearance and pathology**' accompanied by the study of its context, deals with the preparation of a 'Measured Dataset' of representations, this process is called the 'metric survey study'.

In addition, the definition of a 'dataset' is associated with the study of values and dimensions as expressed by the term 'Authenticity' (Nara Conference on Authenticity, 1994)[2] as a multi-layered concept, which has been described already in part I - chapter II. It is defined as a significant historic building worthy of being protecting and conserved for future generations.

Furthermore, this part describes the 'State of Art' on 'Metric Survey' tools outlined below and, which have been selected according to the following consideration:

- Techniques, which can be use for recording the geometry and texture of the subject and its context, excluding alternative referential use of digital or analogue photography supporting a written report.
- Techniques, those are both cost-effective and sustainable in recording Built Heritage.
- The Techniques, which have been previously, tested first-hand.
- Techniques that have proven successful in their application to study heritage from an analytical point of view, based on scientific and commercial literature available.
- Techniques using electronic measuring instruments that are able to exceed the 50 m range in surveying standing structures and archaeological sites.

In addition, the most common problems of the large gamma of tools available for 'gathering 3D data of architectural-scale real-world objects' are based on:

- The development of specialized tools adapted to the different applications aimed at studying and disseminating built heritage.
- The combination of different recording instruments, processing tools, and dissemination application using defined standards and systems of verification.
- The objectives to prepare a measured set of representations in documentation are not clearly stated.
- The selection of the sources of information in the process of documentation is not clear, relevant or stated in the measured dataset resulting from the process.

In Chapter V, these techniques are enhanced and grouped in tools, with the contribution of first-hand experiences; as well as, in numerous recent scientific, conventional, and commercial publications.

In addition, this chapter incorporates the principals of conventional hand–survey techniques in understanding the fabric of a building and its history and the notion that the documentation of built heritage is a slow and 'time constraining' task.

Furthermore, the previous Chapter dealt with describing a building by depicting it in elements and components; as well as, functions and modifying elements.

In this sense, the preparation of a 'measured dataset' of the components in relation to their values and dimensions relates to applying techniques described by the phase of work involving 'bauforschung'.

Subsequently, this first phase of work deals with defining and selecting relevant 'data' or information to be recorded and further analysed. The result of this analysis is used for defining the intervention required for improving the state of the building fabric and thereby extending the life of a monument.

Furthermore, the aim of this chapter is to evaluate the application of available and emerging techniques for recording in digital documentation and dissemination of built heritage based in these fundamentals exposed in Bauforschung.

These tools are implemented for collecting, analysing and synthesizing the different sources of information available in the geometry and texture of the monument's fabric, in order to produce an adequate and effective tool of visualization, representing its actual state of conservation.

This evaluation is based mostly on techniques that have been tested throughout first-hand experiences; as well as, analysed in recent



Figure 19: recording the building geometry of the fabric using non-photographic direct tool, An REDM Total Station linked to a CADR package, Kallo 2002, Belgium. Author.

scientific and commercial publications. The case studies are further explained in part II.

3.1 BAUFORSHUNG IN STUDYING BUILT HERITAGE: THE ROLE OF METRIC SURVEY TOOLS

In Studying Built Heritage, 'bauforschung' is an extensive comparative process, studying the geometric attributes of the building and its context; as well as, the historical sources available for establishing the historical stratigraphy of the subject and its current condition of conservation. The 'measured dataset' produced by this comparative study is called the '**bauafname'** (Schmidt, H. 1996)[3].

'The term Bauaufnahme is

> *understood as the method of the exact recording of a three-dimensional form or structure into two-dimensional drawings (including a floor plan, frontal views, sections, orthogonal projections) based on exact measurements. A Bauaufnahme is thus on the one hand an exercise in measuring and analysing, and on the other a graphical representation. It results in a proportionally correct structural plan and a description of an existing site. (Schmidt, H. 1996)[4].*

Moreover, it is important to bear in mind that bauforschung is an inter-discipline activity that involves the use of several fields and tools of investigation, each field of study has something unique to offer. This phase of study should be executed prior to any conservation assessment, restoration project or any scientific publication about historic buildings.

> *A 'bauforscher can in fact be translated literally from German as "building researcher", implying not only a mastery of the skills of the historian, archaeologist and architect, but also of the materials specialist and the surveyor' (Bruno, A. 1996)[5].*

The researcher or bauforscher is primarily required to understand the history of the subject by observing, measuring and representing its fabric; as well as reviewing archives and other reference material about its history, when available.

In addition, this technique is especially effective '*when other evidence, such as written or graphic documentation, is missing or incomplete, as is often the case for historic buildings*' (Schuller, M., p.7, 2002)[6].

In relation with bauforschung, the metric survey tools or techniques presented in this investigation are based on this principal, with the objectives of optimising the amount of time required for the observation, measuring, and reproduction of the object using electronic, image-based instruments and computer applications.

Furthermore, the advanced recording techniques increase the speed of collecting, and enable the bauforscher to reach remote areas in the monument that otherwise were not possible to record using conventional hand-survey techniques.

On the other hand, it is important that the fundamentals depicted from using conventional surveying techniques are not overlooked, but that they are joined to recent innovations in electronic and image-based tools of documentation and representation.

These fundamentals deal with the need to control and verify at all stages of work, related to the type of devices used in collecting, processing applications and final dissemination product or 'bauaufnahme'.

3.1.1 BAUAUFNAME: THE DATASET

The 'dataset' or 'bauaufnahme' is the result of the bauforschung study (or the documentation phase) in the study of built heritage.

The methodology to obtain this 'measured dataset' is described using the phases of work: **Collection, Analysis and Synthesis**.

Collection is related to the process of capturing and storing the 'raw measurements and records' obtained by the 'metric survey instrument(s)' applied to record the geometry and texture of the subject.

This phase is characterized by the implementing a 'reconnaissance' or rapid assessment of the subject and context to be recorded; as well as to define the aim of the survey, consisting of the scope and the target-audience for such application.

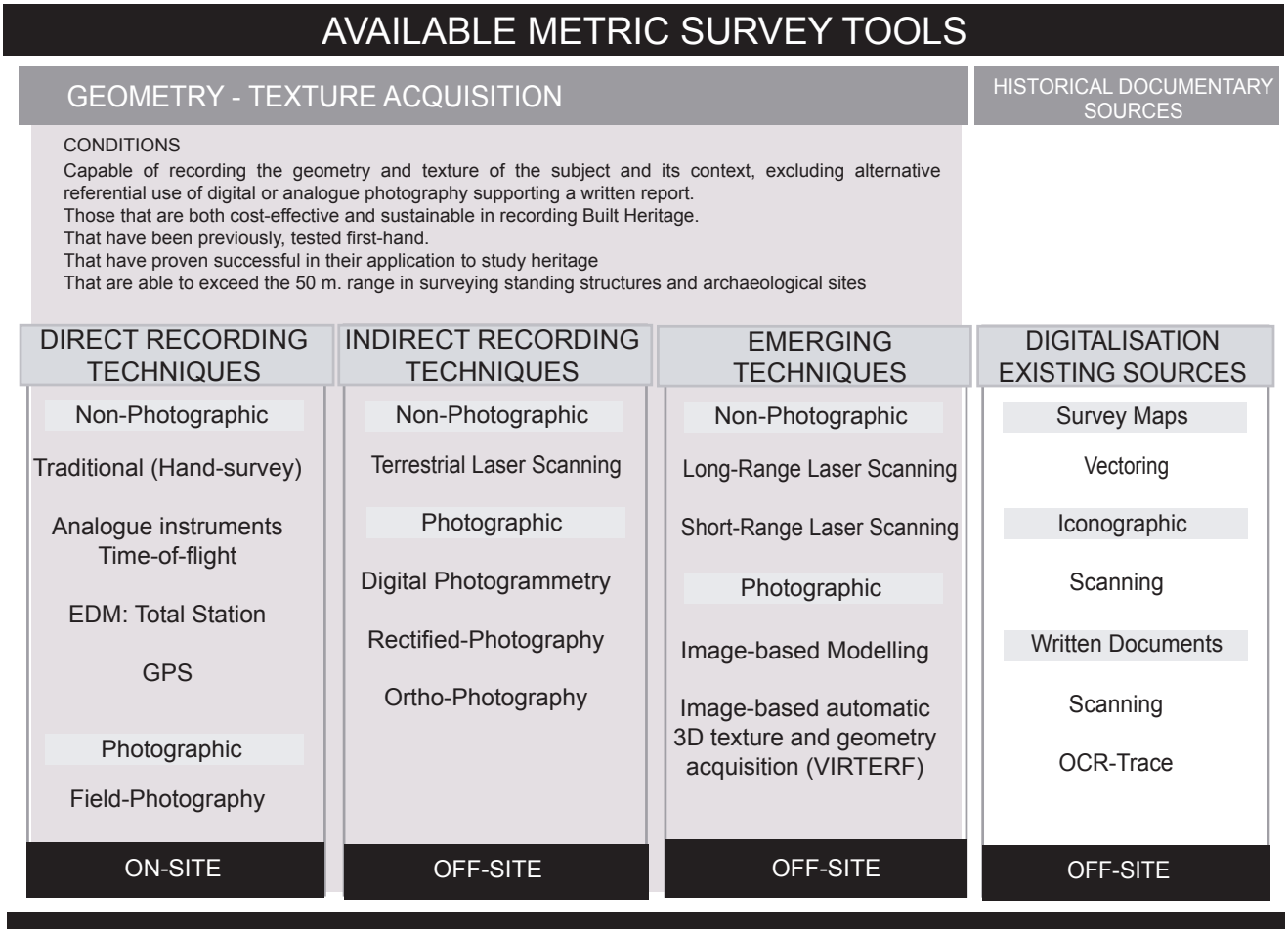


Chart 05: metric survey tools available for acquiring the 'measured dataset' of the geometry and texture of the subject and its context.

This 'preliminary assessment' involves an estimation of the intended work to be recorded, by visiting and observing the subject on-site, quantifying the possible uncertainties, defining the area to be recorded (most relevant information of the subject), timeframe, and quality of the survey product required.

In addition, based on this preliminary research, it is possible to determine the selection of the 'metric survey tool' (further explained in Chapter V) for recording, processing and disseminating tools to be applied. These methods combine the use of several techniques in each phase of work (E.g. EDM Total Station for acquiring, a CADR application to process the points recorded and produce a model, and finally paper representation as dissemination tool)

Furthermore, the **Analysis** phase is related to the processing and modelling of the 'raw dataset' collected, emphasized in the process of verification and control of the measured data; as well as, the matching and merging of the measurements in the case of using multiple recording tools.

On the other hand, the output of this phase will be produce according to the needs of the Synthesis phase.

Finally, the **Synthesis** phase deals with the use of information-systems capable of disseminating the information through adequate tools for retrieval, management and storage of the information.

The product of this phase should be adequate to the primarily needs of the Objective of the Application (see chapter V – part I for a definition of different applications), according to the different levels of expertise and types of visualizations that can enhance

each target audience's understanding of the object.

Furthermore, the dataset produced in this last phase will be used for mapping thematic information about the subject and its context, such as its historical stratification and condition.

Each of these phases is associated with existing instruments (or Hardware) and applications (or Software). The following pages provide an overview of these techniques, which can be used according to the principles and requirements of producing a 'Bauaufnahme' for the study of built heritage.

3.2 COLLECTION TOOLS (ACQUISITION)

Collection tools for a 'metric survey study' consist of measuring equipment (E.g. Conventional Hand-survey, EDM, Laser Scanning, Photogrammetry, etc) and in thematic content assessments: equipment for the digitalisation of historical documentary sources (E.g. Scanners, OCR software, Raster Image processing applications, etc).

These tools can be defined as Recording techniques, referring to tools for capturing information of the geometry and texture of the subject's fabric (see chart 03).

In addition, the conversion into a readable computer format of 'historical documentary sources' is implemented by digitalisation tools (e.g. scanning of iconographical sources, vectoring of old drawings, etc) (see chart 03).

3.2.1 RECORDING TECHNIQUES: DIRECT AND INDIRECT

Recording tools consists of 'Metric based survey techniques[4]' used in acquiring the building's geometry and texture.

These techniques can be classified using different criteria, but in this research they are grouped into two main categories: direct and indirect techniques. This classification is based primarily on the level of engagement or contact with the fabric of the building during the on-site work and secondarily, the amount of fieldwork time required for processing.

Moreover, indirect tools consist of 'remote sensing techniques', where the information is acquired from the building through a photograph or using a electronic measuring device, and that involves a lower degree or no contact with the fabric of the subject and where off-site working time is increased for preparing the 'raw dataset' of measurements.

Subsequently, each of these two classifications can be sub-divided into non-photographic (or point and vector collecting survey techniques) and photographic (or where point, vector, and other image-based measured representations are conceived by means of using photographs).

For optimal results these techniques should be used in combination, in order to both create verification and control systems to assess the integrity and quality of the dataset measured and in the most of cases to complement themselves. This relates to the measurement of parts with other techniques, where the original tool is not capable for yielding good results (E.g. a non-photographic technique would not provide enough information about weathering processes, therefore requiring a complementary image-based technique to acquire the texture of the fabric).

Moreover, in some cases conventional hand-survey techniques can interact better in confined spaces or indoors, where more advanced techniques are useless, while in outdoors this second group is more effective than hand-survey.
In this case it is recommended to implement good merging and verification methods to combine the information collected by the

different techniques.

3.2.1.1 Direct recording techniques

Direct techniques are associated with entering into direct contact with the fabric of the object. These are also called '*contact or touch techniques*' (Addison, A., 2000, p 27)[7].

Contact technologies are known to be systems that '*are fundamentally speed-constrained, since a probe tip, reflective target, receiver, mouse, or tape end must be physically moved to every 3D coordinate in question*' (Addison, A., 2000, p 27)[8].

It is important to point out that the terms direct and indirect survey techniques have been already addressed by many researches, but they are quite ambiguously described.

This ambiguity is perhaps because they do not take into consideration the main fundamental in investigating buildings or 'Bauforschung', related to the need of multisciplinary teams of researchers having previous knowledge of the object and site; as well as constant interaction with the fabric of the building in order to have understanding of its historical layering and weathering processes affecting its consistency that can not be achieved by any other means other than direct and trained eye-contact with the subject.

Furthermore, the 'non- and thematic assessments' for the 'core data' giving grounds to produce the 'critical and analytical report' of the monument could be complemented by on-site observations, sketching, and other notes to complement the metric survey study (review Chapter IV), condition assessment, and historic assessment.

This investigation encourages direct contact with the object in all phases of work for ensuring an effective assessment of the

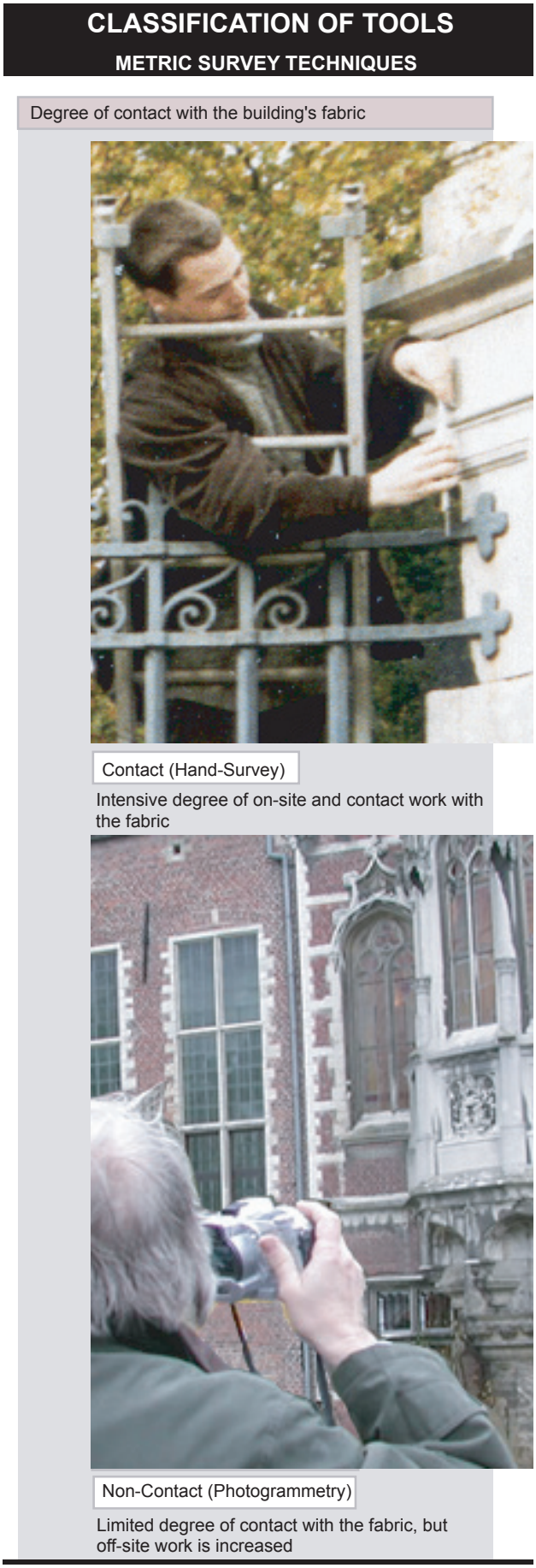


Figure 20: example of Contact and Non-Contact techniques. Castle of Arenberg 2001, Leuven Belgium. Author.



Figure 21: example of tools in the use of conventional hand-survey. Above -Bottom: Castle of Arenberg, Belgium, Middle: roman theatre of Jebleh, Syria. Author.

fabric's geometry and texture.

Conventional Hand-Survey techniques

Traditionally in architectural design, '*the communication of knowledge and information has been communicated through signs made of ink on paper. The signs are two-dimensional representations of a three-dimensional artefact such as a building*'. (Bertol & Foell, 1997, p.44)[9].

Hand survey is applied using different instruments and methods; the most common are Trilateration (or triangulation) and Transverse (Polar system).

Moreover, nowadays most conservation recorders or Bauforscher continue to use these tools, claiming that they provide the closest *'contact with the building, enabling an understanding of the structure and attention to detail not available from other techniques*' (Clark, K., 2001, p.82)[10].

In relation with the statement above, this research acknowledges the need to understand these fundamentals, but suggests to combine them with more advanced recording instruments to provide the same level of engagement with the understanding of the fabric of the subject and its context. Doing so they offer the Bauforscher more time to actually concentrate on the observation of the subject and increasing the speed and integrity of the measurements acquired.

The integrity and quality of a survey 'dataset' not only depends on the capacity of the instrument or method itself but on the ability and experience of the surveyor (expertise required); as well as the prediction of obstacles and environmental conditions of the subject and context to be studied.

Furthermore, in these conventional tools the precision is affected by the desired plotting scale and size of the representation produced, while these issues are less inherent to the product quality of electronic

and image-based techniques, taking into consideration that the output can be modified and improved (upgradeable) at any stage of work in a future, since the principal source of information are photographs.

However, an important advantage from the experience using Hand-survey is the preparation of measured records directly on-site. These graphics provide an 'in situ' instrument for verification and control of the survey being carried out. These activities however can be perfectly adapted to more advanced methods.

Trilateration or triangulation: is the most common technique used by traditional architectural surveyors, it consists of recording the features of the object by measuring diagonals from one corner or network point (Triangulation Station) and preparing a good collateral triangle. This point has previously been set up by establishing a grid of triangles (local grid system) using hand-measuring devices, such as rulers, meters, Theodolithes, etc.

The readings can be transferred directly to the paper 'in situ' with a convenient scale or, if required, marked in a field sketch, and draft after surveying at the office (off-site), however the first method is more effective but time-constraining.

Transversing or Polar system:

> *'Traversing is a method of fixing the location of a series of station points by means of distance and bearing measurements. The technique thus depends upon linear measurements and measurement of horizontal angles' (Hewitt, R., 1976, p. 139)*[11].

The Traversing system is executed by setting a network of points covering the entire subject and context to be documented; each point should be visible from at least two other stations. Firstly, after preparing the network of points, the surveyor measures the distance and bearing angle from a Station to a second fixed point. He transports the instrument and continues the measurements of the network using the second point as a bearing.

Furthermore, he continues measuring all the remaining points using the same method described above, always re-measuring the bearing station, if he returns to the initial station the method will be called Close Traverse and if not Open traverse.

Close Traverse is aimed at increasing the accuracy of the reference system and therefore the integrity of the whole set of measurements acquired. The readings from this system can be improved with least square calculations.

Subsequently, after the polygons are measured and improved, the bauforscher will now measure the object by placing a plane table or other instrument capable of measuring distances and angles from the station point to a desired element. The readings will be drawn 'in situ', choosing a convenient scale.

This system has proven very efficient, since the reference system is fixed using external features, such an external grid of points.

On the other hand, this method is the base of all modern measuring systems, such as a Total Station and Long-range scanner systems.

Conventional hand-survey equipment

Hand Survey instruments consist of a large range of tools, such as plane tables, tapes (metal or plastic), ranging rods, plumb bobs, measuring ruler, rules (wooden and plastic), rope, handheld levels, compasses. It is important to remember that each of these tools has its own limitations or error parameters that should be known by the Bauforscher prior to engaging in a survey.

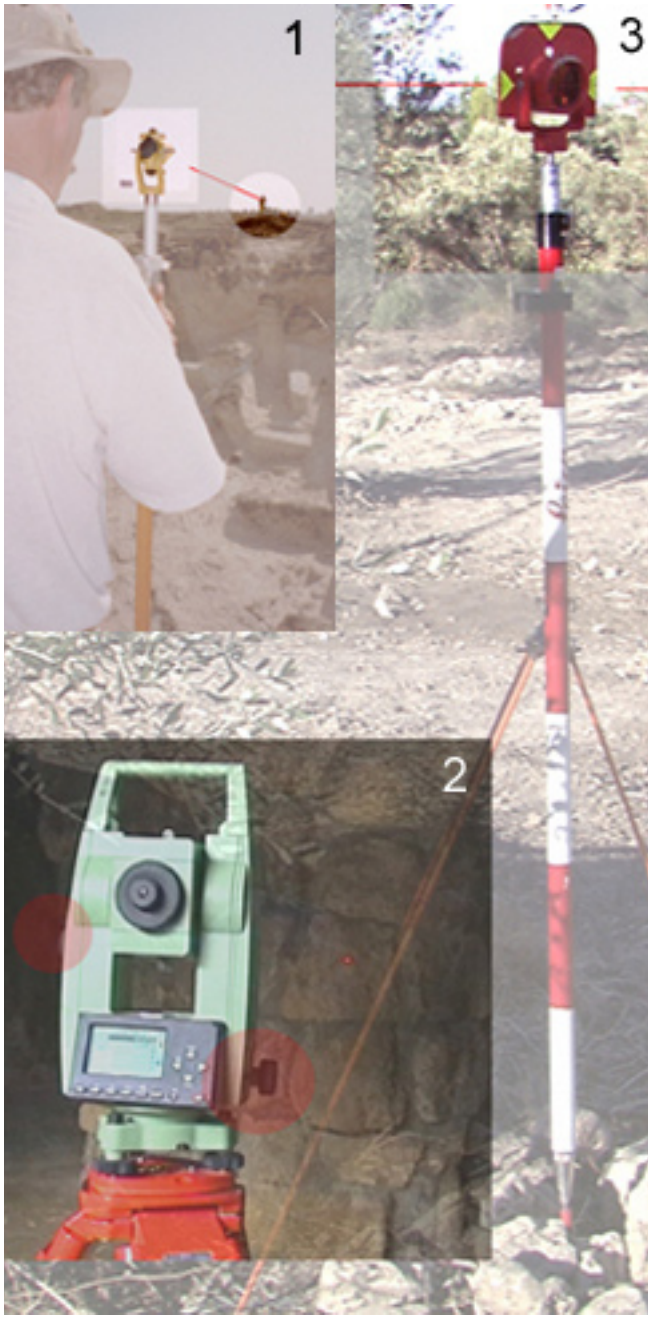


Figure 22: EDM device: Total Station (1) - REDM device: Reflectorless Total Station (2). Author.

3.2.1.2 Conventional Analogue instruments (optical): Theodolithes and levels:

Analogue Level

An analogue level requires careful levelling prior to start measuring. This device enables the operator to calculate the difference of height and distance between two points

> *'After the instrument has been carefully levelled, the first sight is made to the bench mark; that sight, called the back-sight, is then recorded. The levels made of the various parts of the building are called the fore-sights. The difference between the various foresights and the back-sights is the absolute level in relation to the bench marks' (Detweiler, A.H., 1948, p. 22)*[12].

On the other hand, levels with availability of angle readings are considered to be most useful, since the surveyor can read an angle from a station point in addition to the other features available.

It is recommended to transfer and verify the accuracy while executing the survey. A drawing can be made in-situ with the information, or combining a more advanced method by inputting directly the data to the computer using a notebook powered with a CADR package.

Analogue Theodolithe

A theodolithe is capable of measuring angles (horizontal and vertical) and distances (range from the instrument station, '*in order to operate properly, they must be levelled. Once levelled, they can be used to set a datum plane on structures through the telescope reticle (cross hairs)*' (HAER, 2000)[13]. This instrument requires at least two people to operate.

3.2.1.3 Time-of-flight (Addison, A., 2000, p 27)[14]

An electronic tape measure device (or hand-held laser distance meter) is capable of projecting a laser beam to a surface and measuring the distance between the device and the pointed element. The range of these instruments varies between '0,3 to over 100 m' (Leica, 2001)[15].

There are several possibilities with these equipments. They can be useful to measure

interiors in a relatively faster way and are able to give the Bauforscher measurement from higher points than using conventional metal or plastic tapes.

In more advanced time-of-flight instruments, the measurements collected can be used for calculating the area and volume of the space measured using the device's internal memory (see figure 23).

3.2.1.4 EDM (Electronic Distance Measurement): Total Station

This instrument called EDM after being properly levelled in a fixed measuring point and orientated using a base bearing from a second measuring post (bench-mark or standpoint) records points to a measuring point by projecting an infrared beam (EDM mode) to a prism rod (reflector), or a laser beam to a surface up to 80-100 m. from its position (REDM mode)[16].

This action permits calculating the three-dimensional co-ordinates, and if required, other geodetic information between the point and the original reference point, such as angles, distances, different of heights.

The measured points are stored in the memory of the Total Station or other device. After surveying, the collected data is transferred to a notebook computer using communication software that transforms it into an ASCII list of co-ordinates readable by the selected CADR applications or other CADR readable format (e.g. DXF).

EDM Total Station (Electronic Distance Measurement)

This instrument can record points by projecting an infrared beam to a reflector (as mentioned above. Calculating the three-dimensional information between the point and the original reference point (see figure19).

EDM Survey: a line sight

Time of Flight - Example Disto Leica



The instrument is used to record distances, single collection, more advances devices allow recording to an internal memory

GPS Receiver - Example Trimble



The instrument is used to record positions, covering a large area, accuracy in cms. only outdoors operation.

Figure 23: Time of the flight and GPS receivers. Leica and Trimble product website. Author.

measurement method using an EDM instrument and a target to measure to. Data is recorded by measuring the distance, horizontal and vertical angles to a reflector, giving a very precise measurement. EDM is rapid and precise but requires the surveyor to select the data to be recorded in the field: it is not a mass data capture method like photogrammetry or laser scanning (Clark, K., 2001, p.81-82)[17].

An important characteristic on this system is that it requires at least two people 'to operate them effectively--a transit operator and someone to mark a point, or hold a measuring tool or prism rod in alignment with the telescope' (HAER, 2000)[18].

REDM Total Station (Reflectorless Electronic Distance Measurement)

A REDM total station uses the same principal explained previously '*but will operate over 5-200 m without reflector which has the advantage of rapid targeting and access to remote targets*' (Clark, K., 2001, p.82)[19].

On the other hand, the range of the laser measuring method might be affected by the reflective properties of the material (see figure19).

3.2.1.5 Global positioning systems (GPS) receivers (Addison, A., 2000, p 27)[20]

There is a very long-range of GPS receivers available depending in their accuracy and speed to engage with satellites to provide geodetic information.

GPS or Global Positioning Systems. The advent of satellite-based navigational systems has led to the development of very precise land surveying instruments that rely on satellite signals to determine location. Many of these instruments can resolve land coordinates in three dimensions to within an inch, but it takes the instrument about 5 minutes per station to determine the figures. These systems also operate well only in open areas. Significant tree cover attenuates the satellite signals too much for accurate work (HAER, 2000)[21].

These systems are widely used for surveying very large areas, especially in archaeological sites or historic towns. It is recommended to use this instrument for establishing references from a local grid system to a wider coordinate system and which calculates the exact altitude of a surveying point (see figure 23).

3.2.2 INDIRECT RECORDING TECHNIQUES

Indirect techniques are used to reduce the amount of work off-site, reducing the time required to record the whole thing. This does not necessary mean that there is no planning work prior to and during the survey process. Mostly these techniques are effective if the site is studied, planned ahead and all devices are tested and verified during and after completion of the documentation using other direct measuring techniques.

Moreover, image-based or photographic-based techniques such as digital photogrammetry and rectified photography could be both considered a direct (contact) or indirect (non-contact) techniques in terms with requirements of using 'receiver, mouse and picking must be physically moved to every 3D coordinate in question' (Addison, A. & Gaiani, M., 2000, p.27)[22]. However, in relation with this research, they have been classified as indirect, since the processing work is mostly offsite.

3.2.2.1 Photographic based (image-based survey)

Photographic techniques can be used for simple reference reporting without having to perform any metric conversions or involving 'the use of visual images to generate a line drawing or scaled image form' (Clark, K., 2001, p.79-80)[23].

These systems used either analogue and/or digital photography. Each of these formats has its own constraints. On the one hand analogue format has to be digitised using specific parameters for taking the photograph, as well as to digitise the negatives for calibration purposes (e.g. parameters such as: film, fixed focal length, inner reticule or fiducials required, measured targets for orientation and scale the system).

> *'The output may be in the form of a record photograph, a line drawing, a three-dimensional digital model, an orthophotograph or a perspective view. Image-based survey is economic value there is clear open view of a large subject, such as an exterior wall. The image itself is also a useful archival document' (Clark, K., 2001, p.79-80)[24].*

There are several photographic based techniques available, however the most common used in architectural heritage studies are: field or observational photography, rectified photography, photogrammetry and generation of ortho-photographs.

Field or Observational Photography

Field photography is divided into two techniques oblique and parallel. These techniques are basically used for referencing and roughly measuring applications. They are very useful for the planning stage of other more advanced and metric survey techniques.

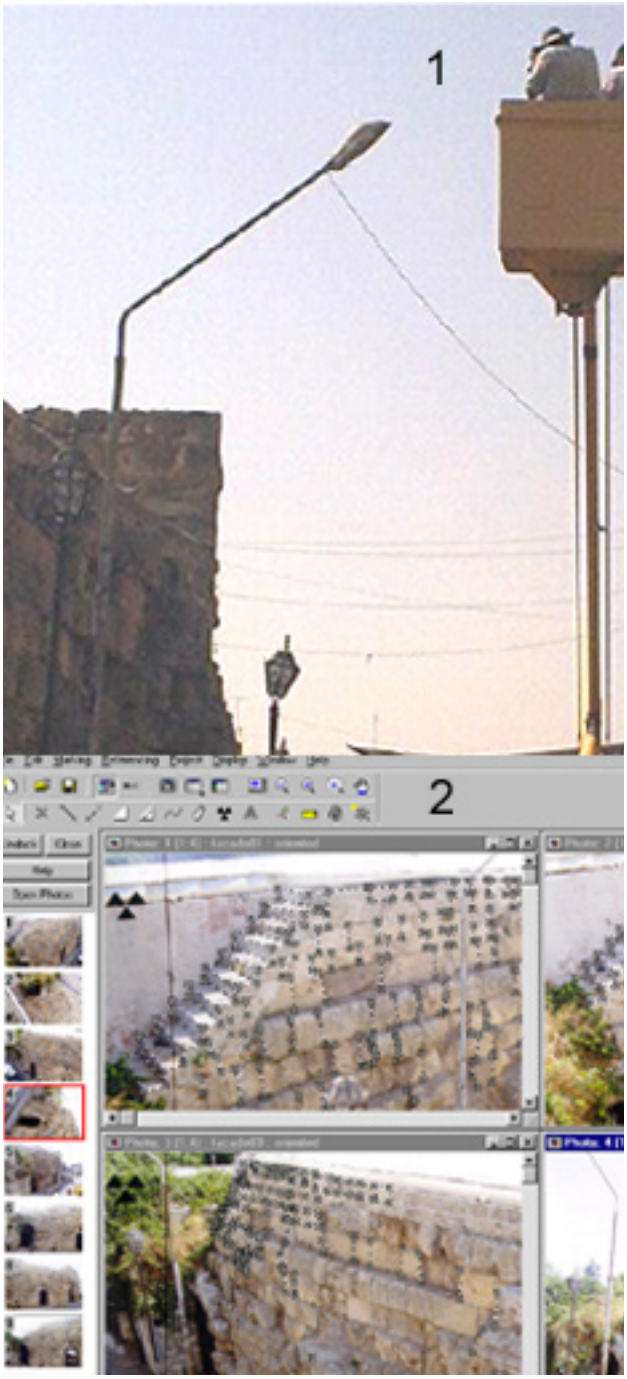


Figure 24: digital photogrammetry: data acquisition (1) - aata restitution (2). Author.

Oblique photographs

Oblique photos are two- or three-point perspectives intended primarily for contextual coverage and only secondarily for any dimensioning purposes. However in metric surveys they are used for photogrammetry, photographs required having a good overlapping, parameters of the camera (internal orientation) should be previous knowledge of, and sufficient coverage of the targeting system (external orientation).

Furthermore, these types of photographs are used for observational purposes, in order to describe condition reporting or historical events and changes. In this case the photographs should have a simple orientation system (using the north and photo-position maps with exact location of the shot), scaling and the integration of a colour-referencing chart if the operator wants to describe decay proposes.

Parallel photography

Parallel photograph is used for creating photographic records, which can be used as roughly measured representation without more processing work. They are best limited to things that lie in fairly regular planes, since parallax errors unavoidably introduced by perspective effects can cause scaling problems and unacceptable distortions in objects that project or recede from the object.

This type of observational photography can be of further use if rectified using processing and reference techniques using Photogrammetry or ortho-photography applications.

Close-range Digital Architectural Photogrammetry: Stereographic processing or Bundle Adjustment

Although analogue photogrammetry continuous to be a widely used techniques still nowadays in 'Metric Survey' for the documentation of built heritage, Close-range Digital photogrammetry is both cheaper and more reliable, therefore this part concentrates on explaining this latter technique only.

> *'The photogrammetric approach offers several significant advantages compared to classical surveying methods. Field operations are reduced to the acquisition of photographs and the measurement of a few control points' (Albertz, J. & Wiedemann, A. 1995)*[25].

Photogrammetry is a technique used to acquire accurate three-dimensional geometric 'Stereographic processing' (Grussenmeyer, P. Hanke, K. Streilein, A., 2001, p. 303)[26] or Stereo-plotting or from a multiple sequence of overlapping photographs where a set of homologues features can be identified using 'Bundle restitution' (Grussenmeyer, P. Hanke, K. Streilein, A., 2001, p. 304)[27] techniques.

Stereo-Plotting

In Stereo-plotting, the technique is implemented through the view of a pair of photographs of an object that viewed together generates a 'spatial (stereoscopic) impression' (Grussenmeyer, P. Hanke, K. Streilein, A., 2001, p. 303)[28], which is used for the restitution of a three-dimensional set of points and vectors (Wireframe).

In the case of the restitution of a whole subject, this method should be applied in recording each plane using a single pair of photographs and subsequently combining the products and merging them in a 3D model with the help of the network of reference control points that cover the entire subject.

Bundle Restitution

This process of restitution is in some cases more effective than stereo-plotting, because the Bauforscher is capable of covering the entire subject with the use of a multiple number of photographs, '*the strategy of taking photos is that each point to be determined should be intersected by at least two rays of satisfactory intersection angle*' (Grussenmeyer, P. Hanke, K. Streilein, A., 2001, p. 305)[29].

The combination of known internal and external orientation parameters from the acquisition camera and the Bundle adjustment calculations to identify each homologue point allows the production of 3D Wireframe of points and vectors; as well as, ortho-photographs.

Process

The process of implementation in both systems of photogrammetry is divided in five phases: data-acquisition, data-restitutions, data processing or modelling, data-verification, and data-export.

Data-acquisition: three-dimensional data from buildings will be extracted by photogrammetric means of calculating or previous knowledge of the external and internal orientation inherent to the parameters of the camera used and position; as well as, photographs taken.

Internal orientation consists of knowing the characteristics and position of the camera used.

Characteristics of the camera deals with knowing the focal lens, lens distortion, format size, digital image format, and middle image point.

Furthermore, external orientation deals with the identification of at least three homologues points in each photograph, which can be relative (local) or absolute, if a control network of points covering the whole site is referenced in each photograph. This last method is used for scaling and orientating the results.

This phase is executed 'in situ'. The first part consists of the selection of an adequate reference system (control points) for absolute External Orientation.

The camera used for acquiring the photographs should rely on already known parameters with one or several camera focal lengths used for internal orientation.

Data-restitution: this process consists of identifying homologues points in each photograph. This phase is executed after the scanning of the negatives, in case of the use of Analogue cameras and subsequent digitalisation or by importing images from a digital camera.



Figure 25: rectified photography, example: East front, Citadel, al-Baleed archaeological site, Salalah 2001, Oman. Author.

Firstly, this process consists of contrast enhancement, filtering, correction of geometric or radiometric distortions etc.

Furthermore, the homologous control points are identified in each photograph and referenced using single numbering for matching and orientation of each of the photographs[30].

When this process is finished, the photographs are ready for further acquisition, processing and modelling of the data collected.

Data-processing (Modelling): in this phase the operator selects points from the fabric of the building to construct a three-dimensional Wireframe of the building, either using stereo plotting with the use of a mounted or infrared stereoscopic lenses or by picking and referencing the points in each photograph separately (Bundle restitution).

The process is executed by 'the identification of homologous points in two or more images which can automatically be achieved by digital matching techniques' and 'the simultaneous overall adjustment of all bundles of rays in a project yielding the highest accuracy which can be achieved' (Albertz, J. & Wiedemann, A. 1995)[31].

The matching process and resulting modelling is a speed constraint action that requires a lot of hours behind a computer screen, matching points and defining entities.

Data Verification: the use of photogrammetry is widely recognized and it can ensure accurate acquisition of geometrical and texture information of the scene, however it is important to implement a control technique to ensure adequate results. Data verification is built in several applications to evaluate the sources of error and provide the operator information about the survey.

This process can also be executed by measuring specific points in the fabric using other EDM devices and they in turn compare the results with other systems.

Furthermore, verification also deals with reviewing the results of the restitution on-site, observation is a very important factor to improve errors in the process of modelling.

Data export: several photogrammetric applications have the possibility of being linked to a CADR package as plug-ins so as to increase the amount of modelling and processing tools to construct a three-dimensional representation of the building and even produce accurate ortho-photographs.

However, it is very common that after selecting and matching all the lines and points this information is exported to other CADR applications for further processing or to Visualization tools, such as Virtual Reality or image-based rendering.

Rectified photography

This technique is relatively inexpensive, quick and reliable. It can be a highly effective technique generating a corrected image-based representation for fully or roughly regular surfaces; this method can be use if the following conditions are available:

- Surface should be flat, not irregular. Nevertheless depending on certain needs the recorder can use a certain degree of assumption about the irregularities of the surface.
- The camera should be roughly or absolute parallel to the surface to allow proper recording.
- An external reference system should be implemented to ensure acquiring the scale of the object and accurately reduce the distortion of the photograph.
- Overlapping of at least 30% is required for recording the surface, if multiple photographs are required

It is important to bear in mind that each regular plane should be rectified separately to cover the whole subject's fabric. This technique is executed in three phases of work: photo-acquisition, photo-rectification

and photo-export.

Photo-acquisition: this phase is related to the required 'in situ' work and the preparation of a regular horizontal and vertical reference system for facades or horizontal reference system in aerial photography.

The regular reference system is prepared by placing a specific number of control points in the surface, if an EDM if not available, the fixing of the points should be performed using conventional tools, such as a plumb for the vertical axe and levelled strings for the horizontal system. The interval distances between strings should be known.

Furthermore, the photographs should be taken parallel to the plane whilst using adequate focal lengths and at the same distance to the subject if several shots are required. Each string intersection or target measured using an EDM device should be visible in each corner of the photograph.

Photo-restitution: the produced photographs should be digitised and transferred either to a specialized rectification package or Raster-image application for a mechanical distortion adjustment. The last is more economical but less precise, since the correction is based on the eye-point identification instead of an automated homologues technique.

> *'Complex surfaces have to be rectified with differential rectification methods There are two classes of rectification approaches: The parametric and the non-parametric approaches. Whereas for the parametric approach the knowledge of the interior and exterior orientation parameters is required, non-parametric approaches require more control-points' (Hemmleb, M. & Wiedemann, A. 1999)*[32].

This part explains the use of non-parametric techniques in which the establishment of a parallel plane to the photographed scene is crucial. This allows for the rectification of distortions. This can be achieved by manipulating the coordinate system and defining a parallel plane to the horizontal-vertical reference system using a CADR package. Furthermore, the resulting view is transferred to a raster application where it terms the background to the photographs, which are modified using stretch and distort commands to match the points in the rectified view and the photographed targets previously prepared.

After fixing the distortion, the photographs can be matched together in order to cover the whole area. The resulting rectified photograph can be vectorized by placing it as background in a CADR application.

Photo-export: rectified photographs can be clipped in a CADR application for mechanical vectoring, orientation, scaling of the image as a parallel source of information. In this case the photograph will be exported as a raster image and print out in paper.

Ortho-photography or Ortho-images

The principles of Ortho-photography are very similar to rectified photography, however the differences radicate in the data-restitution and data-processing phases, where they are prepared as a product of a photogrammetric restitution.

> *Orthophotographs are a product of digital photogrammetry. They are two dimensional photographs which have been corrected for scale errors, with a consistent scale across the whole image, irrespective of relief or changing plane in the subject. Orthophotographs are useful if the subject is too three-dimensional for rectified photography to be applied (Clark, K., 2001, p.79)*[33].

Orthophotographs can be very useful to eliminate this interpretation and simplification

of photogrammetry, where the information is reduced to vectors and points.

> *'Where the complex image information is reduced to some simple lines. This enormous reduction of information can be avoided by preparing orthoimages. Orthoimages are orthogonal projections of three-dimensional objects on a mathematically defined surface' (Albertz, J. & Wiedemann, A. 1995)*[34].

In this technique, photogrammetry is used for creating orthogonal projected photographs with a flat plane (view) in order to be vectorized or used as supporting source of information.

> *Digital orthoimage techniques, like differential rectification are well known in aerial photogrammetry, but they are rarely used in architectural photogrammetry (Hemmleb, M. & Wiedemann, A. 1999)*[35].

The resulting ortho-photograph or image is used for condition recording and other techniques.

3.2.2.2 Non-photographic techniques

In the framework of this investigation, terrestrial long-range Laser Scanning are classified as an emerging tool, however this technique is already proving to be effective in recording a large amount of measurements of the geometry of the subject in a short timeframe.

Laser scanning is based on measuring a large set of points with defined intervals and an accuracy expressed in millimetres. The range varies approximately between 10 to 120 m.

Furthermore, these points are processed by specialized applications for reducing the amount of points, merging different scanning readings and the production of solid modelling or surface modelling representations. This technique is explained in more detail in the paragraph devoted to emerging technology.

On the other hand, this '*second group of technologies has emerged in the last decade and that doesn't require contact with the object, offering clear advantages when working on landscape or monument scale. These non-contact or camera tools include projected light stripe (or moiré pattern) digitisers, prototype auto-mated stereo video photogrammetry systems, and an array of laser-based scanners, ranging from triangulation to phase shift and laser radar (lidar). Although these tools have their own limitations, they are generally much faster than contact systems—a key requirement for preparing complex 3D representations for virtualised reality*' (Addison, A. & Gaiani, M., 2000, p.27-28)[36].

These new technologies have a lot of potential, nevertheless most of their limitations eradicates on transportation, weight, dependability, reflection of the material and robustness, as well as the large investment required.

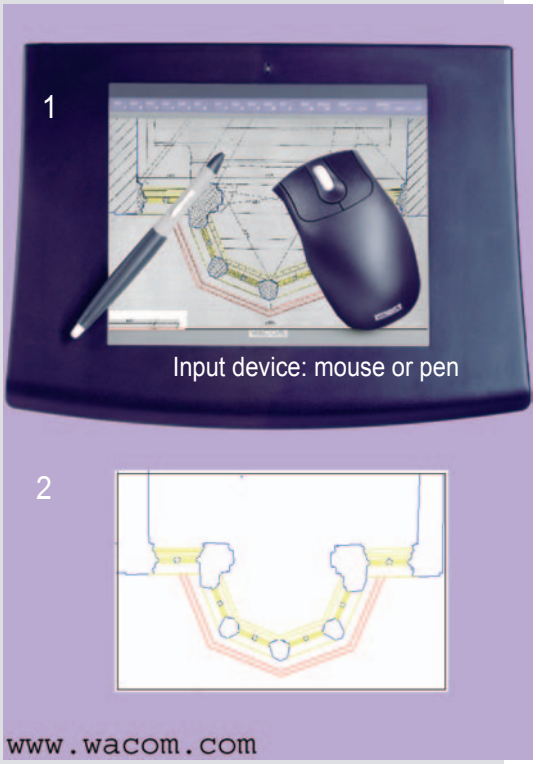
3.2.3 DIGITALIZATION TOOLS FOR HISTORICAL DOCUMENTARY SOURCES OF INFORMATION

Digitalisation is the process whereby data is translated from an analogue format to the computer's digital format, in order to store them in the memory of the hardware for future manipulation.

These tools are used exclusively to digitise data from indirect sources of information, as most commonly used as reference systems for the direct survey of the building's fabric. They are classified in:

- digitalisation of existing survey maps:

Vectoring with a digitiser tablet



1 The digitiser is configured with AutoCAD and the drawing is scaled with the features available in the programme.

2 The drawing is digitised by vectoring the important features, such as windows, doors, walls, etc. The resulting drawing is scale and digital in AutoCAD.

The quality of the result will depend on the ability of the operator to digitise the features and the quality of the drawing source.

Figure 26: vectoring maps using a digitizer tablet. Wacom website on digitizers.

scanning and vectoring
(Digitisers or Raster-trace software).

- digitalisation of iconographical sources and old photographs:
scanning (pixel-image creation).

- digitalisation of written documents:
scanning (pixel-image creation) and optical character recognition (OCR trace).

It should be bear in mind that these techniques are normally very laborious and require sufficient operational knowledge of the applications and ability for interpreting the sources to be digitised.

3.2.3.1 Digitalisation of existing survey maps

These techniques are used to convert a 'hard-copy line drawings or photographs into digital vector data' (English Heritage, 1998, p. 24)[37]. The limitations of these applications are based in the quality, scale and other graphical restrictions of the prepared map.

Most commonly these maps are used for background information and to complete information for historical phasing in maps collected using direct sources of information.

Vectoring maps: Using Digitiser tablets or vectoring scanned plans

These techniques are use when an accurate survey already exists. They can be classified in the type of contact or touch classification.

Mechanically or rudimentary vectoring

This is a rudimentary technique of digitising existing survey plans by means of reading the graphic information of the drawings through the use of a ruler and other traditional drafting instruments (e.g. tracing paper, tee-squares and setsquares) and transferring the data to the computer by inputting the data manually to a CADR application.

> *'Drawing instruments are usually slightly in-accurate' (Hewitt, R., 1976, p. 156)*[38]

Although this technique might be inexpensive, it is time consuming and the integrity of the results are based on graphical representation limitations. Further, and any small calibration mistake in interpreting measurements and angles can cause a chain of errors affecting the reliability of the

results.

3.2.3.2 Vectoring with a digitiser tablet

These instruments are used to input a two-dimensional point from a drawing or rectified picture using a pointing device that has beneath it a sensitive electronic grid connected to a CADR application. They are available in any size from A4 to A0.

The resulting integrity and quality of this process depends on the quality of the drawings used to digitise and the ability of the user to calibrate the scale of the plan and the point-eye-selection with the mouse for creating vectors and other abstraction elements (see figure 26).

3.2.3.3 Vectoring using a clipped image as background

This is a recent feature provided by most CADR applications. A scanned map is clipped on forming the background in the model space of the application. Vectors and other features are then prepared using embedded commands though vectoring the drawing shapes. Furthermore, it can be positioned to scale using other features of the software.

This technique is similar to the vectoring of rectified photographs. The constraints or disadvantages of these methods are based in the embedded and scanned quality, and the reliability of the source. Meaning the user's capacity of interpreting the width of the drawn line-weight (or eye-point-selection with the mouse), as well as the interpretation of irregular shapes.

Vectoring with a Raster-Trace application

This application is a widely used method in order to gain a reliable amount of information on towns, regions and other large-scale areas. However for the heritage it has hardly been used. Thanks largely to the huge initial investment in software and large-scale scanners needed, and to the level of specialization needed to make convenient use of the software. Prices have dropped recently and there is a large price range of applications nowadays.

This application works by specifying new computer vector lines or shapes according to the quality, colour and line-weight of the lines to be vectored. If the software is not used with care the results can be extremely time-constraining and it probably is preferably in this case, to review other more simple techniques.

On the other hand, and to a certain extent, an operator can use relatively cheap software and improve the resulting vectored plans using the CADR application. As already mentioned however this can be time consuming and perhaps a digitiser would be more suitable and faster.

The disadvantages of these techniques are similar to other tools; however there is more emphasis in the correct manipulation of the software settings and features.

Iconographical sources and old photographs

Iconographical sources and old-photographs are normally digitised to pixel images to be used as a reference and support sources for historical facts and traces in the fabric of the building. They should be scanned to an adequate resolution depending on the requirements of the dissemination tool (e.g. for public distribution on the Internet the resolution will be lower than a printed publication).

Many of these sources are partially damaged and very delicate requiring adequate handling that does not always allow them to be scanned using hand-held or desk scanners. In this case digital cameras can be useful.

On the other hand, should there be a large enough budget, old wooden and plaster

models can be scanned using short-range laser scanning, which a turn are merged to the actual 3D survey in order to create hypothetical reconstructions.

Digitalisation of written documents

3.2.3.4 Scanning of archival records

Archival records can be transferred to pixel images using a scanner or digital camera with an adequate resolution adapted to the application requirements.

Moreover, following principles of historical research, references from the archives can be transferred to the computer by retyping the text. There are some applications that can recognize hand written work but they are quite limited and time consuming.

3.2.3.5 Scanning and Optical Character Recognition (OCR – trace) of typed written documents

Depending on the age of the monument, many of the documents might have been already typed; in this case the application of OCR-trace technology for recognition of written text can be of use.

Moreover, a new generation of hand-held scanning devices with OCR-Trace capabilities has been released on the market. These devices allow the inputting of a relative large amount of text that will be directly transferred to an ASCII format.

Both techniques should be practiced with care and with adequate verification of the contents in terms of paragraph structure and other issues related to written documents.

3.3 PROCESSING TOOLS (ANALYSIS)

There is a large amount of processing tools available for manipulating and modelling the 'raw data' collected with direct and indirect recording techniques.

A strategy for implementing useful 'metric survey tools' could be used to make use of more conventional or more cost-effective techniques for recording in collecting and more advanced techniques for processing, or vice versa.

There is a vital relation between the type of recording and processing techniques implemented; they should be compatible and adapted to the requirements of each other.

According to the classification described in previous pages, processing tools can also be divided in non-photographic based techniques and photographic techniques.

However, it is important to mention that non-image based techniques can recourse to these tools to complete the 'measured dataset' and vice versa.

This research promotes the use of approaches that can capture and model the measured information about the geometry and texture of the object's fabric and context, observing that in reality, there are a number of acquisition and processing tools that do not necessary require the acquisition of measured data to produce photo-realistic representations of the subject (e.g. image-based rendering) but that restrict their accuracy and visual flexibility.

> *'The lack of geometric model impedes the accuracy and the freedom to render the environment from arbitrary viewpoints' (El-Hakim, S.F. 2001)*[39].

3.3.1 GEOMETRIC MODELLING (VECTOR, SOLID AND SURFACE MODELLING)

Traditionally when representing architecture, the use of metric or measured representations

leads to the definition of different levels of abstractions (level of detail) depending on the needs and conventions requires representing reality, such as orthographic projection, perspectives and paraline projections.

It is clear that computer modelling uses the same conventions and principals of conventional hand drafting. However, its tools provide tools for experiencing real-time interaction in a three-dimensional environment.

In geometric modelling, it is possible to identify tools for vector drafting, solid modelling, and surface modelling. These techniques are based on the retrieval, storage and further processing of vectors, surfaces and points captured from the subject of study using direct and indirect recording techniques.

In built heritage, the most used and perhaps most reliable technique for manipulation of the 'raw data' collected from the instruments is a computer-aided drafting application (CADR) for architecture and digital terrain modelling (DTM) for modelling the landscape.

Nowadays there are roughly over 30 different commercial applications of this type at the market. They were mainly developed for the following fields:

- Architectural and civil engineering design
- Landscape design
- Mechanical and Industrial design

This part focuses on explaining CADR and DTM as applications used for modelling and representing the geometrical characteristics of the information contained on and beneath the area surveyed.

3.3.1.1 Computer Aided Drafting (CADR) applications

Computer-aided drafting (CADR) applications were originally designed for manufacturing engineering, '*where accuracy is of extreme importance'* (Ashton, R., 1995, p.42)[40]. Today however they are used in any field that is related to design and conception of objects using measurable techniques including the study of built heritage.

In the specific use to simulate the actual state of conservation of monuments they offer interesting tools for modelling the building and context geometry.

Furthermore, it can be used to reconstruct the phases of construction and modifications of a building, always based on a geometric representation.

These packages are fundamentally capable of working with objects represented to a full scale, without previously having to establish an output scale.

Moreover, they are capable of creating both two- and three-dimensional representations with specific levels of abstraction, using standard conventions (e.g. orthographic, perspectives…) and other more dynamic representations (e.g. real-time animation, renders and transparent views).

Vector modelling (Two-dimensional)

A vector is a straight line connecting two points in space. Furthermore, '*vector graphics is a term used for specific computer graphics defined by lines*' (Kerlow, I.V. & Rosebuch, J., 1994, p. 14)[41]. This type of modelling technique is mainly used for the creation of two-dimensional representations, such as elevations, sections, plan elevation, and plan section.

> *"When an artist makes a freehand sketch, the intended entities and relationships are rendered only*

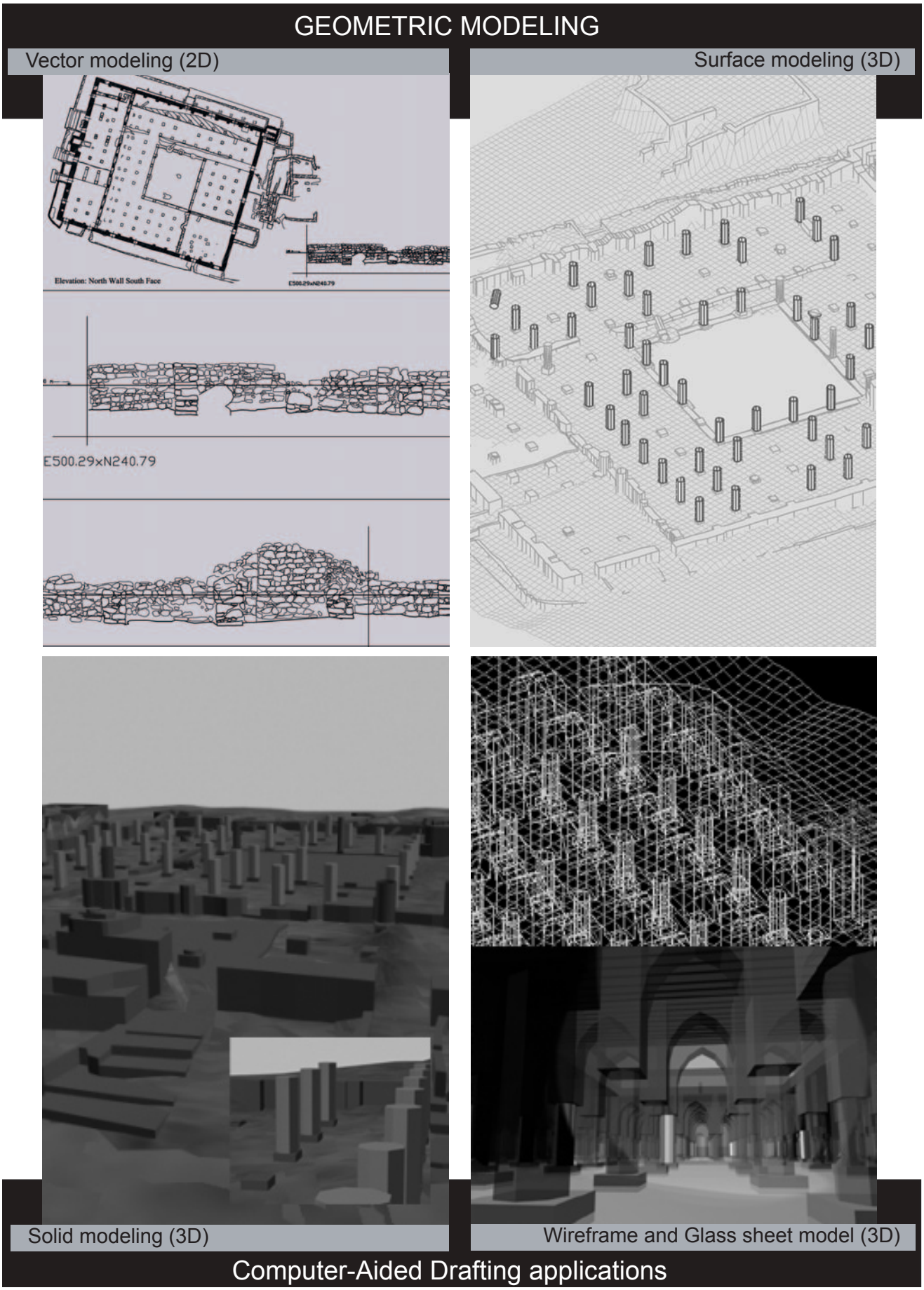


Figure 27: examples of different geometric modeling tools: vector modeling, surface modeling, solid modeling, wireframe modeling, and glass sheet modeling. Author.

> *approximately by marks on paper. In technical drafting, though, geometric entities and relationships are rendered precisely through use of instruments such as straightedges and compasses, and relationships are formed accurately through execution of geometric constructions.*

Similarly, '*computer graphics software designed for use in technical drafting provide tools for precise manipulation and accurate presentation of geometric entities*' (Mitchell, W.J. & McCullogh, M., 1991. P. 99)[42].

On the other hand, although vectors are associated with two-dimensions, they can be drawn between two points with different height; this can be used for the creation of other three-dimensional representations.

Two-dimensional operations (vector and polygons)

A vector can be drawn using different two-dimensional operations available in CADR packages.

Furthermore, a group of drafting tools, such as line, composed lines, circles, etc allows one to construct simple or complex shapes that can be modified in the future, "*complex geometrical relationships can be resolved by graphical means rather than by recourse to trigonometry*" (Penz, F. 1992, p.67)[43].

Coordinate System: a Cartesian system can be established, where each point is localized in a computer context (or model space). In this case a point can be drawn by the use of coordinates, a pair of numbers, one identifying the X axis and the other the Y axis.

Point specification: this feature provides an accurate method of inputting a point in space by its location using a coordinate. However, it is also possible to locate a point by clicking the mouse, but it is less accurate.

Moreover, a drafting application is built with a snapping point feature, which allows adjacent lines to be drawn from specific properties of the selected elements already drawn. This feature permits one to locate points more quickly and precisely without paying much attention to selecting the right spot (e.g. setting the snapping function to endpoint, it is possible to click and accurate select the edge of a line and drawn a second vector to an adjacent position).

Types and operations with Vectors

CADR applications have a large repertoire of lines, specifically straight lines, elliptical or curved by inputting certain parameters.

For instance, a circle is defined by inputting different sets of points, such as the radius and the starting point, or by specifying two points of the diameter.

Furthermore, this application has introduced a new type of vector composed element called polylines, which is an element composed by a certain amount of chain lines and/or arcs, if the last element is connected to the first point, it forms a '*closed circuit'* (Mitchell, W.J. & McCullogh, M., 1991. pp.130-131)[44].

Manipulation and Duplication of Vectors: there are different tools capable for inserting, selecting, and/or deleting vectors; as well as other more sophisticated features, such as breaking, extending and trimming.

"Break" cuts a vector in different segments, 'the extend procedure lengthens a selected line by a specified amount or to meet some specified line. '*Conversely, a trim operation shortens a selected line by a specified amount or cuts it back to some specified line*' (Mitchell, W.J. & McCullogh, M., 1991, p. 109)[45].

In addition, the creation of new sub shapes can be performed by introducing new rectangles, triangles or complete building blocks. These can be modified using commands like translating, rotating, scaling,

reflecting, stretching, shearing, projecting or deforming.

Moreover, these systems allow replicating forms making repetitive tasks easier and fast. This is very useful for the creation of more complex forms that have repetitive components or building representations that have many similar elements, such as windows and doors.

CADR has the ability of generating very fast geometrical transformation of objects or group of objects. There are five types of transformations (Stenvert, R., 1991, p. 128-129)[46]:

- Translation: movement of planes that does not alter the orientation of the object.
- Rotation: the object preserves its shape but can be rotated through different planes.
- Reflection: the initial shape is mirrored to another plane.
- Shearing: the object is moved in the same plane without loosing its shape.
- Scaling, the object is enlarged or diminished conserving the initial shape.

However one should be aware that they were developed to design new projects. Specific behaviours of these packages limit the accuracy of the representation. They have mostly been created to represent architectural features as regular forms.

Geometric construction

Trigonometrical calculations and manipulation of drafting instruments are used in traditional drafting techniques for finding points in space in recording historic buildings. These operations and techniques are no longer necessary in CADR.

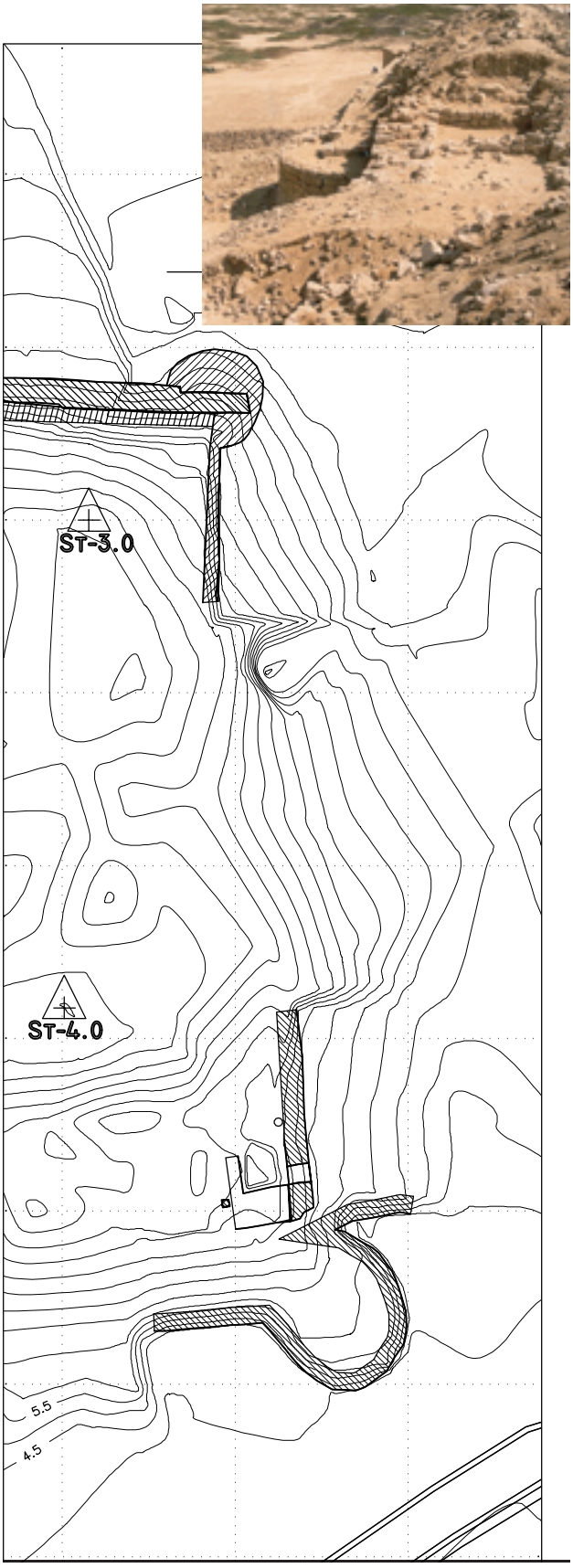


Figure 28: digital terrain model (Contour lines), Citadel, al-Baleed archaeological site, Salalah 2001, Oman. Author.

In computerized drafting techniques finding a point is made by applying different features, such as finding the centre of a straight line by setting the “midpoint” as a snapping point.

Moreover, in addition to this feature, it is possible to create perfect parallels from every type of line (curved or straight), calculate subdivisions, angles, and alignments; as well as extending, breaking, trimming, and creating curves or corners. Specifically the setting of the amount of divisions in a vector can be performed by introducing a set of numbers, lengths, angles or an arbitrary path.

These features increase effectiveness in drawing without the requirements of knowing how to do these calculations. Thus, CADR is very useful for creating very complex elements that were not possible to make using traditional techniques in the past else or that required a lot of mathematics.

Structuring drawings

In traditional pencil drawings the hierarchy of the lines and drawings was made by different pens, width, textures, overlaid sheets of transparent paper and colours. Using the computer, it is possible to have this same hierarchy of graphic levels, but in a simpler way.

‘Drafting systems provide mechanism for organizing drawings, the introduction of entities or layers’ (Mitchell, W.J. & McCullogh, M.,1991, p. 159)[47], assigning an entity to a layer is like drawing it on a particular sheet.

> *They provide for creating and naming layers, working in specified layers or combinations of layers, shifting elements and shapes from layer to layer, and selecting layers or combinations of layers for display, editing, or printing (Ibid 43).*

This feature is very helpful in working with large sets of data, which is classified in different layers (or levels). It allows identifying types of information (e.g. metric survey points, photogrammetric, types of architectural components, etc).

On the other hand, in the beginning of the drawing a set of construction to construct more complex entities can be assigned to a layer. Then these lines can be made to disappear by turning off the specific layer or by erasing it.

This point is discussed in detail in Chapter IV dealing with a Methodology of Structured drawings in the Data-processing phase of a Metric Survey study.

Automated Measurements and analysis

As expected, computerized systems are structured in a way that entities can be measured exactly by simply snapping between two or more points using different variables and parameters provided by the application.

Furthermore, ‘the simplest measurement facilities merely report measured values on the screen. More ambitious systems provide interfaces to spreadsheets or programming languages so that further analyses can be developed from extracted values’ (Mitchell, W.J. & McCullogh, M., 1991, p. 130-131)[48].

Representing and manipulating polygons

The association of adjacent vector objects having an equal height can be defined as a two-dimensional closed polygon. The use of polygons is very useful to create elevations and sections.

These can be filled with patterns or colours to represent different materials (Hatching).

Three-dimensional operations (Solids and Surfaces)

This section explains the use of drafting tools and operations in CADR for construction of

three-dimensional solids and surfaces.

Prior to explaining these techniques, it is important to bear in mind that two-dimensional operations are used for the creation of a wire frame model, which through clipping and windowing techniques is transformed into different desired three-dimensional solids and surfaces.

Basics in three-dimensional entity construction

Construction planes: this system is similar to 'Point Specification' techniques in a two-dimensional plane, only that in this case it is possible to input the height or "Z" value using the keyboard or by snapping the height of an object.

Furthermore, these systems "usually provide a set of commands for specifying a construction plane –by giving the coordinates of three points on it or by tilting up from another plane" (Mitchell, W.J. & McCullogh, M, 1991, p. 156)[49].

Once a new plane has being established it can be stored in memory for a future recall. This can be useful for the construction and manipulation of a three-dimensional model.

Wireframe or glass-sheet models:

> *"The dimensions and construction lines can be carried over from one construction plane to another. This operation enables to work very easily between plan, section and elevation to produce a kind of glass-sheet model in which the essential geometric organization is defined by shaping and positioning profiles and contours in intersecting horizontal and vertical planes" (Mitchell, W.J. & McCullogh, M., 1991, p. 157)[50].*

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This method allows working in different parallel planes at the same time, each of which is associated with specific objects. In addition, it allows for the adaptation of other construction operations in order to create more complex entities, such as elliptical and rounded shapes.

Solid-modelling

CADR packages that allows constructing three-dimensional models using 'constructive solid geometry' (Stenvert, R. 1991, p. 104)[51] or the so called solid-modeling features are effective in simulating irregular shapes of historic buildings.

Most CADR application provide a library of solid primitives for insertion in a drawing by executing '*sweet operations*' (Mitchell, W.J. & McCullogh, M., 1995. p. 240) [52], however in the case of modeling built heritage these features are of no interest, since the fabric is irregular.

On the contrary to primitive solids or '*sweet operations*', 'skinning and tweaking operations, and spatial set operations' (Mitchell, W.J. & McCullogh, M., 1995. Pp. 242-246)[53] provide possibility of creating complex solids using functions such as extruding, intersecting, interfering, subtracting or fusing, which are potentially more appropriate to built heritage.

The function of **extrude** creates a '*solid by extruding two-dimensional objects (profiles) along a specified path*' (AutoDesk, 1994)[54]. One or several different vectors, such as curved, define the path straight or elliptical lines that could be read as a single unit or that are possible to fusion and make a single unity by using another function.

Moreover, in order to create relations among different solids next to each other the '*Interfere'* (AutoDesk, 1994)[55] feature finds the '***interference*** *of two or more solids and creates a composite solid from their common volume*' (AutoDesk, 1994)[56].

Subsequently, a third function is available '*to calculate the overlapping area of two or more*

existing regions and the common volume of two or more existing solids' (AutoDesk, 1994)[57] called **Intersect**.

Subtract, creates a composite region or solid by subtracting the area of one set of regions from another and subtracting the volume of one set of solids from another CADR subtracts the selected objects from each subset of the selection set.

'*A single new composite solid or region is created for each subset'* (AutoDesk, 1994)[58].

Finally, **Union** might composite a solid as result of combining the total volume of two or more existing solids. It also can join solids that do not share a common area or volume. '*The resulting composite solid includes the volume enclosed by all of the selected solids*' (AutoDesk, 1994)[59].

Certain knowledge of the functions and parameters of the CADR application is needed to make three-dimensional modeling. In addition, it is also important to have ability in manipulating the level of detail to comprehend the complexity of the architectural elements to be modeled, as well as, the skill of finding different alternatives to construct an element using the features available.

Eventually, it is recommendable to have acquiring experience in modeling of objects for manufacturing companies, because many tools are also used to built pieces or objects that are smooth and irregular.

The main advantage of this modeling technique is that '*volumetric and engineering analysis*' (Mitchell, W.J. & McCullogh, M., 1995. Pp. 258)[60] can be depicted by the construction of models.

Surface modelling

This type of modeling is based on the 'boundary representation' of shapes, in this case a historic building is modeled by the generation of faces covering the entire subject, and these can be of regular or curved form.

The construction of surfaces can be through the use of 'sweet operations' (Mitchell, W.J. & McCullogh, M., 1995. Pp. 188)[61], where the bounding or profile is produced from a planar primitive or path (e.g. a circle to create a cylinder, a polyline path to create a profile).

Furthermore, '*surface patches*' Mitchell, W.J. & McCullogh, M., 1995. Pp. 193)[62] can be either used to create irregular curved surfaces by the selection of multiple edges or to generate triangulated irregular networks (TIN), the latter is mostly used in topographic modeling, where the terrain is represented by triangular surfaces generated by the combination of three points in different heights.

A TIN surface with sufficient density of triangles is very useful to represent the topography of a site, enabling the user to calculate the volume of the area and create 3d profiles.

Combination of solid and surface modelling

Most CADR packages allows the user to use surface and solid modelling features, these tools allow to make possible to model the irregularities of the building fabric, as well as to represent its landscape.

However, solid modelling is more powerful in the calculation of engineering data that can yield important information about the structural behaviour and consistency of the fabric, while surface modelling is more effective to create smooth and lighter representations to display to a broader audience.

Three-dimensional Geometric Transformations

These transformations are basically the same applied in construction of two-dimensional shapes. They differ in the use of different planes for construction of three-dimensional entities.

Furthermore, a glass-sheet model can be transformed into a complete wireframe model by defining a shape associated to a plane and extruding it through a pre-defined path. A similar feature is performed by rotating elements about axes in their construction planes.

On the other hand, a reflection operation occurs across specified planes, rather than across lines as in two dimensions. Other operations, such as scale, stretch, shear, and perspective-distortion are being introduced with specific parameters for the creation of three-dimensional shapes completing the available repertoire of tools.

Sweeping points: this operation is related to using two-dimensional elements to construct three-dimensional objects. For instance to create a solid, a particular profile is swept along a fixed path.

Space curves: in the past it was very difficult to construct rounded spaces, however it is very easy nowadays with the new technology introduced by the Wireframe modeling.

A rounded space is design by translating and rotating a straight line. Other profiles can be swept creating these kinds of spaces.

Viewing: is related to operations to create three-dimensional views of the scene and object. There are preset projections available, such as axonometric, orthographic projections, perspective, etc.

Alternatively, viewing operations can be used in modelling by rotating the polar coordinate system and to adapt it to the required position.

Furthermore, the program allows zooming using different geometrical projections. If required these views can be stored for future use.

The application of these tools should be subjected to the needs of the measured representation.

3.3.1.2 Digital Terrain Model (DTM) applications

Digital terrain model techniques are used for creating a Digital Ground Model (DGM), which is a '*three-dimensional, mathematical representation of the landform and all its features, stored in a computer data base*' (Schofield, W. 2001, p.12)[63].

A DGM is calculated by using on the one hand the information about the topography of the site being studied or and on the other hand numerous computer methods for calculating the Digital Elevation model (DEM), related to calculations aiming at providing different types of representation techniques.

Topographic information required

The information required to create a 'digital elevation model' is related to collecting a numerous set of three-dimensional readings or points from the topography of the site. These points can be collected by digitising direct and indirect sources of information from the topography.

Direct sources in DTM: field EDM surveying of surface points using a specific interval (or density) for recording readings and stereoscopic measurements from (optical) satellite data (SPOT) or photogrammetric surveys,

Indirect surveying sources in DTM: digitalisation of contour lines from topographic maps previously made or DEM models provided from a regional, national or international agency.

Calculation method for DTM

The most efficient and common technique is the use of the 'triangular grid method', which is the use of the '*best fit triangles that are formed between the points surveyed*'

(Schofield, W. 2001, p.12)[64].

This type of triangular calculation method using the position and height of surveyed points is named a Triangular Irregular Network (TIM). Most DTM applications provide tools for modifying the triangles and heights for improving the representation and provide more accurate results.

Therefore, '*the ground surface therefore comprises a network of triangular planes at various angles*', which can be used for creating a solid model or surface mesh of the landscape, and if necessary the generation of '*contours, sections and levels*', obtained by the '*linear interpolation through the triangles*' (Schofield, W. 2001, p.12)[65].

3.3.2 IMAGE-BASED MODELING AND RENDERING (GEOMETRIC-BASED AND SCENE-BASED)

Image-based modelling and rendering (IBMR) systems are methods that derive '*the structure and appearance of the scene from photographs of the real world*' (Debevec, P. 2001)[66].

They can be grouped in to extraction methods: Geometric Image extraction and Scene Image extraction systems. The first is related to the use of '*priori knowledge about the scene*' (El-Hakim, S.F. 2001)[67], or information about the type of camera parameters, position and overlapping average; as well as, the use of control points and other referencing systems for scaling and positioned the model.

'A principal endeavour of computer graphics research has been the pursuit of photorealism' (Debevec, P., 1997)[68].

On the other hand, Scene-Based systems are related to the use of 'image sequence, projective geometry and automatic correspondence, and no or little knowledge about the scene' (El-Hakim, S.F. 2001)[69]. This system is characterized for having a limited level of accuracy dependent to many parameters about the scene (environmental conditions and access) and type of camera used for retrieving the information.

These techniques are still under development. They provide a highly realistic renders, but produce relatively accurate geometrical modelling. In part on '*incomplete models may result particularly on irregular geometry or sculptured featureless surfaces*' (El-Hakim, S.F. 2001)[70].

3.3.2.1 Geometric Image-extraction

This method is an associated product of photogrammetric applications. It is related to the identification, correspondence and extraction of surfaces in stereo-match photographs of an object by measured geometry.

> *It applies basic photogrammetry for image registration followed by stereo matching to add details (El-Hakim, S.F. 2001)[71].*

The processing is based on previous knowledge of the scene, meaning camera parameters and camera position; as well as, absolute scale and if required, the position of the object.

3.3.2.2 Scene Image-extraction

In Scene image-extraction systems the user is capable of creating a three-dimensional model 'by specifying a collection of geometric primitives such as boxes, arches and surface of revolution'. Subsequently, 'the user corresponds edges in the model to edges marked in the photographs, and the computer works out the shapes and positions of the primitives that make the model agree with the photographed geometry' (Debevec, P., 1997)[72].

> *'These methods can be useful for*

applications that do not require high geometric accuracy but need realistic looking and easy to create models' (El-Hakim, S.F. 2001)[73].

These systems are dependent to a successful correspondence and specific parameters related to taken photographs 'close to each other (Short baseline). This makes them more noise sensitive and numerically unstable' (El-Hakim, S.F. 2001)[74].

3.4 DISSEMINATION TOOLS (SYNTHESIS)

'*Representations are stand-ins for the real environment; they are not duplicates of that environment. All representations are more abstract than concrete reality of the actual environment*' (Laseau, P., 2000, p.85)[75].

Synthesis is the production of the final 'measured Dataset', the phase where the set of graphic representations are shown to a group of experts as foundations for preparing other assessments, in order to reach a 'Critical and Analytical report' about the relevance of the subject or for preparing a visualization for a wider group of people. These dissemination tools are prepared according to various needs, meaning the objective of the visualization and a set of pre-establish parameters providing the type of application and media[76] used.

Furthermore, the product is related to the target audience in relation to their level of expertise. The Synthesis or dissemination phase is explained in more detail in Chapter IV dealing with presenting a Methodology for Documentation and Dissemination of the Building-Context Geometry and texture of historic structures.

There is a large amount of available tools for disseminating the measured dataset; they could be classified in Printed and On-line Information Systems. This classification is related to the type of media used, user-interaction and user-immersion level.

Printed information systems are characterized by the use of static media in representing the subject and its context imprinted on paper or in a computer screen. The level of user interaction depends also on visually looking at the static representation. Most common applications used are maps (or mounted-presentations), slides, static computer graphics, digital or analogue video, and other paper-based representations.

On-line Information systems are conventionally associated with the production of electronic media (Internet, CD-ROMS or Virtual Reality Displays) to browse the results. These applications are characterized by providing with the user the capability of browsing, viewing, and modifying parameters for retrieving and managing the information from a historic building. Among the most common systems are: Non-interactive reference systems, Expert Systems, Case-based systems and Virtual Reality Immerse.

3.4.1 PRINTED INFORMATION SYSTEMS

Printed Information representations are based on presenting the information using a static media, which cannot be modified by the user and where the navigation is related to the level of eye-perception and movement, in some cases this media can be browsed by the person looking and moving around it.

These systems are normally composed of written documents, photographs, static computer graphics (e.g. screenshots, renders..), animations, and other illustrations. They can be presented using written reports,

mounted presentations, slides (electronic or analogue), and simulations (digital or analogue).

The quality of these representations is characterized for an emphasis in the type of composition and contents selected to be presented statically.

3.4.1.1 Written reports

Reports are the most common medium of spreading information about historic buildings. They are normally ordered following a hierarchy or sequence according to specific standards.

Photographs and maps are included in a report illustrating the information that has been written.

The interaction between then and the user is performed by following the sequence and comparing the illustrations. Written reports are a single-user instrument.

3.4.1.2 Mounted Presentations and slides

Composition of mounted presentations is a widely used system, especially in museums. It is similar to a report but it can be displayed to a larger group of people. The sequence is hierarchical and the interaction between the user and the representation is performed by the eye and physical movement of the individual through the presentation.

On the one hand, slide presentations are used for displaying information to larger groups of people. On the other hand, they are structured in a permanent sequence of information hierarchically prepared and the user is not capable of browsing through it. Digital slides can be placed on the Internet or other electronic media making them more interactive and navigable, in this case the user can browse the contents.

3.4.1.3 Simulations (Analogue or digital)

Simulations can be stored either in an analogue or digital media, the can also be displayed to a broader audience using a projector or to a single-user in front of a screen. They are characterized for presenting animations of a three-dimensional model, which can be combined with static images (photographs), and narration.

3.4.2 ON-LINE INFORMATION SYSTEMS AND THEIR ROLE IN STUDYING BUILT HERITAGE

On-line Information systems are characterized for being real-time interactive, where there is an exchange of information between the user and the system. These types of systems are classified according to purpose, level of interaction and immersion in virtual reality.

According to their level of interaction and immersion, they can be classified in non-interactive, '*Pseudo-3D-immersive environments, and Virtual Reality or Immersive Environments*' (Haval, N. 2001)[77].

On the other hand, related to purpose they can classify in Expert, Case-based, Reference, and Reporting systems.

Moreover, the type of media used can be disseminated on Internet websites or CD-ROMs. In addition, they can be displayed in theatres using specialized interactive-immersive facilities.

3.4.2.1 Systems according to User-navigation, -interaction and –immersion

These systems are based on first hand observations made by Haval, who has been studying these systems in Virtual Heritage applications. However, this research emphasizes in the analysis of these

techniques in a broader sense and always using a measurable object as Graphic User Interface (GUI) for accessing the other sources of information.

Non-Interactive or '*Non-interactive picture book system*' (Haval, N. 2001)[78].

Non-interactive systems are characterized by storing digitised data from historical sources that are available for both the scientific and general public. They are mainly used for referencing purposes. These systems are made available through different mediums, such as the Internet or Software applications.

The information is catalogued according to purpose, local needs and other relevant categories.

For accessing information these systems are normally equipped with a two-dimensional map used as a static GUI. This representation is normally raster based, where a map of pixels is defined and linked to the database or a single file.

Pseudo-3D-immersive environments

A Pseudo-3D-immersive environment is based on accessing the information through a 360 panoramic model composed of a series of overlapping pictures.

This Graphic User Interface method has been included only for referencing purposes, it is not included in this research, because there is no measurable information extracted from the object of study, the model is only an image.

In this method 'environments are created from photographs taken from a fixed point, in all possible directions (mostly 6 – top, bottom, front, back, right and left) and seamlessly mapped on a cube or a sphere. The viewpoint is then defaulted to the fixed point from where the user can then view the stitched photographs in all possible directions, giving the user a feeling of virtually being at the site' (Haval, N. 2001)[79].

'Hotspots can be created in these spheres' (Haval, N. 2001)[80] linking information from other historical sources and other similar environments with different or closer viewpoints.

Virtual Reality or Immerse Environments

These environments are characterized by the use of a three-dimensional model platform sourcing of other types of information. In this system the user is capable of using real time navigation through the model.

These systems are classified by Kerlow, I. & Rosebuch (1994, pp. 244-245)[81], according to their immersion, interaction, participation, and a reality levels.

The '**immersion level**' is the variable that enables us to determine how surrounded one is in a virtualised environment. It is composed by a view and motion platform.

Subsequently, the '**interaction level**' determines how freely a virtunaut may move around the environment. The virtual reality browser limits these parameters.

The '**participation level**' is related to the number and activities the virtunaut are experiencing.

The '**reality level**' deals with the kind of environment factors used to increase the level of abstraction and the instruments allowing virtunaut to interact in the virtual world, as in the case of hands, eyes, etc.

On the other hand, the models can be made accessible to the public by using different types of display technology. They are classified in desktop display, head mounted displays, panoramic projection, and surround projection. This classification is defined according to their capacity of immersion and interaction in relation with the user or a group of users and a virtual world.

Desktop display

The desktop display is limited to the size of a computer screen and the rendering capacity of the video card.

The biggest advantage of a desktop display system is its cost and accessibility. At the same time, their role in virtual environments can be defined as a display that hardly blocks out the real world, as Virtual-world objects are not presented life size and therefore do not create the illusion of immersion (Brooks, F., 1999)[82].

Head Mounted Displays

Current HMDs improve the level of immersion of a single user in spite of the interaction with a bigger group.

Panoramic projection

One or more screens are alternatively arranged in a panoramic configuration. One person manipulates the viewpoint.

Surround projection

This type of display is used in high-end virtual reality facilities such as CAVE and kin. The great advantage of these systems are their shared experience to small groups and a wide, surrounding field of view.

3.4.2.2 Expert systems

These are specialized systems used for conservation purposes for developing a systematic procedure capable of solving a specific task that has not been previously processed. It is the automatization of certain rules applied to specialized cases in order to achieve to multiple or single solutions.

They have proven very useful in terms of conservation and allow the creation of systems that are capable of giving solutions by providing the required data. The system is built by accumulating different types of information through a methodology. It provides a powerful decision making solution.

This method has been included with the idea of enhancing their application by defining 3D Graphic User Interface for linking the information required to the decision making process.

3.4.2.3 Case-Based systems

The most relevant application of case-based systems relating to conservation is in use of architectural conception, redesign or design. Particularly in cases where the architect provides a solution to a design problem by experiencing different approaches to architectural applications, designed by other architects.

This system could be particularly interesting for conservationists, where encountering alternatives solutions used in the past in similar cases. However, it can only be used for comparative studies, since restoration work focuses on investigating the fabric and history this specific building.

In this case, knowledge from these systems is used for understanding better the various phases of the building's construction and by applying similar solutions for its protection and reuse. As well as, providing education to future conservators.

Case-based reasoning should be enhanced by using 3D Graphic User Interfaces based on three-dimensional models, where the user can access the solutions and other complementary information.

3.4.2.4 Reference Systems

Reference systems are applications that link different types of information to an historic building. They are classified in an electronic database under hierarchies and categories

defined by the operator.

These informations are linked to an electronic medium (e.g. map, model..) by defining a hotspot. This Graphical User Interface is composed by vectors and polygons, and is used for accessing and retrieving information. The type of representation and links with the database establishes the navigation tool.

Nowadays, Geographic Information Systems are the most known Reference application available. It is used in many fields, where visualization of different variables is required, such as urban planning, traffic management, etc.

Geographic Information Systems

> *Geographic information systems can be produced by establishing cross-references between polygon geometric data and files of associated non-geometric data. Thus non-geometric information can be accessed conveniently by selecting polygons (Mitchell, W.J. & McCullogh, M., 1995. P. 153)*[83].

In 'geographic information systems', a two-dimensional map is used as a medium or platform for providing access to the information; this is linked to the map. This is done by associating collections of raster images, other maps, documents and other records relevant to the use of this reference system to a single or multiple polygons. '*Indeed any electronic document can serve as a multimedia access structure – maps are just especially familiar guides for cross-referencing materials*' (Mitchell, W.J. & McCullogh, M., 1995. P. 153)[84].

More advanced applications use three-dimensional models as information-platforms; in this case single or multiple defined solids are linked to the required information (hot spots).

> *Sophisticated geographic information systems and facility management systems need the capacity to combine results of area, density, and distance calculations with results of database searches yield new graphic displays (Mitchell, W.J. & McCullogh, M., 1995. P. 153)*[85].

The potential of this system is the combination of information from different sources that can be stored, shared, retrieved, and presented using a familiar Graphical User Interface (GUI) linked to a database management system (DBMS); as well as calculating different types of quantities by mapping the amount of contents.

3.5 EMERGING TOOLS

There are a great number of new recording instruments, processing tools and visualization applications available on the market. Most of these have been developed with the intention of generating more realistic disseminations of the real world, some of them emphasize registering the geometry of an object very accurately. Additionally may deal with realistic imagery based on image-based acquisition.

In this part, there have been a selection of the most relevant applications adjusted to the needs in studying built heritage. These techniques are divided in two categories: non-photographic and photographic based techniques.

3.5.1 NON-PHOTOGRAPHIC BASED TECHNIQUES

Non-photographic or non image-based tools are related to the use of application capable of capturing the geometry of an object. This part deals with the use of Long-range Laser Scanning Mapping systems based

on demonstrations and literature from two companies manufacturing these tools: Cyrax and Callidus systems.

At the same time, some complementary long-range and short-range scanners have been reviewed, whereby the approach is based on commercial literature and scientific papers only.

3.5.1.1 Terrestrial Long-range three-dimensional Mapping Systems

The documentation of large sets of information from a site is performed using Long-range Laser Mapping systems through several phases of processing: Collection, Matching-Merging, Generation of Models and Export to other applications.

These devices are equipped with an active sensor that automatically acquires dense 3D sets of points (point cloud) using a previously specified interval in a short time. Subsequently, most of them provide a software application that is capable of matching and merging scans from different scan-positions using targets or similar surface matching techniques.

The data collected and merged can be manipulated by the software to generate pre-defined 3D tools for the creation of solids or surface representations from the various points. '*However, the sensors can be costly, bulky, and affected by surface reflective properties. Also a range sensor is usually designed for a specific range, thus a sensor designed for a close range cannot be used for a long range. In addition*, *it is particularly difficult to find active sensing technology suitable or accurate enough for the medium range of between 3m and 20m*' (El-Hakim, S.F. 2001)[86].

Collection

The scanner uses a system called 'pulse time-of-flight', which by projecting a laser beam from the instrument to the desired object generates a set of measurements or point cloud. The scanner calculates '*the time difference and then adjusts proportionally to give the distance between the scanner and*' (Cadalyst, 2000)[87] the desired object in space (or obstacle).

The generated points are measured by directing the head of the scanner to a specific area; in some cases the device is equipment with a rotating head that enables it to record in a circular path close to 360º.

Normally, these instruments are operating correctly regardless of light conditions; this is related to the type of Laser used.

On the other hand, each scanned object will generate a blank shadow, where objects are not visible to the scanner. To solve this problem multiple overlapping positions and views should be chosen to cover the whole site.

Moreover, the multiple scans are merged using external targets or similar surfaces. The first is more accurate and verifiable that the second. The Cyrax system is a good example of this technique.

Results may depend on the range and density of points selected, according to the manufacturer Cyrax delivers 0.2 mm precision regardless of the range while Callidus provides from 0,5mm up to 100 mm precision depending on range and reflective properties of the surface to be scanned.

Furthermore, Cyrax is fully portable and independent using batteries while Callidus has to be plugged. They are both very heavy, but robust.

Matching-Merging

The scanner is always accompanied by an application for control, manipulation, and reduction; as well as modelling of the

scanned points.

It is important to establish a site grid and a parallel control system for locating and orientating the scans according to local or international coordinates systems. This can be executed by measuring the targets or surfaces using other EDM devices.

Density of points: manipulation and reduction

The user is capable of reducing the number of points captured while recording or afterwards during the processing phase.

Matching relocated scanned positions

Subsequent to the reduction of points, the user is required to identify common targets and/or surfaces for matching multiple overlapping readings. There are basically two techniques: surface matching or target matching.

On the one hand, Cyrax uses mainly target, while Callidus uses surface matching. Both techniques are effective, however the first enables us to make cross-verification by measuring it with other EDM devices.

Surface matching technique: the scanner matches multiple scans by matching properties in common surfaces.

Targets matching technique: the system is equipped with a 'built-in global registration' system that enables the user to identify the targets with numbers in the scans. The application will, then be merged with automatic readings and will in turn verify surface matching properties.

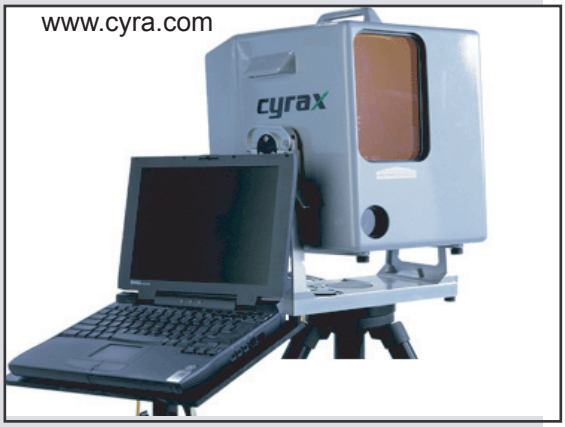
Generation of polygons and models

The generation of an accurate model of the object is a time-consuming task using

Terrestrial Long-range three-dimensional Mapping Systems: Examples



1 Scanner Callidus, manufactured by Callidus-Trimble



2 Scanner manufactured by Cyra, model Cyrax 2500

Figure 29: examples of terrestrial long-range three-dimensional mapping systems: callidus and cyrax. Callidus and Cyrax website. Author.

these systems. Nevertheless the user can be confident that the base-data (point-cloud) acquired is highly reliable. This system is certainly faster than any other remote sensing or indirect recording technique.

The generation of a model starts by identifying and selecting a set of points. Subsequently, these points are converted

to polygons, vectors or pre-defined 3D primitives (solids and surfaces). The third is less reliable for monuments, since most of the laser-scanner software is accompanied by a library of manufacturing objects (e.g. pipes, metal profiles…) that do not agree with basic principles in representing historic buildings dealing with the uniqueness of each building's component.

On the other hand, the software has the potential to create irregular meshes and vectors that can be further processed using a CADR package.

Moreover, this approach can be used for the generation of Digital Surface Models based on the points measured, similar to the DEM technique described previously. 'On architectural surfaces it may be difficult to achieve. If the surfaces is plastered, there is insufficient texture, and if the surface is build up of different planes, you have to deliver different initial values according to the depth of each plane' (Wehr, A. & Wiedemann, A., 1999)[88].

It is important to mention that these software applications are normally equipped with the most common CADR facilities, such as powerful navigation (e.g. zooming, panning, viewing, rotating..), construction, and manipulation tools (e.g. trimming, extending, line construction, etc). As well as, rendering and other commands.

Exporting data to other applications

The application is capable of outputting different formats to be further processed and analysed using modelling and visualization packages.

Two-dimensional sections using a specific axe can be defined and exported for creating other orthogonal representations, such as maps, elevations and axonometrics.

3.5.1.2 Potential and critical issues to be reviewed in terrestrial three-dimensional Long-Large Mapping Devices and applications

Potentials

The 3D output generated by a Laser Scanner is very reliable and accurate. It is one of the most effective ways of measuring a very complex structure in a short time.

Critical issues to be reviewed and improved

These issues deal with problems related to the transportation and robustness of the equipment; as well as the application in documenting built heritage.

Related to Transportation and Robustness: scanners are somewhat delicate and heavy to transport. The scanner itself is robust but perhaps the notebook and wiring can be affected by dust, wind, heat, and rain, thereby limiting their application on remote areas or generating a bigger investment to improve the conditions 'in situ'.

Moreover, scaffolding is required in most cases to unveil blank and shadowed areas that are not visible from the ground, these platforms can be unstable and therefore the scans will be affected by vibration.

Related to recording built heritage: certainly the application of laser scanners in historic buildings is one of the most effective and quickest techniques used for the precise recording of the geometry.

However, texture (colour and patterns) is also important for analysing the history and actual state of conservation of an object. In this case, the restricted use of only laser scanners are limited, because the use of digital images to be wrapped into the 3d laser scanner point clouds output is still under research. This

feature will be very useful to collect a high density and geometrically correct dataset, as well as a 3d image-based representation to study the weathering of the surface.

In addition, the merging of geometric representations, such as vectors and points with 3d images can open new horizons in the actual representation of heritage in 3d without having to produce a 2d representation to prepare condition and historical assessments about the building being studied.

However, the point cloud is generated in different colours, depending in the reflective properties of the material being measured; this result should be studied in more detail to perhaps produce an automatized detection of material present in the fabric of the building.

Moreover, the initial budget required for such instruments is still very high for most of the projects aimed at studying built heritage. This problem can be solved by establishing cooperation agreements between institutions and the commercial sector.

Ultimately, the use of this type of technology has a very promising future. It can be combined with existing image-based modelling techniques to ensure that the documentation, verification, and combination of an accurate metric survey instrument (geometry based) and images, providing information on colour, patterns and other sources of information relating to photographs.

3.5.1.3 Other systems

In addition to the existing systems described above, there are other terrestrial long-range laser scanner capture systems available. These systems are described according to the commercial and scientific literature available.

Terrestrial Long-range scanners

The Soinic Laser Scanner (Mensi) 'i*s based on the plane triangulation. The equipment is designed with precision in mind rather than scanning speed. It needs no external lighting*' (Cadalyst, 2000)[89]. This system apparently has problems operating in full daylight.

Range varies between 0,8 to 40 m. The system is equipped with a video micro camera, which can acquire texture maps for further analysis, however, the resolution is somehow limited.

Moreover, the Riegl System '*Fast angular scan (line scan)' scans by 'a rotating polygon with a number of reflective surfaces deflects the laser beam. The polygon rotates continuously at an adjustable speed to provide a unidirectional scan within an angle of Ø = 80°. The slow scan (frame scan) is provided by rotating the complete optical head up to 340°*" (Cadalyst, 2000)[90].

The range '*is up to 350m for natural targets, with reflectivity of more than 50%, and up to 150m for natural targets with a reflectivity of more than 10%*' (Cadalyst, 2000)[91].

The manufacturer is planning to adapt the Cyclone software to its acquisition device; the Cyra Company has already developed this application.

However, the use of these devices in mapping built heritage is currently under discussion, they are several new developments in this field that due to time has not been included in the current text.

Short-range Scanners

Short-range scanners are suitable for capturing three-dimensional data only from a close range. Although accurate acquisition can be ensuring using these instruments, they can only cover a limited area and require designed mechanical arms to cover more of the object. This additional structure requires careful calibration and robustness

to hold and manipulate the instrument.

3.5.2 PHOTOGRAPHIC BASED TECHNIQUES

3.5.2.1 Image-based modelling and rendering

New developments in Image-based modelling methods are very promising, especially, those related to the use of '*high-accuracy videogrammetry software to record colour, texture, light, and some dimensional data*' (Addison, A., 2000, p.27)[75].

One of these methods is recently under development by the Department of Electronics at the Catholic University of Leuven in Belgium.

This Image-based modelling system approach is based on the research of Pollefeys on '*Self-Calibration and Metric 3D Reconstruction from Uncalibrated Image Sequences*'[76], which deals with the automatic generation of three-dimensional models from uncalibrated images.

The resulting model looks very realistic, combining a dense 3D texture map and a shadow model.

3.6 CLOSING REMARKS

The most common critical issues of the large gamma of tools available for 'gathering 3D data of architectural-scale real-world objects' are based on:

- The development of instruments and applications are not adapted to the irregular state of the fabric in built heritage.

- The combination of different recording instruments, processing software, and dissemination application using defined standards and systems of verification.

- Standardization of objectives and methodologies for collecting measured data from historic buildings are not clearly stated and studied.

- The extend and parameters for the selection, collection, processing and dissemination of the different sources of information (e.g. historical documentary, geometry, texture, etc) from the monuments is not clear and the process of selection is mostly not explained in the report describing the works of recording the dataset.

Furthermore, '*current geometry-based methods of modeling existing architecture, in which a modeling program is used to manually position the elements of the scene, have several drawbacks. First, the process is extremely labor-intensive, typically involving surveying the site, location, and digitizing architectural plans (if available), or converting existing CAD data (again, if available). Second, it is difficult to verify whether the resulting model is accurate. Most disappointing, though, is that the rendering of the resulting models are noticeably computer-generated; even those that employ liberal texture-mapping generally fail to resemble real photographs*' (Debevec, P, Taylor, C. & Malik, J., 1996)[92].

On the other hand, many scientists working with monuments believe that traditional techniques are more suitable for understanding the fabric of the building and its history, without paying attention to the amount of time required for executing these techniques.

3.6.1 BASIC COMPARISON OF 3D METRIC SURVEY COLLECTION INSTRUMENTS AND APPLICATIONS

This part is based on the research of A. Addison and M. Gaiani, including real first-hand examples, and complementary scientific literature concerning the use of these techniques in studying built heritage.

The applications are classified in recorded and integrated tools. The first is related to techniques used for the acquisition of geometry and texture of the object, and the second relates to technologies combining the acquisition and processing of the measurements in order to create visualizations (see charts 04 and 05).

3.6.1.1 Recording tools:

The comparison criteria deal with the type of technology studied, name of the manufacturer, speed, accuracy-range, robustness, and transportation of the equipment. Additionally information will include: the estimated initial budget, the expertise required, and intended application sin studying built heritage (see chart 04 and 05).

Type of technology

This is related to the use of direct or indirect surveying technique. The first requires entering in direct touch with the fabric of the building, and the second, indirect techniques are based on the application of remote sensing techniques.

Photogrammetry and Laser-Scanners has been included in integrated systems for processing.

Name

Model, title and manufactured studied to make the chart.

Speed

This is based on the time required to measure a record (e.g. point, vector, and) and is expressed in record per second measured.

Accuracy and Range

Accuracy is based on the single point-measured, without taking into consideration post-processing and other operational errors.

Expertise required

This concerns the user's background and his/her ability to operate the instrument or application.

Levels:

Professional: this relates to the professional surveying and advanced knowledge of either Computer Aided Drafting or Pencil Aided Drafting knowledge.

Mid-professional: expects minimal knowledge of surveying and drafting techniques to be sufficient.

Amateur: limited or no previous knowledge about surveying or drafting is required.

Operational issues

This deals with the need of careful calibration of the instrument or application

Levels:

Careful: levelling and setting required.
Slight: slight levelling and setting required.
Automatic: the instrument is equipped with automatic calibration features.

Robustness and transportation

Deals with the capacity of the instrument to

AVAILABLE COLLECTION METRIC SURVEY TECHNIQUES FOR DOCUMENTATION OF BUILT HERITAGE

Non-Photographic techniques

Technologies Type/Name	Speed Point/sec	Accuracy-Range mm - m	Expertise required	Operational issues
Non-Photographic				
Traditional (Steel tape, Calipers)	0,01	1 - 50	Professional	Careful
Analogue Instruments (Theodolithe - Level)	0,2	1 - 100	Professional	Careful
EDM Instrument (EDM Total Station)	0,15	1 - 5000	Professional	Careful
REDM Instrument (REDM Total Station)	0,1	1 - 100	Professional	Careful
Time-of-flight (Disto, elct.tape measures)	0,2	10 - 10	Mid-Professional	Slight
GPS (Hand-held units)	120	800 - 1000	Amateur	Automatic
GPS - Satellite (Triangulation)	1	50 - 1000	Professional	Careful

Photographic techniques

Technologies Type/Name	Speed Point/sec	Accuracy-Range mm - m	Expertise required	Operational issues
Non-Photographic				
Time-of-Flight* Cyrax Long-range Laser Scanners	1000	2 - 100	Professional	Careful
Time-of-Flight* Callidus Long-range Laser Scanners	77	5 - 32 (Radius)	Professional	Careful
Photographic				
Stereo (Low-end) Photogrammetry (PhotoModeler,PhotoBuilder)	1	~5 - 10	Mid-Professional	Careful
Stereo (High-end) Photogrammetry (Rollei, Intergraph, Zeiss,Phidias)	1	1 - 100	Professional	Careful

* Consider emerging technology

Chart 06 - 07: comparison chart: collection tools for documentation of built heritage direct techniques - non photographic and photographic

Robustness Transportation	Budget	Applications	Summary remarks
Slightly affected Easy transport	Sustainable	All	Labour Intensive Limited Range
Moderate affected Easy transport	Sustainable	All	Labour Intensive Careful calibration
Moderate affected Easy transport	Moderate	All (Suitable for Archaeology)	Labour Intensive Careful Calibration
Highly affected Easy transport	Moderate	All	Careful Calibration Limited Range
Slightly affected Easy transport	Sustainable	All (Suitable for Standing Buildings)	Labour Intensive Limited Range
Slightly affected Easy transport	Sustainable	All	Only used as rough reference system
Slightly affected Easy transport	High	All (Suitable for Large areas: Landscape)	Used for referencing

Robustness Transportation	Budget	Applications	Summary remarks
Slightly affected Heavy - 4h Battery	High	All (Suitable for Standing Buildings)	Heavy Fast - Accurate
Moderate affected Heavy - No Battery operated	High	All (Suitable for Standing Buildings)	Heavy Fast-Accurate
Slightly affected Easy transport	Sustainable	All (Suitable for Standing Buildings)	Labour Intensive Limited range Operator error issues
Slightly affected Easy transport	High	All (Suitable for Standing Buildings)	Labour Intensive Well established Operator error issues

be transported and operated in remote areas with limited facilities.

Robustness levels:

Highly affected: the instrument is affected by environmental conditions, requires special conditions for operating.
Moderately affected: some environmental conditions affect implementation, such as heat, dust, etc. But it can operate with a basic set of measures.
Slightly affected: very robust, stands severe environmental conditions.

Budget

Economical restrictions related to the required initial investment to purchase and operate the equipment in a remote area, expressed in a budget in euros for an initial investment of a single documentation campaign.

Levels:

High: the initial investment for acquiring the equipment exceeds 25000 EUR per documentation campaign.
Moderate: the initial investment for acquiring the equipment exceeds 12000 EUR per documentation campaign.
Sustainable: the initial investment for acquiring the equipment is below 11000 EUR per documentation campaign.

Applications

Description of suitable areas or applications in studying built heritage, such as archaeological sites, standing buildings, and representations aimed for the general public.

Summary remarks

Complementary observations about the tool, relevant to documentation and dissemination of built heritage.

3.6.1.2 Indirect tools (Integrated systems: Recording and Processing)

The comparison criteria deals with the type of technology studied, name of the manufacturer, speed, robustness, and transportation of the equipment; as well as, initial budget requirements and intended application for studying built heritage.

Types of technology

Related to the use of Non-photographic or photographic surveying technique.

Name

Model, title and manufacturer reviewed and included in the chart.

Speed

This is based on the amount of time required to acquire and process a record and it is expressed in record per second. This however, remains a bit ambiguous in relation to the use of a specific density of records to define an architectural component.

Accuracy and Range

Accuracy is based on a single point-measured, without taking into consideration post-processing and other operational errors.

Expertise required

This is related to the background required by the user to operate the instrument or application:

Levels:
Professional: advanced knowledge in calibration, surveying and Computer Aided Drafting knowledge is required.
Mid-professional: slight knowledge about surveying and CADR required
Amateur: no previous knowledge about surveying or CADR required.

Operational issues

This deals with the need of careful calibration of the instrument or application:
Levels:

Careful: complex calibration procedures are required for setting the instrument.
Slight: the calibration procedures are semi-automatic; the operator interaction is required to a certain level.
Automatic: the instrument calibrates itself without the operator's interaction in the setting process.

Robustness and transportation

Deals with the capacity of the tools to be used and transported to remote areas and the further execution thereby off-site.

Robustness levels:

Highly affected: the instrument is affected by environmental conditions, requires special conditions for operating. Unstable ground is critical.
Moderately affected: some environmental conditions affect the implementation, such as heat, dust, etc. But it can operate with a basic set of measures.
Slightly affected: very robust, stands severe environmental conditions.

Budget

Economical restrictions related to the required initial investment to purchase and operate the equipment in a remote area, expressed in a budget in euros for an initial investment for a single documentation campaign.

Levels:

High: the initial investment for acquiring the equipment exceeds 25000 EUR per documentation campaign.
Moderate: the initial investment for acquiring the equipment exceeds 12000 EUR per documentation campaign.
Sustainable: the initial investment for acquiring the equipment is below 11000 EUR per documentation campaign.

Applications

Description of suitable areas of applications in studying built heritage, such as archaeological sites, standing buildings, and representations aimed for the general public.

Summary remarks

Complementary observations concerning the tool relevant to the documentation and dissemination of built heritage.

3.6.2 NOTES ON THE APPLICATION OF DIGITAL PHOTOGRAPHY IN STUDYING BUILT HERITAGE

The potential of digital photography is 'its intrinsic liberation from film' (Insight, 2001)[93], because a greater number of images can be made in remote areas without having to have a processing lab facilities and storage for the negative and prints.

Nevertheless, the replacement of analogue prints and negative is questionable when recording heritage. Especially in dealing with problems inherent to obsolesce and decay of digital media in a period of time, referencing procedures, and classification of large amount of photographs.

Moreover, the digital resolution of the prints is a critical issue, because higher quality requires a higher initial investment, while a film camera is cheaper.

AVAILABLE COLLECTION TECHNOLOGY
Comparison between Long Range Laser and Photogrammetry

Issues	Long-Range Laser	Photogrammetry
Object texture	Not necessary	Necessity depends on application
Light Conditions	Largely insensitive	Sensitive
Instrument Costs	High	Low
Recording	Sequential	Instantaneous
Preprocessing	Linking scans together is straight forward	Orientation is complex - First matching step with special software
Mapping	Labour-intensive, special software required	Labour-intensive, special software required

(Chart by Lemmens, M.J. & van den Heuvel, F.A., 2001)

Chart 08: comparison between long-range laser mapping instruments and photogrammetry

3.6.3 CADR AND CONVENTIONAL DRAFTING TECHNIQUES

Pencil-aided design (PAD) or conventional drafting tools are essentially 'unstructured, each line is drawn independly of every other line. Thus, if the resulting drawing requires modification, individual lines have to be erased and redrawn'.

In a CADR drawing the graphic primitives (lines, rectangles, polygons, arcs, circles, etc.) are arranged in a three-dimensional coordinate system, making it possible to change their location or scale.

Furthermore, scale in PAD drawings is pre defined and fixed after the representation is completed (e.g. 1:100, 1:50, etc.). The result is that the drafter is required to draw a higher or lower level of detailing of an element according to the different size used.

In this sense, a CADR drawing is more advantageous, because it is stored in full size, the scale will be specified in the plot output, which modifies the size of the view appropriately to the required scale and paper layout.

Mainly, these two features are related to quality, flexibility and properties and therefore are very helpful for translation purposes, retrieval, and storage of a specific measured graphic representation.

3.6.4 THREE-DIMENSIONAL MAPPING SYSTEMS AND PHOTOGRAMMETRY: COMPARISON

This part is based on the work by Lemmens, M.J.P.M. & van den Heuvel, F.A. (2001)[94] in relation to the use of Laser mapping systems and photogrammetry in documenting architecture (see chart 06).

3.6.4.1 Labour intensity

Photogrammetry is very labour intensive. It involves the identification, selection in multiple views, referencing and verifying each desired point. A Laser scanner on the other hand collects a large amount of the geometrically correct points of the building automatically. Further this equipment does not discriminate in the need of recording a specific number of measurements.

3.6.4.2 Amount of recorded data

Laser scanners generate large amount of data that might be unnecessary and be time consuming for computer engineering power, while photogrammetry allows the user has the opportunity to select what is relevant to

the survey.

3.6.4.3 The documentation of complex three-dimensional features: accuracy and speed

Laser scanners are capable of collecting any irregular surfaces (e.g. relieves, sculptures, pillar capitals..) in a very short time. On the other hand, although photogrammetry can achieve the same accurate results, they are subject to the judgement and expertise of the operator and are time consuming.

Furthermore, photogrammetry can automatically collect texture Information with an unlimited range. Further, it allows for the possibility of using and linking 'historical imagery' for reconstructing various construction phases of a building.

3.6.4.4 Transportation and flexibility on-site and off-site

Transportation and the use of cameras in photogrammetry is a very flexible and simple activity to perform, while a Laser scanner is normally heavy and accompanied by other accessories, such as a portable computer, tripod, and wires.

3.6.4.5 Initial budget requirements

The budget required to purchase a Laser Mapping system is '*presently more expensive, by a factor of ten, than photogrammetric systems with comparable precision*' (Lemmens, M.J.P.M. & van den Heuvel, F.A., 2001)[95].

However, this comparison only takes into account the initial budget in spite of other characteristics, such as the speed of measuring and the amount of processing work required afterwards.

3.6.4.6 Matching overlapping positions

Photogrammetry requires that a fixed set of parameters and procedures be followed when taking the shots. This allows for a successful calibration and extraction of points from pairs and/or multiple sets of photographs.

Additionally, Laser Scanners are equipped with an application that can merge the different scans automatically. This merging is executed by identifying the targets or surfaces to be matched.

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The traditional stereophotogrammetric approach requires a series of orientation procedures comprising the following three steps:

• Reconstruction of the bundle of rays of the camera by means of the calibration data (interior orientation).

• Determination of the relative position of the two images of a stereo pair (relative orientation). The result of this procedure is a three-dimensional model of the object.

• Transformation of the three-dimensional model into the coordinate system chosen for the project, making use of some control points (absolute orientation).

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CHAPTER IV

METHODOLOGY:

DOCUMENTATION AND DISSEMINATION OF BUILT HERITAGE

THE NON-THEMATIC MEASURED DATASET: METRIC SURVEY

CHAPTER IV:

METHODOLOGY: DOCUMENTATION AND DISSEMINATION OF BUILT HERITAGE: THE NON-THEMATIC MEASURED DATASET: METRIC SURVEY

In line with the principles and statements outlined in previous chapters relating to the preparation of a '*critical and analytical report*' for the conservation of built heritage, this part aims to introduce a methodology for the recording of a building-context geometry and texture.

In addition, this chapter examines matters relating to the documentation and dissemination of a building's heritage in order to generate greater public knowledge and thus guarantee its protection.

Furthermore, this chapter acknowledges the existence of specific needs for specific groups of people and therefore discusses the need to define the purpose of documenting built heritage, the relation relationship between the scope and the people that will use it (target audience).

Subsequently, each phase of implementation, and specially the dissemination dealing with Information Systems should incorporate variables for making the process transparent and consistent at every stage, verifying the targeted precision, observational accuracy, and the relevance of shared information both selected, and interpreted.

Furthermore, this chapter deals with the introduction of a methodology for the adequate retrieval, management and presentation of the measured dataset of the subject's fabric and context, whilst at the same time studying a building's geometry and texture. The resulting 'Metric survey dataset' is aimed at mapping sources of information embed in monuments and other external references, such as condition and historical assessments.

The resulting set of 'metric survey and thematic assessments' are used in the



Figure 30: Architectural conservation students using a REDM device to measure the vault of a chapel, Castle of Arenberg, Leuven 2001, Belgium. Author.

preparation of a 'Core data', which in turn forms the basis for a 'critical and analytical report' concerning the subject's relevance or authenticity.

In this sense, the preparation of a 'metric survey dataset' is a process whereby measured data (e.g. 3D points, shapes, photographs, etc) retrieval and processing is aimed at identifying the values and dimensions of a monument and its context. This knowledge is then linked to acquiring and comparing information from the building's fabric and other sources, such as historical documents and investigation into the stratification.

Moreover, the proposed 'Methodology' of implementation primarily involves gathering a vast amount of measured information. This relates to its fabric and context, which in turn is complemented by the study of the condition of conservation (Structural assessment, weathering processes, etc) and historical phasing (study of iconographic, written documents, old drawings, etc) for further analysis and presentation. This methodology is developed through a series of phases, and it focuses in the implementation methodology is composed of three work phases:

- Data- collection: acquisition and organization
- Data-analysis: processing and modelling
- Data-synthesis: information system and dissemination

Each of these phases involves making a series of decisions on how the sources of information are selected, recorded and stored in multiple and specialized layers of information.

The phases are closely related, although they are represented using a linear sequence. One phase cannot be executed without taking into account the next step (e.g. the tools selected for the collection phase will partially depend on the processing and modelling techniques available; as well as, taking into account the type of visualization to be use to present the end-result).

At the same time, this research does not seek to offer an absolute value or method, but to provide guidelines for applying and adapting methods of documentation and dissemination to various fields of work. The objective being to provide general solutions for multiple objects, scales, locations, and environmental conditions. As well as, attending to adapt current digital documentation and dissemination tools when studying built heritage.

This process is based on applying 'Metric-survey' techniques for the investigation of sources of information that provide information about the fabric of the building, measurable and quantifiable, whilst taking into account the ambiguities and uncertainties related to the nature of built heritage.

Moreover, the proposed 'Metric survey' methodology is complemented by the use of comparative digitalization and processing of other sources of information (Historical documentary research).

Finally, it is important to bear in mind that this research addresses just a part of the whole study designed for the protection and conservation of built heritage.

The implementation phase described in this chapter address the first step in the phase called '*anamnesis'*[1], forms four steps: '*anamnesis, diagnosis, therapy and controls (*Searls, C.L., Binda, L., Henriksen, J.F et al, 1997, pp. 199-221)[2] and is used in the study and execution of works for the conservation of architectural heritage.

METHODOLOGY: IMPLEMENTATION
DATA-COLLECTION: ACQUISITION AND ORGANIZATION

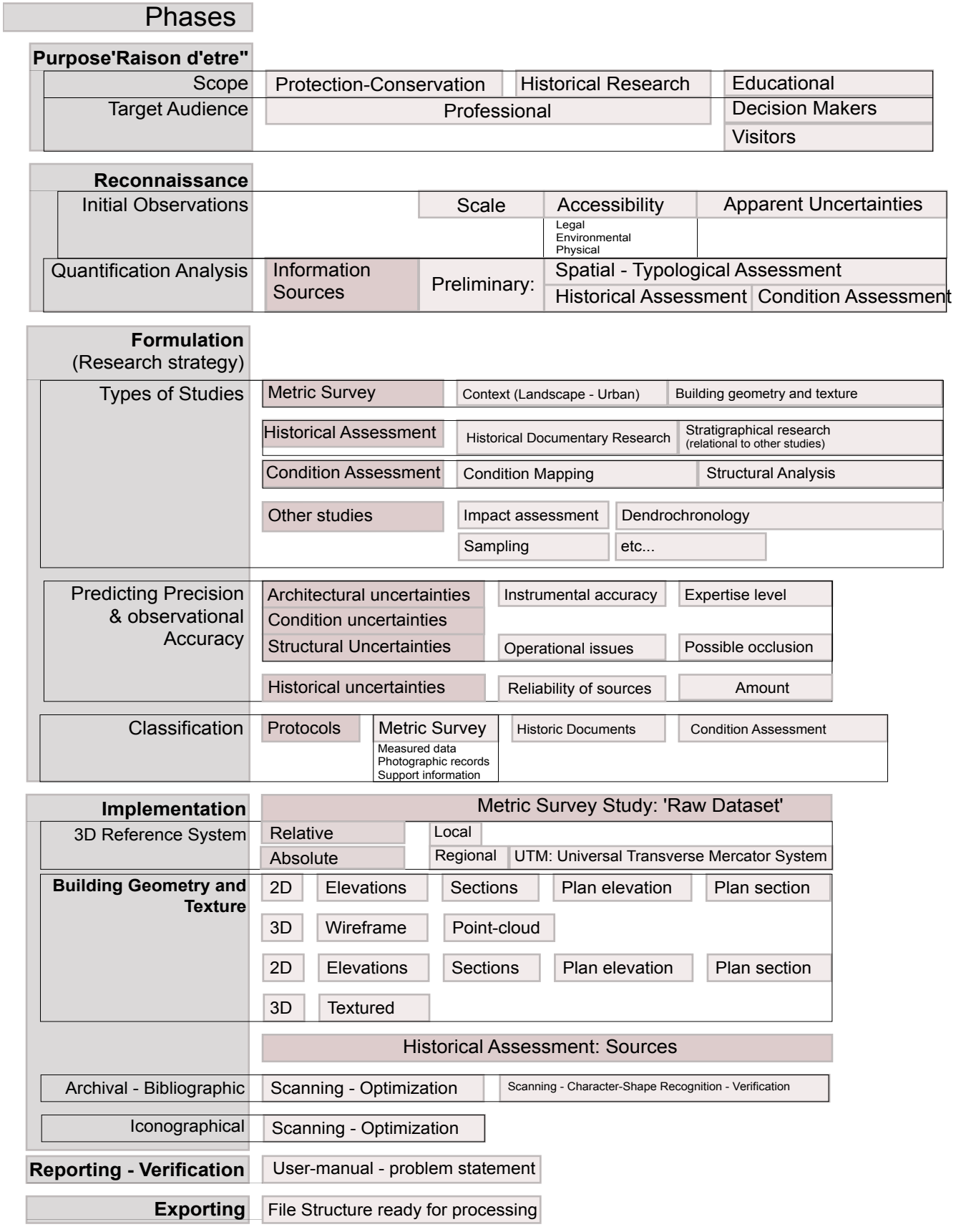


Chart 09: phases - data-collection

4.1 DATA-COLLECTION: ACQUISITION AND ORGANIZATION

Data-Collection relates to the definition and execution phase, where all the material necessary for carrying the analysis and synthesis phases is selected and retrieved. This stage is characterized by being a 'selective and interpretive process' (HAER, 2000)[3] according to the requirements of the planned study.

Moreover, the selective nature of this phase is characterized by the definition of the needs, related to the purpose of the proposed documentation and its relation to the amount/quality of the information available.

A particular characteristic of this stage is that the 'dataset' should be measurable and quantifiable, providing the expert with a tool for further processing in the following phases, the main aim being to understand the geometric characteristics and texture of the monument's fabric and context.

This 'measured dataset' will be used as a mapping instrument for the recording of thematic content assessments and will include historical and condition studies. Subsequently, the result of the first measured dataset and thematic mapping studies will be used in the decision-making analysis that ensures a monument's future protection.

It will also consider, the first stage of this phase to be quantified and predict 'a priori' the availability of Metric and Thematic sources; as well as the possible uncertainties and limitations to be encountered during the process of acquisition.

Data Collection is developed using the following phases of work (see chart 9):

- Purpose
- Reconnaissance
- Formulation
- Implementation
- Reporting and verification
- Exporting

4.1.1 PURPOSE: 'RAISONS D'ETRE' OF DOCUMENTING BUILT HERITAGE

The definition of the purpose is the most relevant variable directing the process and extend of obtaining the 'Metric Survey dataset' when documenting built heritage. Prior to beginning any investigation definitions of intent need to be set.

Moreover, purpose or 'raison d'etre' of the monument needs to be investigated. In other words:

> Purpose (scope)* of investigation = needs of the target audience

* The ideal scope for investigation being the protection of heritage by documenting their values to the highest possible standards.

4.1.1.1 Scope of investigation

Although the definition of the scope can be associated only to the needs of the target audience, three main types of scopes can be defined. The first relates to documenting sites for their protection. The secondly as a 'referencing tool' for historical research, and thirdly as an 'educational instrument' used for a broader audience or decision makers.

Subsequently, each of these scopes adapts a specific level of precision and observational accuracy for the processing and retrieval of sources of information.

For protection: inventorization, conservation of built heritage, and monitoring of built heritage

Protection can be defined as research aimed at identifying the relevance of a site within its local, regional, or universal values. In other words its 'authenticity' needs to be reviewed and studied, in order to prepare the 'Critical and Analytical report', which will state its actual condition of conservation and history. Later this can be included in a legal framework instrument for its conservation (e.g. regional inventories, UNESCO World Heritage List).

In addition, it can relate to previously enlisted monuments and sites using minimal documentation requirements. The proposed study is executed to heighten the knowledge and prepare preventive intervention, monitoring, or a full-scale restoration project.

Historical research: scientific publications

Historical investigations are used for enhancing an object's historical knowledge as a referencing tool for relational studies or else to prepare future academic dissertations.

This application mainly deals with the historical relevance or other dimensions depending on the subject (e.g. comparative historical studies). These studies cannot be made unless as objects specific conservation needs are considered.

This research recognizes the need and value of these applications in the field of architectural history and archaeology. However, it would encourage future studies relating to built heritage to ensure that the intrinsic values of a historic building are protected.

Broader audience presentation: education of visitors

This scope of investigation concentrates on how best to explain the intrinsic, historical value of a monument to the wider public. These tools are generally used on expositions, historical sites, and museums; as well as, for public consumption in the commercial media.

Although the precision and observational accuracy of this application are debatable, this research promotes the idea that all the information extracted and presented from a monument should be based on reliable acquisition and processing of 'measured data' and that all hypothetical reconstructions should be sufficiently based on verifiable facts.

4.1.1.2 Target audience

The definition of the target audience is important to understanding the limits and levels of abstraction required throughout the whole process of recording disseminating the measured dataset of representations. However, it is not the only dictating factor. A scientific method for adequate documentation should always be executed.

It is possible to identify three main different groups of target audience: professional, decision makers, and other users (visitors). This research encourages that all metric survey studies in documentation should be implemented acquiring the highest possible amount of sources with a reliable precision that can be used for different scopes and target audiences.

Professional: contributor - collaborator

Professional audience can be defined as scientists working on studying built heritage. This group can be divided into conservationists architects, civil engineers, archaeologists, anthropologists, historians, and other professionals related to the factual study of built heritage (e.g. such as restorers).

They are potential evaluators, but also contributors and collaborators in the

implementation phase.

Decision makers

"Decision makers" are governmental bodies, non-governmental organizations, entrepreneurs and other individuals that provide funding for the study of built heritage (e.g. the UNESCO World Heritage Commission and who decide which sites should be added to the list of World Heritage Protected Monuments).

Visitors: users - collaborators

"Visitors", represent the broader audience who visit and browse through information on a particular monument. Their interest is focused on understanding the relevance of the monument, particularly its historical dimension. This target audience includes visitors to heritage sites.

This group can form a useful function by heightening overall awareness of a site.

4.1.2 RECONNAISSANCE: ESTIMATION OF THE EXTEND OF THE SURVEY REQUIRED

The reconnaissance of the subject involves making a preliminary assessment to identify the difficulties and amount of work invested. Such a study allows more accurate decisions to be taken in forms of selecting the most appropriate 'Metric Survey technique(s)'.

> *'Reconnaissance is the first and most important step in the surveying process. Only after careful and detailed reconnaissance of the area can the surveyor decide upon the techniques and instrumentation required to economically complete the work and meet the accuracy specifications' (Schofield, W., 2001, p.21)*[4].

The process of reconnaissance is characterized by the need to prepare initial on-site observations, preliminary critical analysis, prediction of uncertainties, preliminary understanding of authenticity (values), and the quantification of sources.

4.1.2.1 Initial observations

An initial observation is aimed at having a preliminary idea of the site's scale, accessibility, and most apparent uncertainties.

Complementary to the initial observation, is a photographical referencing report (colour schema, map orientation, scale). This allows for future assessment about the possibilities of carrying out a metric survey study.

Graphic scale and/or level of detail

In most cases graphic scale is associated with two-dimensional representations. However it can also be applied into the level of detail required in a three-dimensional model.

The scale is linked to the measured dataset output requirements, prior to start the metric survey process; the revision of the targeted end-user and research needs should clarify the graphic scale or level of detail requirements according to the needs of the research.

Moreover, a product can consist of multiple scales, which are associated to different levels of detail (LOD) according to the needs of each representation (e.g. an urban map will be presented using a higher scale than a construction detail or historical phasing analysis).

Accessibility

Accessibility deals with accessing the site or its sources, ranging from ownership issues

and problems related to the legal status of the object in terms of environmental limitations, and other physical limitations (distance and local facilities for operating the surveying equipment).

Legal accessibility

"Legal accessibility" issues deal with matters such as the site's accessibility, whether the site is available for study purposes and whether the site's owner permission is needed prior to beginning work.

Furthermore, the timing available for surveying and other factors dealing with the legal statue of the site and social situation.

Environmental accessibility

Environmental or accessibility limitations deal with the time of year when the survey can be carried out, weather conditions (which can affect the operation of the selected measuring devices), as well as the effectiveness of the operators and timing.

Physical accessibility: occlusion and other limitations

Physical accessibility, relates, on one the hand, to the 'in situ' facilities for the equipment to carry out the survey and lodging of the operators.

On the other hand, it relates to occlusion of parts by physical boundaries, trees, and orientation of the building, height, and other limitations dealing with the position of the object.

Apparent uncertainties

Preliminary reconnaissance reports should examine apparent uncertainties in the fabric and surroundings of the site. These uncertainties are based on the existence of missing parts and alterations due to decay.

4.1.2.2 Quantification analysis: rapid-assessment (Clark, K., 2001, p.33)[5]

The quantification analysis is defined following the scale requirements and amount of information available from sources of information, taking into consideration predicted uncertainties.

Sources of Information: preliminary analysis

The preliminary observational analysis of sources of information can lead to the preparation of a report addressing the obvious characteristics of the architecture, history, condition, and structure of the object.

Preliminary geometric and texture assessment (monument and context)

The preliminary architectural analysis is based on '*a visual assessment of the fabric*', specifying the '*nature of the building and its landscape*' Clark, K., 2001, p.33)[5].

This report includes descriptions, photographs, and sketches of the physical boundaries (taking into consideration buffer zones), height, proportions and the dimensions of a structure. As well as the characteristics of the topography of the object and its emplacement.

Preliminary historical assessment

A preliminary report on historical sources comparing it to the fabric is aimed at establishing the preliminary Historical Analysis of the site. This research should address the '*significance of the site*' (Clark, K., 2001, p.33)[7], its style, past significant events, and apparent phases of construction.

Furthermore, this report should specify the amount and sources of information available for preparing a detailed historical documentary research.

Preliminary observations about its condition

The preliminary metric survey dataset should be complemented with observations about the most apparent types of alterations and '*weathering forms*' (Fitzner, B, Heinrichs, K& Kownatzki, R., 1995, p.41)[6]; as well as the apparent structural problems present in the site, in order to assess future specialized investigation requirements for preparing a complete condition assessment.

4.1.3 FORMULATION OF A RESEARCH STRATEGY FOR THE METRIC SURVEY STUDY

The combination of the 'rapid assessment' and 'purpose of documenting' provides the information to formulate a research strategy to carry out a deeper and more advanced mapping of the site in question.

Subsequently, the formulation of the research is based on determine the type of studies required to complete the documentation and the prediction of the precision based on different types of uncertainties associated to the nature of built heritage.

4.1.3.1 Type of studies

Sourcing information embedded in a monument is executed primarily by preparing a non-thematic dataset. This consists of a set of measured representations of the building and its context called 'metric survey study' that will be used as a basis to map other thematic studies, such as spatial and typological assessment (Context and architecture), historical assessment, condition assessments, and other relevant investigations adapted to the specific characteristics of the subject (see chart 10).

Non-thematic: metric survey

This is a study aimed at acquiring a set of measurable representations of the building's shape and its context. Including the study of the geometry (Non- and image-based survey) and texture fabric (image-based survey).

Moreover, this study involves the preparation of analytical sketches and hand measured drawings.

The representation is a partial mirror of the site. A successful metric survey is based on an adequate and adapted determination of the precision and accuracy required. In this research precision is defined '*as a number of measurements of the same distance are taken the degree of repeatable agreement between them is the precision of the set. Precision is measurable and is usually expressed in terms of the tolerance of the survey. The tolerance is the allowable range in which measurement must fall; the output scale usually determines the tolerance for the survey*' (Andrews, D., Blake, B., et al 1999, p. 3)[7].

Furthermore, accuracy will be defined according to the term '*observational accuracy*' that '*describes the completeness and reliability of the data*' (Andrews, D., Blake, B., et al 1999, p. 3)[8].

Context geometry and texture: topographic & urban survey

The topographic and urban survey is design to acquire the existing conditions of the context surrounding the building: as well as the landscape.

The survey should be targeted to capture the 'boundaries, transportation systems, influential geography (rivers, valleys), and significant site structures and services'. As well as, the 'topography, and significant botanical materials (trees, shrubs, plants)' (HAER, 2000)[9].

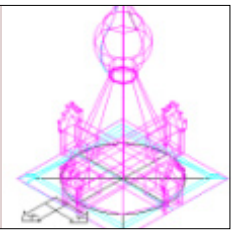
IMPLEMENTATION: DATA-ACQUISITION: FORMULATION
RESEARCH STRATEGY FOR STUDYING BUILT HERITAGE: TYPE OF STUDIES

Type of Study

NON-THEMATIC

Metric Survey
Study aimed at acquiring a measurable 'Dataset' of the object's morphology and its context. Including the study of the geometry and texture of the fabric.

- Context (Landscape - Urban)
- Building Geometry and Texture



THEMATIC

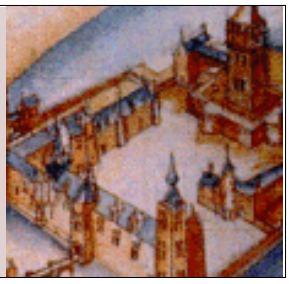
Spatial - Typological Analysis
Study aimed at understanding the spatial and typological characteristics of the object and its emplacement

- Building Morphology Analysis
- Topographic - Urban Analysis



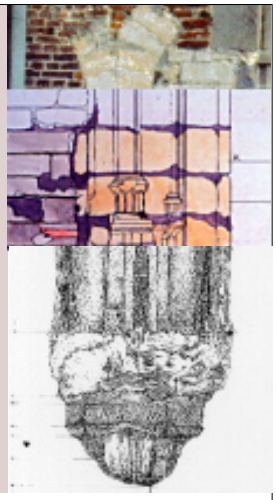
Historical Assessment
Study aimed at understanding the phases of construction and modifications carried out to the object. Collection of documents from archives and other historical sources. Important relation with the Metric Survey for Confirmation

- Historical Documentary Research
  - Archival and Bibliographical research
  - Iconographic research
  - Map Regression
- Stratigraphical research (relational to other studies)



Condition Assessment
Study aimed at understanding the current state of conservation of the object's fabric by investigating the type of construction materials present and alteration pathologies associated to these types of material and environmental conditions.
As well as, to understanding the construction systems, quality of the grounds, and cracks, in order to determine the causes of decay for possible operation to improve the stability of the structure

- Condition Mapping
  - Materials analysis
  - Analysis of Weathering Forms
    - Loss of Material
    - Discoloration/Deposit
    - Detachment
    - Fissures/Deformation
- Structural Analysis
  - Construction systems
  - Technical -Scientific analysis
  - Fissure Mapping



Other studies
Complementary studies aimed at understanding issues adapted to specific projects and situations, where other type of analysis are required

- Impact assessment
- Dendrochronology
- Sampling

Chart 10: type of studies in the 'core data' for an analytical report' in studying built heritage

Building geometry and texture

The building survey seeks to assess the geometry and fabric texture of the building by applying both two- and three-dimensional recording techniques.

Geometry: this is not only related to acquiring the shape of each component of the building, but also their functional relation, adaptation to the topographic conditions, significant structural issues, and detailing of the masonry. The level of detail (LOD) can provide evidence for the studies relating to the historical stratification, weathering processes, and structural problems.

Furthermore, several detailed views should be included, 'showing significant architectural and engineering features whose relationships cannot be clearly displayed' (HAER, 2000)[10] at lower levels of Abstraction.

Texture acquisition: the measurable acquisition of texture should be a complement to the geometry. This study provides metric information that can be used off-site for further analysis, and as verification to the vector drawings generated from the survey. This type of survey is used mainly for condition mapping.

The level of detail (LOD) of this approach depends on the quality and resolution of acquisition of the imagery information, related to the type of camera, lenses, digitalisation, and quality of the processing.

This assessment makes use of different techniques, such as historical documentary research (map regression, iconographical research, and archival-bibliographical research) and study of the stratigraphy of the fabric.

Historical assessment

The study of historical documentation seeks to understand the architectural, historical, social, and scientific dimensions of the building by establishing the phases of construction and modifications carried over time.

> *'Historical research: this stage consists of the acquisition, analysis and interpretation of the available documentation concerning the construction (drawings, designs, surveys, etc), and a chronology of events such as work affecting the structure and the foundations, failures, alterations, earthquakes, etc. Special care should be given to events that might have influenced structural behaviour, while the reliability of the sources should also be considered' (Croci, G., 1998, p.)*[11]

This analysis is based on collecting and reviewing documentary sources of information from documents, iconographical and other available sources that might be available in archives.

Furthermore, previous analysis should serve to establish a relational study with available documents and the historical stratigraphy by looking and investigating the fabric of the site, taking into consideration its current geometry and condition of conservation.

Historical documentary research

This involves carrying out investigations into iconographical sources, archival and bibliography available, and techniques of 'map regression'.

Iconographical research: this technique relates to the collection of 'Topographical or other drawings, published views and historic photographs' in order to acquire information about the 'building's function, patterns of

alteration, and perhaps ideological intentions of the original' (in case of illustrations) (Clark, K., 2001, p.73)[12].

Furthermore, pictorial sources include pictures and videos related to history or references of the studied site.

Archival and bibliographical research: comparative research conducted through the national or international records, including: libraries, and other related bodies.

Sources may include, for example, manuscripts, research papers, and bills of historical value. They may offer a clearer view of a building's alterations, designer's intentions, and other considerations.

Map regression (Clark, K., 2001, p. 75)[13]: this technique requires collecting a vast amount of 'all relevant maps' (Clark, K., 2001, p.76)[14], starting with the most recently ordnance survey sheets to the whole sequence of drawings available of the object, either metric or not, that might be available from local, national or even international authorities and/or institutions of the site. This allows for a better understanding of the building's development overtime.

Particularly, if available, in situ surveys preliminary sketches made during the preparation of an old measured dataset. These could be of great value for interpreting the completed map.

Stratigraphy

This is a non-intrusive analytical technique. In this application, based on the observation of a building's fabric. Its purpose is to find evidence relating to historical documentary research, such as map regression and historical images. In order to assess the '*structural sequence*', '*logic of construction*' of a building (also studied in Condition Assessment), '*evidence for absolute dating'*, (ICOMOS, 1990, p. 43)[15]. As well as, the nature of the material used, giving evidence about the '*social organization, the time, the energy consumption and effort that went into the acquisition, manufacture or transportation of the material*' (Conway, H. Roenisch, R., 1994, p. 69)[16].

This research also involves the use of 'comparative and contrasting' tools to 'reveal similarities and differences' (Conway, H. Roenisch, R., 1994, p. 34)[17] with other related existing or documented buildings or sites.

On the other hand, a stratigraphical research can aim at studying the fabric of the building in order to understand modifications that have not been described in other accounts.

Condition assessment

This research emphasizes in the developed an adequate 'measured dataset' of representations from the metric survey study. This assessment aims to understand the current state of conservation of the site's fabric and structural problems. For this reason, the concepts dealing with mapping weathering forms have been summarized, to be use as guidelines.

On the one hand, the purpose of the assessment is to map the type of construction materials, including the masonry, structure and joinery; as well as to determine the type of weathering forms and alteration processes that are affecting the fabric of the object, these issues are associated to the orientation of the structure and environmental conditions.

On the other hand, the objective of a condition assessment is to study the structural problems. This allows for a better understanding the construction systems used, quality of the grounds, and fissures, in order to determine the causes and possible operation to improve the stability of the structure.

The main output of this study is a model, which is 'a simplified outline of the structure, with sufficient information on loads and dimensions to enable the first steps in

calculation to be made' (Robson, P., 1999, p.43)[18].

Construction systems

The study of construction systems present in the building is based on the evidences found in the metric survey and historical documentary relating to the construction and state of the structure.

The assessment will thus study the geometry, material, and present state of all the elements composing the masonry in the specific structural feature (e.g. stones in an arch).

Technical-scientific analysis

More advanced technical-scientific analysis relates to acquiring information from monitoring techniques and other laboratory tests.

Fissure Mapping

The fissures should be recorded in the metric survey in order to have a clearer and more general picture of apparent critical areas. Fissures are also included in the condition mapping as a weathering form.

Materials: masonry, structure & joinery analysis

A variety of construction materials are used in the fabric of built heritage, in general, the following are the most common (Franke, L., Schumann, I. Et al, 1998, p. 5-9)[19]:

Bricks: fired bricks, adobe, and brick masonry.
Glass/Glassy phase
Mortar: mortars in general and rendering and plastering mortars
Natural Stones
Stucco: stucco marble
Wood
Metal
Concrete
Other

Furthermore, these materials are grouped according to their origin, mixture, and composition.

Analysis of weathering forms and their alteration causes

The analysis of weathering forms is a time-consuming task based on adequate mapping classifications, which has been developed for each type of material and joinery.

> *'Weathering forms are the result of the weathering processes occurring at the surface. These are initiated and controlled by the interaction of various weathering factors. The weathering factors and the weathering processes can normally be identified and quantified only by large-scale and time-intense investigations' (Fitzner, B, Heinrichs, K& Kownatzki, R., 1995, pp.42-43)[20].*

A mapping process to determine the condition of the fabric should take into consideration the characteristics of each material and adapt the classification chart to address each of these pathologies.

General guidelines for classifying weathering forms:

The following classification of weathering forms has been particularly developed for stone in built heritage, however it can be adapted to classify other types of materials. It has been extracted from the research undertaken by B. Fitzner, K. Heinrichs, & R. Kownatzki from Aachen University[21].

Loss of material: this form relates to the losses of material, which has occurred on the surface due to alteration processes. The different sub-classifications are based



Figure 31: An example of weathering forms and structural problems, Saladin Castle, Syria. Author.

on the '*morphology of the weathered stone surface*' (Fitzner, B, Heinrichs, K& Kownatzki, R., 1995, p.44)[22].

Discoloration/deposit: this group by weathered forms includes all forms describing a modification of' the material colour and deposits on' (Fitzner, B, Heinrichs, K& Kownatzki, R., 1995, p.44)[23] the material surface or near the material surface.

This type of weathering includes discoloration or deposits due to biological growth.

Detachment: this type of weathering precedes the actual loss of material; it describes different types of alteration process, such as '*granular disintegration, crumbling, splintering, flaking, contour scaling, detachment of material, and detachment of crust*' (Fitzner, B, Heinrichs, K& Kownatzki, R., 1995, p.48)[24].

Fissures/deformation: relates to the presence of fissures in the fabric of the building, a difference has been stated between fissure related to the material used and structural causes.

Implementation of the study: mapping and representation

The Evaluation of a building's condition is based on the implementation of an adequate weathering forms mapping schema, which has been adapted to the specifications and characteristics of each of the materials and joinery in the fabric of the building.

Furthermore, the mapping processes are prepared by identifying the state of the material and the intensity of the damage. The method of representation should be able to present a quantification of these results for further evaluation by conservators.

The mapping process is based on the maps prepared by the metric survey study. Identification of the weathering forms can be performed on site, but can be also executed off-site using measurable photographic records, such as rectified photographs or photogrammetric applications.

Other relevant studies

Complementary studies aimed at understanding issues adapted to specific projects and situations, where other type of analysis are required.

4.1.3.2 Predicting precision and observation accuracy

The use of metric survey tools for the representation of built heritage is based on approximations and a process of interpretation. The correctness of these approximations is in turn, based on observational accuracy rather that accuracy 'per se' as has previously been mentioned, related to the '*completeness and*

reliability of the data ' (Andrews, D., Blake, B., et al 1999, p. 3)[25].

Moreover, precision is associated with the level of determining the position of an object or point in space. In other words the closest possible '*true or absolute value*' (Ciciarelli, 1991, p.38)[26] to reality by a specific instrument, this level can be express from millimetres to centimetres in the study of built heritage. In more specific applications, such as monitoring, where the precision required is higher.

At the same time, accuracy depends on the specific requirements and purpose of an activity. This issue has to be studied prior to mapping the fabric of a building.

The correct prediction of conditions affecting the precision and observational accuracy will determine whether the documentation process has been successful or otherwise.

Furthermore, this term is a controversial issue among experts working on built heritage, particularly when it deals with a three-dimensional visualization. This discussion is based on the tools used for documenting, processing and presenting the object and the aim of the dissemination, partially related to the targeted audience.

Therefore, the prediction should not only take into account the obvious variables affecting the recording process (e.g. the instruments used and environmental conditions), but should also take into account the different views of an interdisciplinary group of experts.

Each of these issues or views affecting the precision and observation accuracy has been grouped as:

- Building geometry and texture acquisition uncertainties (instrumental precision – expertise level – operational issues – possible occlusion)
- Condition mapping Uncertainties (instrumental precision – expertise level – possible occlusion)
- Historical analysis uncertainties (reliability of sources – amount of sources – expertise level)
- Structural analysis uncertainties (instrumental precision – expertise level – operational issues – possible occlusion)

Building geometry and texture acquisition uncertainties

Building geometry relates to the level of detail (LOD) and correct geometrically representation of a real building's fabric within its urban and natural context.

Furthermore, texture acquisition relates to the adequate acquisition of the material and weathering form colours.

Instrumental precision

Deals with the type of equipment and procedure used for the collection of measurements, which seeks to simulate the Geometry and texture of the building.

Furthermore, it relates to the correct application of different techniques of documentation and a convenient system of references that can aim to combine the different sources of information.

Equipment

The survey instrument and methodology used has it own limitations and characteristics when measuring a point in space. In this case the precision is embedded and therefore known before hands.

Furthermore, this instrumental precision relates to equipment issues that can affect its operation, such as the measuring-speed, range, weather conditions, and care in the

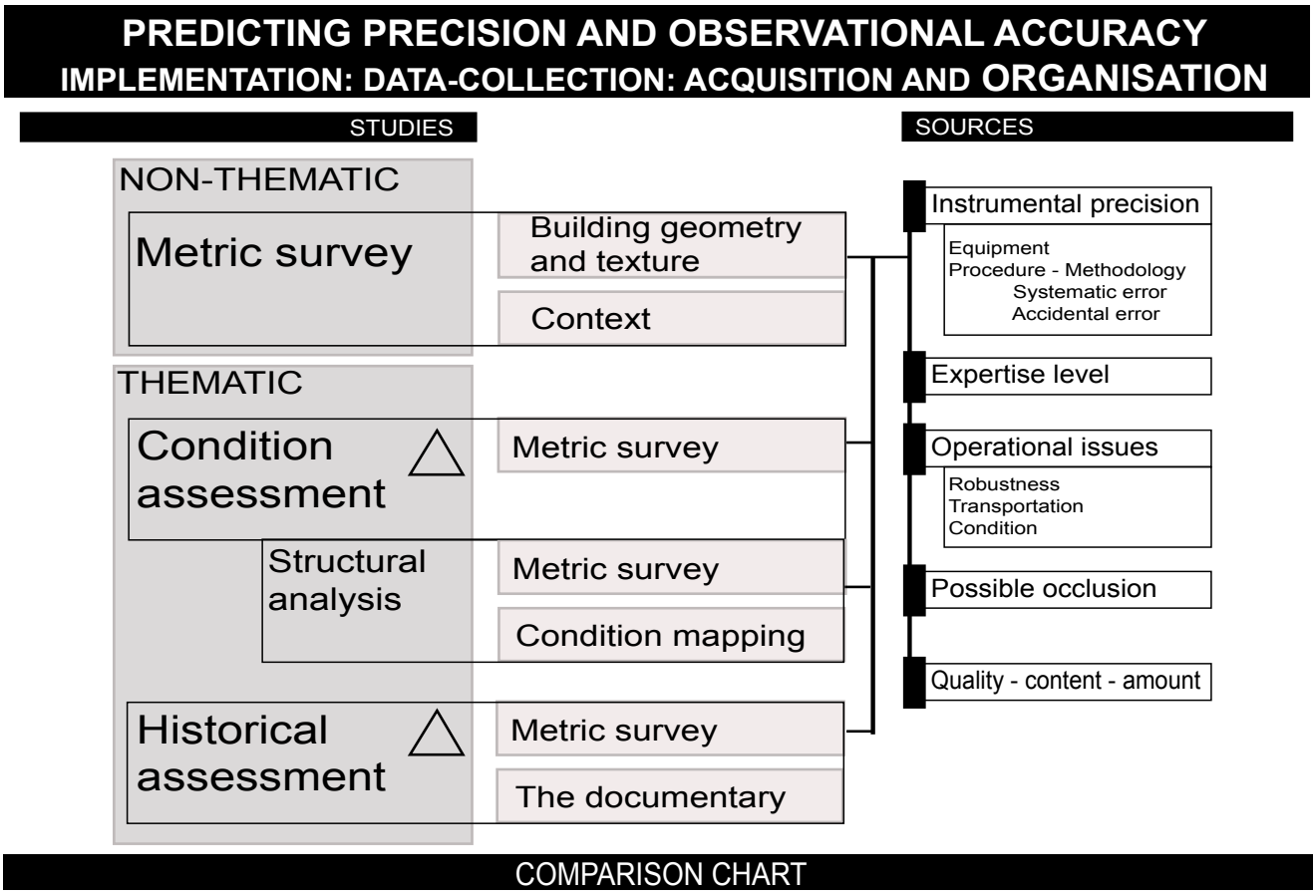


Chart 11: predicting precision and observational accuracy

transportation of the equipment.

However, it is important to remember that instruments that have suffered repairs, been mishandled or neglected can affect the survey (see chart 11).

Procedure or methodology

The methodology can create problems relating to the observational accuracy of the representation being prepared. They are related to two types of errors: '*systematic and accidental*' (R.E.A., 1983, p. 6)[27].

Systematic errors

These types of errors are related to known characteristics of the instrument selected, as has been already discussed in the part dealing with equipment.

The effective reduction of these errors can be done 'by eliminating calibration and adjustment errors in the equipment' (R.E.A., 1983, p. 249)[28].

Accidental errors

These types of errors appear as uncontrolled to the operator. Often they appear in conditions, which are difficult to determine but should be compensate by formulas and several systems of measurements that can be compared. The selection of an adequate system of survey is of paramount importance to avoid these types of mistakes. The instrument should be adequate to the environmental conditions of the place.

Expertise level

The level of expertise required to the simulation of the geometry and texture of the buildings fabric is not only related to the potential of the operator to be able to determine the position of a point with precision, but who to its analytical capacity of identifying '*evidence of construction, alterations*' (Clark, K., 2001,

p.111)[29] and other relevant information that can be subtracted from the fabric of the building.

The record generated from a metric survey is a partial picture of the object, the selection of the most important features and level of abstraction required to present these results is dependant on the expertise of the recorder.

Furthermore, the level of expertise relates to the limitations of the personnel in operating the instrument correctly in relation to the need of careful calibration of the instrument or application.

Field operational issues

Deals with the robustness, transportation required, and the conditions required the proper use of the instrument.

Robustness

This relates to the capacity of the instrument to stand '*variations in temperature, humidity, wind, gravity, refraction, magnetic declination*' ((R.E.A., 1983, p. 249)[30], and lighting conditions of the site.

Transportation

This issue is sometimes taken for granted, but transportation of the instrument is very important for its adequate performance. It relates to the availability of facilities to operate the tool (e.g. electricity for recharging batteries, dealing with voltage and plugs) and the use of adequate packing and handling for transportation it (e.g. special case prepared for the instrument against shocks).

PREDICTING
PRECISION - OBSERVATIONAL ACCURACY



Chart 12: predicting precision - example when defining edges in a metric survey study, Roman Theatre Jebleh, Syria. Author.

Conditions

Other local facilities for the execution of a survey using a specific equipment and methodology should be foreseen; all items should be available (e.g. for vertical photography a scaffoldings or lift might be necessary).

Condition assessment uncertainties

Condition mapping uncertainties are based on the quality of the metric survey executed in the building, however there are other issues inherent to the tools and judgment applied for the mapping process.

Furthermore, the analysis of the structure aims to establish the possible problems with the stability of the structure to avoid collapse. This study is extremely specialized and requires special equipment for monitoring effectively the problems.

Instrumental observational accuracy

This type of observational accuracy relates to the type of scale and instruments used for mapping and representing the weathering forms; as well as equipment to record structural behaviour.

Furthermore, the instrumental quality or type of base data used (e.g. the colour of a rectified photography that can be affected by the day-light and processing of the film).

Expertise level

The judgment of an expert working on- or off-site has a big impact on the quality of the survey. The mapping system can be badly affected through misjudgement of a type of weathering form and simplification of a level of intensity.

The team should have previous training in the use of the tools for identification. A colour chart should be available showing examples. Lastly, a note should be made by the time spent on- and off-site.

For photographic records, a colour chart and scale can be included in the photograph, in order to improve the quality through the use of digital manipulation of the source.

Possible occlusion

Occlusions are related to the expertise level and the type of survey carried out, as well as the scale and size used for the mapping process.

Historical assessment uncertainties

The uncertainties in historical research are related to the amount and content of the documents available about the site; as well as, their reliability, if it can be determined.

This analysis is also affected by the level of expertise of the researcher and operational issues dealing with the type of instruments used for gathering and digitising sources.

On the other hand, a historical analysis cannot be measured, the precision and observational accuracy are terms not applicable in this field, except when it relates to the study of the fabric of the building or building archaeology.

Reliability of the sources

There are two types of sources available when in preparing the historical research of a site. They are directly linked to sources of information. Each of these has different parameters affecting the precision of the survey.

The fabric:

Observing the building fabric and the extensive investigation for looking for prove about alterations and modifications for determining the phases of construction of the structure deal with different types of uncertainties, they deal with misjudgement and/or missing information.

In this sense, uncertainties relating to the historical assessment related to the study of the fabric needs to be reviewed using previously discussed problems in

the preparation of metric survey studies, as well as the variables affecting non-destructive and destructive techniques for dating purposes (e.g. dendrochronology) or building archaeology (e.g. removal of architectural components, such as masonry, floors…).

Documentary sources

The reliability of documentary sources is associated to the quality of the publication and its state of preservation.

Amount and content

The amount and content of the collected sources is an important issue to determine uncertainties, dealing on the one hand with the quantity of information available to identify the alterations and modifications suffered in the building. These problems are related to the missing gaps in the documentation (records and accounts) about a specific period of time.

4.1.3.3 Classification

The phase of Data-Collection involves the acquisition and classification of vast amounts of information from different sources. These have to be classified using a predefined system of file classification that is capable of providing a basic description of the object and its purpose.

The use of digital files imposes new questions that have to be address by the preparation of an adequate protocol classification. Most of those problems reside in having multiple updates and/or corrections of a file during time, which leads to have several versions of a file; as well as the incorrect exchange of data trough a group of people working on the same project and using different coding.

Protocols

Protocols are related to different organize

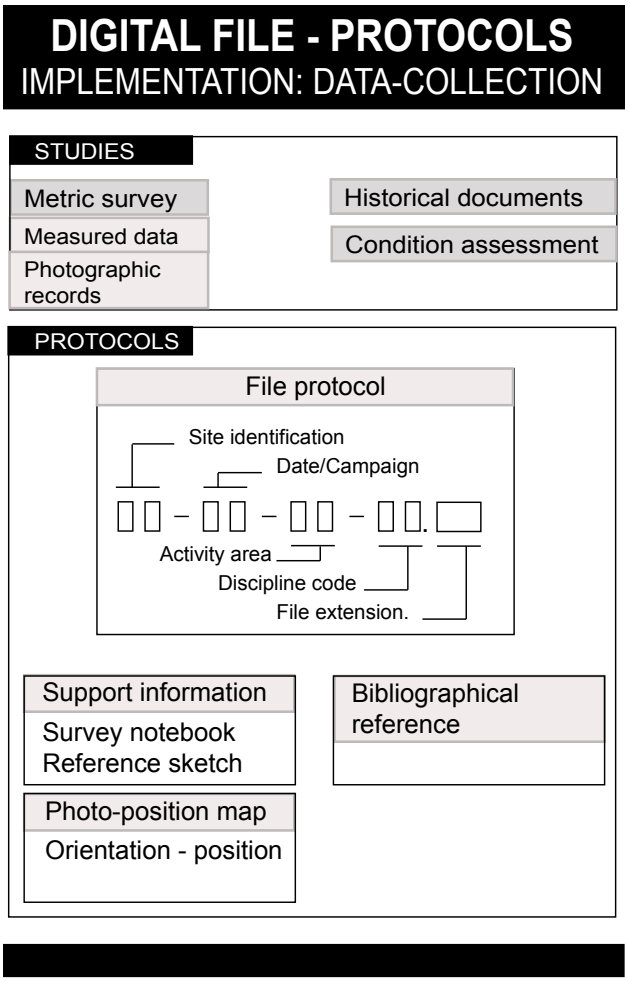


Chart 13: digital file protocols

different sources of information collected in the documentation of a site. At a first stage, the definition of a number of file protocols for the different data collected in the metric survey and the storage file name for digitised historical documents (see chart 13).

Furthermore, where necessary during a second phase the condition assessment files, although these protocols will have a close relation with the metric survey prepared and historical documents found.

The preparation of protocols should clearly state the relationship between ‘time-space’; these two variables are not modifiable across time or change of technology and can be of help to the identification of data.

Metric survey protocols

Each data used for the metric survey should be identified using the following rules. Furthermore a structured directory can be created for easier navigation through the different files.

Measured data (vectors, point of clouds, coordinate lists, etc)

The protocol for a file with measured data for a Metric Survey is composed of prefixes identifying the 'site identification', the 'activity area', and the 'discipline code', these relate to space; as well as, 'date' (campaign) that relates to time. These fields provide information about when, where and for what purpose the metric data was gathered. Furthermore, each of the files will be identified according to its file format.

Photographic records

A Photographic record protocol for a Metric Survey is composed of prefixes identifying the 'site identification', the 'activity area', and the 'discipline code', these relate to space; as well as, 'date' (campaign) that relates to time. These fields provide information about when, where and for what purpose the metric data was gathered.

In both cases, the analogue photograph and digital file resulting from the scanning should have the same name, however for digital images the resolution should be added.

Support information: on-site

Survey notebook: a field notebook should be written during on-site investigations, this support system should describe the recording procedures for preparing the metric survey.

Reference sketches: the survey notebook should be accompanied with a sketch of the survey, identifying target points, areas surveyed and depending on the recording instrument, should include all necessary information concerning the off-site processing of the survey relating to space and time of collection.

Photo-orientation and position referential map

The position and orientation of each of the photographs should be roughly identified using a sketch or pre-printed photo-orientation and position map for proper identification in the context of the site. This relates to space-time.

4.1.4 IMPLEMENTATION METHODOLOGY

In the Metric Survey, the Data-Collection phase is the preparation of the Dataset from the retrieval of the subject's geometry and fabric texture.

4.1.4.1 Metric survey study

The metric survey is associated with a measurable documentation of the geometrical-morphological properties of the subject, including the building itself, urban context and landscape (topography).

> *'The Metric survey is also commonly termed measured survey. Before undertaking major repair, alterations or development at an historic site, a set of metric survey drawings will usually need to be prepared as the basis on which other professionals can develop new designs or specify repair work' (Clark, K., 2001, p. 36)*[31].

The product of this type of documentation is used as a 'measured dataset' for other types of studies. It involves, not only the measurement and plotting of points, but also the study of the fabric with an analytical approach. In this sense, it ' *will require the*

input of professionals with particular skills in the survey, recording and analysis of historic fabric' (Clark, K., 2001, p. 36)[32].

Three-dimensional metric reference system

The establishment of a reference system is the first action towards the implementation of a metric survey study. This site system can have three-dimensional local coordinates, but it is recommended that it a future stage be linked to any absolute system available, such as a national grid or to the UTM (Universal Transverse Mercator projection) system for an exact geographic location and orientation of the site. This reference system will aim to perform comparative studies with other similar historic sites, allowing the researcher to position the site exactly and link other types of geographic data (see figure 32).

However, should the site be in a remote location and there is no information available of any regional system, a hand-held GPS device can be used to roughly acquire the coordinates of the first standing point or station.

Moreover, two known points can establish the position and orientation of the site, one of the points can be a known three-dimensional point (station) and the bearing from the first point to that second point or object (orientation). The north can be used as the bearing for setting the orientation; this can be calculated with an absolute (true or grid meridian)[33] or relative north (Magnetic north)[34].

1.1.4.1.1.1 Site grid: control networks

The Site grid is a set of stations (standpoints), which have already been measured previously with greater accuracy. These positions are used as the '*reference framework*' (Schofield, W., 2001, p.5)[35] to measure the position of other points and objects aimed at interpreting the building, urban, and topographic geometry of the site.

Preparing this 'reference framework' with the '*highest order of accuracy*' (Schofield, W., 2001, p.21)[36] should be based on two basic conditions:

Firstly, stations should be positioned with adequate indivisibility and distances between each other, and a Traverse should be *adequately calculated to 'adjust the co-ordinate values*' (Blake, B., 2000, p. 5)[37] of the stations after they are all measured.

Secondly, it is important to define the needs of a project prior to starting any process of study. This allows one to limit the amount of recordings needed (see figure 32).

On large scale projects it may be necessary to integrate several different survey techniques in order to achieve complete cover. In such cases, a commonly control system should be put in place using GPS (Global Positioning System). CADR can be used right from the start to assemble data from different sources (Clark, K., 2001, p.82)[38].

Vertical datum (Height) (Bryan, P. & Blake, B., 2000)[39]

The site grid should be three-dimensional. It should include not only a geographic orientation, but it also has to be accompanied with the correct referential datum or height, this can be assign randomly according to local needs (Relative) (see figure 32).

However, it is recommended to use devices to calculate the absolute altitude of the points in the site grid, such as GPS if there is no known benchmark with a 'referential datum' (Bryan, P. & Blake, B., 2000)[40] available.

Topographic and urban geometry

On one the hand, the most common procedure to acquire a three-dimensional

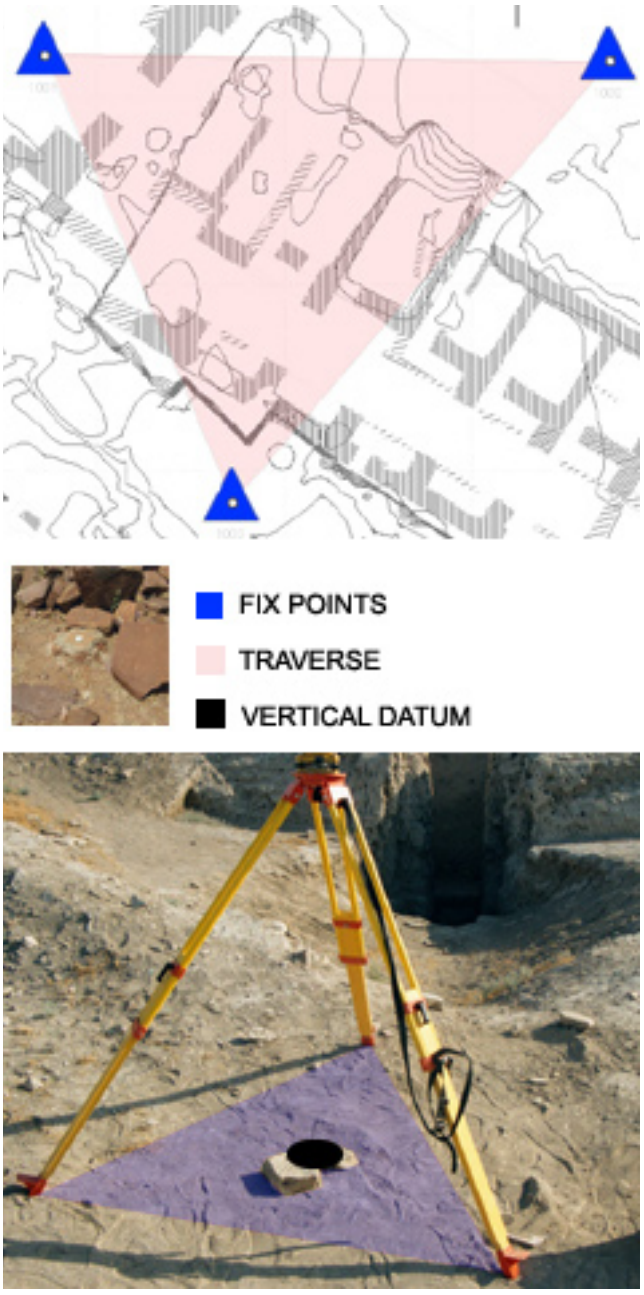


Figure 32: example of the coordinate system and a fix point (showing the reference vertical datum used). Author.

representation of the topography is known as DGM (digital ground model), which is created '*by a sampling points over the land surface and using appropriate algorithms to process these points to represent the surface being modeled. The methods in common use are modeling by 'strings', 'regular grids' or 'triangular facets'. Regardless of the methods used, they will all reflect the quality of the field data*' (Schofield, W., 2001, p.12)[41].

The quality of the representation depends on an '*adequate site cover*' (Bryan, P. & Blake, B., 2000)[42] that relates to the amount and interval of points surveyed in the surface using a logic sequence (e.g. relation between 'density' and the use of a 'regular grid') (see figure 32).

Building geometry

Geometry

The metric survey technique(s) selected is/ are used to calculate a specific amount of points to create an approximated picture of the building, the resulting 'measured dataset' should be capable of providing enough geometric information to define the different entities that constitute the Geometry of the subject.

These points and other measurements will be used in the following phase to model the entities and components (see figure 34).

Entities and components are defined using metric techniques

The process of measuring to simulate the geometry deals with level of detail required. This variable provides the quality and extent in the definition of entities and components to be individually and/or fully measured. Bearing in mind that all this elements are single units constituting the geometry (see the part discussing 'building geometry' in chapter III – part I).

Moreover, the measured definition of the entity is an approximation (e.g. a window is defined measuring its four corners, however more points will provide a better approximation of the real geometry of the object), this process of selection for defining the object is an abstract judgment.

Two-dimensional surveys aimed at orthographic representation (elevations, sections, plan elevation and plan section)

A conventional technique widely used is two-

dimensional projections. In this methodology the output is defined by a sequence of points projected to a plane. The definition of this plane is random, depending on the needs of the documentation.

In the case of elevation and plan elevations, the plane is defined parallel or on top of the monument studied (e.g. a general site map, the components are visualized using an orthographic projection similar to an aerial view)

For plan sections, these views are defined by multiple horizontal planes at different heights, normally in relation with the levels of the building.

On the other hand, plan sections are defined by vertical planes following a regular or irregular axe. Sections are used to perceive inner and outer relations.

The two-dimensional surveys for preparing orthographic projections have the added advantage of preserving 'more of the shape and size of what is drawn than perspective does. It is easier to make things from than to see things with' (Evans, R. 1989, p. 21)[43].

Three-dimensional survey aimed at generation of a three-dimensional wireframe (vectors and points)

Three-dimensional surveys aim to make a closer approximation of the building's geometry by defining each entity by collecting a higher density of measurements.

In this phase, the resulting 'measured dataset' is a point of clouds that can be transformed into a vector wireframe by joining connecting the corresponding points defining each entity (see figure 34).

Fabric texture acquisition

Texture acquisition relates to the use of

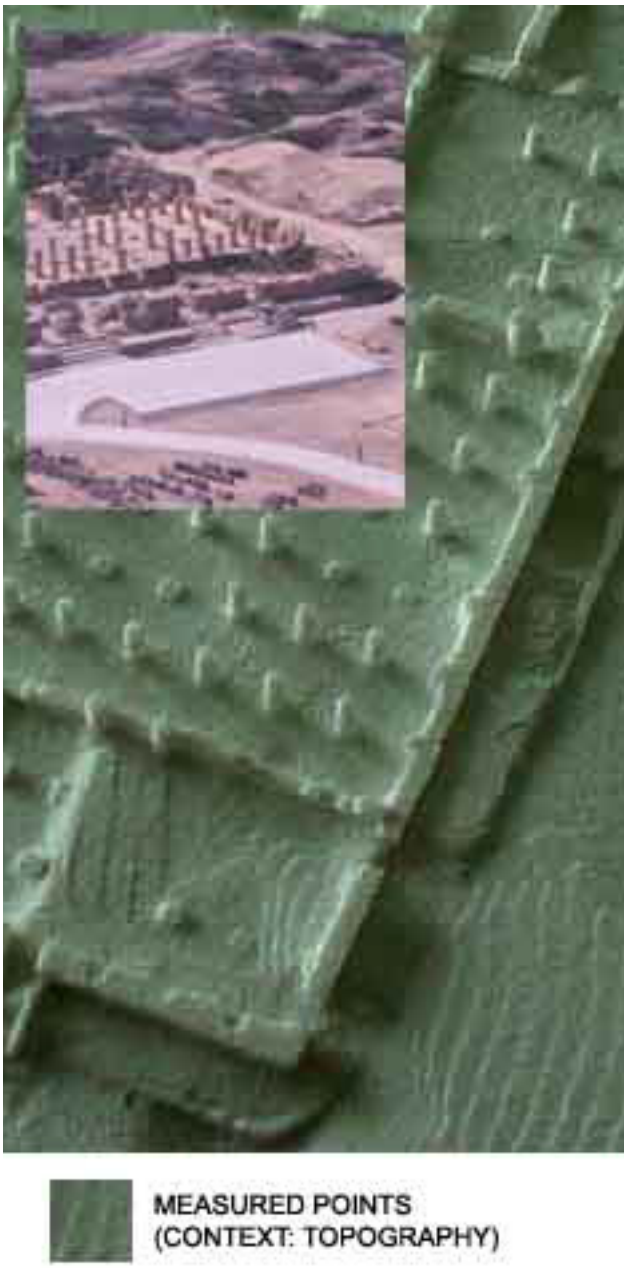


Figure 33: example of a laser cutted model from a topographic survey, Great Mosque, Sultanate of Oman. Author.

image-based systems that are able to acquire measurable planes with orthogonally projected textures or more advanced applications that can extract a texture with the real depth, including the colour, and shape of weathering forms (e.g. the patina).

Two-dimensional survey aimed at orthographic photographic representation (Elevations, sections, Plan elevation and Plan section):

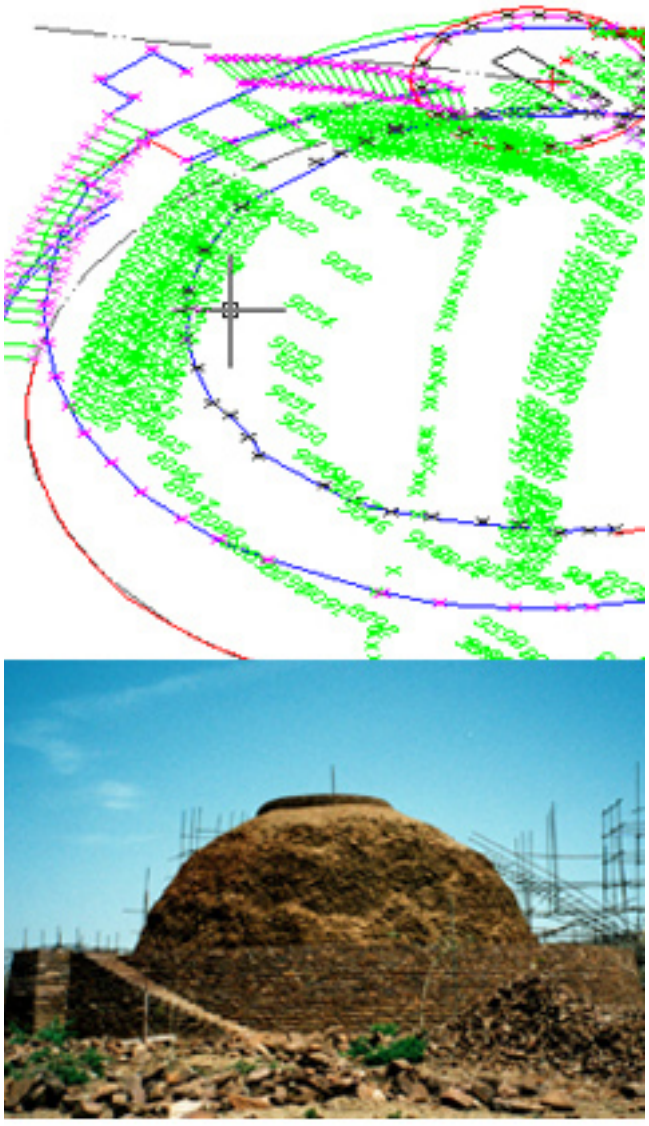


Figure 34: example of measured points to defined the building geometry, Stupa 01, Sadthara, India. Author.

Photographs can be processed through restitution and distortion adjustment procedures to generate an orthographic plane of the texture, such as rectified- and/or ortho-photographs. In rectified photography each plane is corrected separately while in ortho-photographs the resulting texture is completely orthogonal. An irregular surface with different relieves represents a challenge to these techniques.

Three-dimensional survey aimed at generation of a three-dimensional textured model:

In conventional image-based applications, such as digital photogrammetry, a set of there-dimensional textures can be extracted from the photographs used. However this is a very laborious task of defining the borders of each plane and extract each of the textures corresponding to these surfaces.

Recent image-based acquisition and modelling technology, such as VIRTERF[44] currently in a prototype state introduces an '*acquisition tools largely automated*' for the generation of three-dimensional textures or depth maps, and a coloured cloud of points.

4.1.4.2 Historical assessment

This investigation concentrates in the extraction of geometric and texture information of the subject and context, it is important to expose the methods used for digitising historical documents in the process of preparing the 'core data' for the analytical report.

Therefore, the information used for the historical assessment study consists of a variety of archival and bibliographical sources (written documents), and iconographic sources (paintings, old-photographs, measured-drawings, sketches). These sources are selected, digitised, and classified in a source database for further processing and research.

The methods described in this part deal with the digitalisation of a document to produce a bitmap image (raster image) for referential use, as a source that is attached and/or link as an attributes to a single or number of entity(s) conforming the geometry of the monument.

Furthermore, relevant bitmap image scanned from written-documents and measured-drawings can be transformed into a more flexible and modifiable format using character-shape recognition software. These applications are capable of generating a word-processing file and/or a computer



Figure 35: example of REDM measurement to make a wireframe that traces the profile of an ornament, Salle Heraldique, Castle of Arenberg, Heverlee, Belgium. Author.

vectored drawing out of these digitised documents.

These recognized files are further used for constructing the chronology of the building or completing a survey for establishing the actual condition of the object.

On the other hand, the 'measured dataset' generated in the Historical Documentary Research at this stage should be stored, identified, and easily retrievable using consistent, transparent, and efficient guidelines.

The process

The digitalisation of archival and iconographic sources is a time-consuming activity that involves the selection of a coherent, transparent, and consistent method for the digitising of the 'dataset', dealing with the preparation of guidelines for 'entering the data' (Bertels, I., Van Balen, K., 2001, p. 14)[45] and rules for storage in cataloguing. As well as, adding textual documentation describing the image in the 'data structure' (see figure 37).

Furthermore, the selection of the equipment for capturing and the applications for processing the selected documents; as well as the targeted image quality are important factors in the adequate use of the iconographical sources.

Capturing: digitalisation – optimisation

Capturing deals with converting the images to a 'digital form using a scanner, during the image capturing, an image is "read" or scanned at a predefined resolution and dynamic range (digitising). The resulting file is then formatted and tagged so that it can be easily stored and retrieved' (Besser, H. & Trant, J., 1995, p. 10)[46], this phase is called digitalisation.

The scanner produces a specific image quality according to the 'resolution, the dynamic range of the scanned image, the source material scanned, the scanning device or technique used and the skill of the scanning operator' (Besser, H. & Trant, J., 1995, p. 27)[47].

Furthermore, the image will be subjected to an optimisation process to improve the colours, eliminate noise, and 'Image compression' required.

Image compression deals with the process





3D TEXTURE SUBTRACTED FROM THE MODEL (BUILDING GEOMETRY)

Figure 36: example of a 3D textured subtracted with recent advances in Computer Vision (VIRTERF), Castle of Arenberg, Heverlee, Belgium. VIRTEF website.

of reducing the size of an image without losing its original quality. '*A key trade-off in defining an appropriate level of image quality is the balancing of file size and resulting storage requirements with quality needs*' (Besser, H. & Trant, J., 1995, p. 27)[48].

On the other hand, the optimisation required may vary depending on the needs. A low image quality would be preferably for character or shape recognition.

Optical character recognition (OCR)

'*Optical Character recognition*' (Stenvert, R., 1991, p.93)[49] is used to produce word processing files from an archival source, thus avoiding the need to retype the entire contents of the document.

Sources are scanned producing bitmapped images. The 'character recognition' procedure is executed by the use of 'pre-defined shape classes' that are matched with similar patterns and then transformed into a readable word-processing file.

The resulting files should be optimised prior to use, verifying that the contents of the text file generated in the process match the original document. However, Character Recognition applications are only effective in recognizing typed text and not of hand-written documents.

Shape recognition

Shape recognition techniques are used to interpret orthogonal sketches or measured drawings using computer-generated vectors. This recognition of graphic elements is implemented by specifying segmented classes of patterns prior to the recognition procedure.

Patterns suffering a decomposition process are classified '*into elementary primitives*' (Koutamanis, A., 1990, p.113)[50]. They are then classified into pre-established shapes that will automatically be corrected into patterns. The insertion of similar shapes by the software will result in a vectored drawing (boundaries, single or multiple line elements). A critical issue in this type of methods is the possible noise due to the quality of the scanned drawing.

Subsequently, the resulted digital vectored drawing is optimised by correcting mistakes in the interpretation executed by the application, this phase is called optimisation and/or verification.

The structuring and organization required for the correct matching of shapes is a time-consuming task, especially in monuments, where each element is different.

Tracing

This technique is implemented by 'manually' and '*selectively tracing the lines of the drawing*' (Koutamanis, A., 1990, p.59)[51] with either a pointing device in a digitiser tablet or the mouse tracing a bitmapped image as background to a CADR package (see Figure 38).

> *'The technique amounts to an interactive combination of vectorization and transformation of the vectors into the appropriate geometric primitives' (Koutamanis, A., 1990, p.59)*[52].

This process is time-consuming, but enables the user to identify the patterns and associate them with shapes accordingly. The optimisation and verification is executed parallel to the process of digitalisation.

This method is particularly useful in historic buildings, where each component differs, making it impossible to establish pre-defined classes of geometric primitive for automatic recognition.

Verification

The resulting digitised file should be subjected to a verification process in order to ensure that the original information contained in the source is readable and accurate.

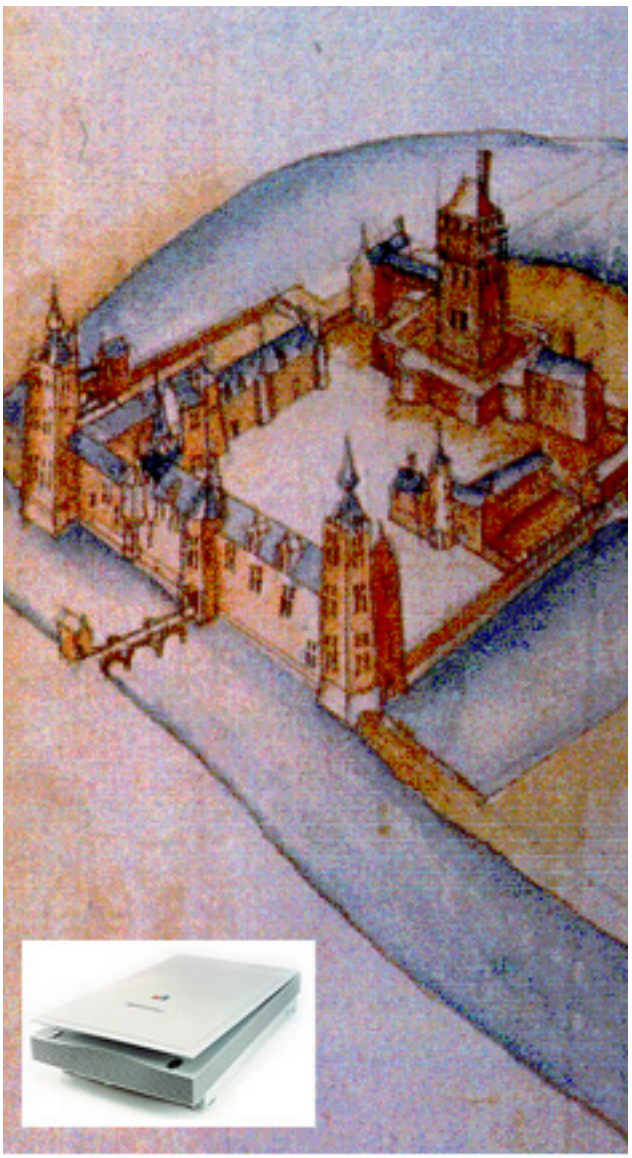


Figure 37: example of a digitised iconographical source, Castle of Arenberg, Heverlee, Belgium.

Applications in digitalizing historical assessment sources

Digitalisation of archival and bibliographic sources

Archival and bibliographical sources are scanned for generating bitmapped images that can be either used as a reference source or that can be further processed through 'optical character recognition' for generating a text or word-processing file.

On the other hand, a number of sources will only be digitised and optimised in bitmapped

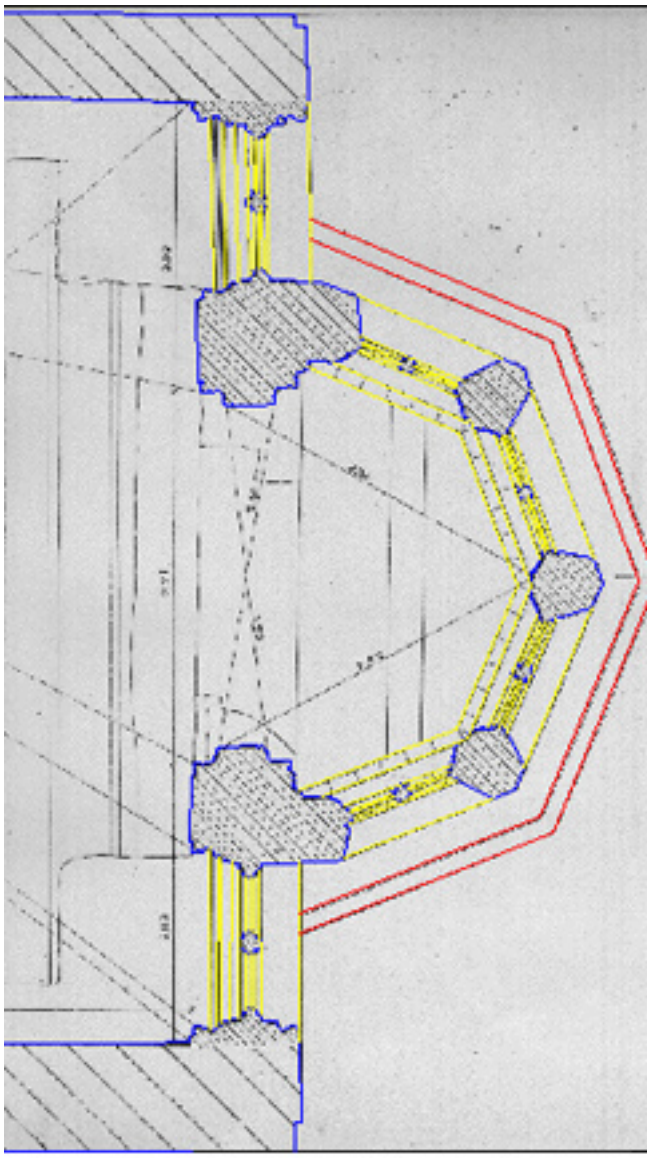


Figure 38: example of a traced drawing from an old metric survey, Chapel, Castle of Arenberg, Heverlee, Belgium. Author.

images for reference purposes, and perhaps where the 'recognition' procedure is not effective in processing the contents.

Digitalisation of iconographic sources

Similar to archival and bibliographic sources, Iconographic sources are 'a priori' digitised into bitmapped images. Depending on the needs, some of them and particularly measured-drawings can be transformed into vectored computer drawings by using shape-recognition or tracing methods.

These vectored drawings can be used for constructing hypothetical reconstructions of the monument's chronology and phase of construction. It can also be used to complete the metric survey as and when the measured-drawing's precision are verified with the current state of conservation of the building.

Classification of historical assessment sources in a database

The classification of the scanned files should be tagged using a consistent and transparent data structure that enables easy retrieval and storage in a Historical Documentary source database.

Each resulting image or file formed from the recognition procedure should be *'accompanied by textual documentation to identify and describe them'* (Besser, H. & Trant, J., 1995, p. 15)[53], and described, in this case, as a record. An indexing method should be made available, as well as the minimum dataset describing the monument.

Data structure

The raster image file stored in the database should be identified by a record consisting of the description of '*the original and digitised document, linked with the digital image*' (Bertels, I., Van Balen, K. et al, 2001, p.14)[54].

Furthermore, any resulting files from a shape or character recognition procedure should be stored and identified by a record showing the process used for recognition and its link to the original raster image.

Subsequently, the records should consist of a '*minimum fiche containing an inventory number, title, type of document, relative date and repository*' (Bertels, I., Van Balen, K. et al, 2001, p.14)[55]. As well as, '*the Location of Original and Digital Document (address, access and restrictions), Material Characteristics of the Original and Digital Document, Relation with other Iconographical Documents and Cultural Heritage, Control*

Area for Cataloguing' (Bertels, I., Van Balen, K. et al, 2001, p.14)[56].

In this particular application, where the dataset is used for building the history of the object and to give support to the metric survey, the records should also identify the location related to the specified site grid, approximate dating of the source, and other relevant remarks.

4.1.5 REPORTING AND VERIFICATION

The purpose of the reporting phase is to produce a user-manual which assesses the amount of information gathered, classification, procedures used for capturing, computer formats, and the protocols used for storing information.

Furthermore, it should contain the limitations encountered, observations about the precision achieved and the observational accuracy of the dataset. As well as recommendations for further analysis and modelling of the information in the following phase of work.

This report is used for verification purposes prior to exporting the information to the following phase of analysis.

Moreover, the level of detail should be described in the report, explaining the level of detail of the 'measured dataset', density of information used for defining the different entities simulating the monument being studied.

Finally, for verification purposes, the report should state the different procedures used for cataloguing the scanned and transformed files resulting from the recognition application; as well as, the fields used for referencing the contents and a description of the sources.

4.1.6 EXPORTING

The phase of exporting is linked to the report and verification process and is the final step prior to follow the analysis phase. The general dataset should include the 'raw data' generated by the Metric Survey Methods, and all relevant information required for further thematic studies, such as historical assessment records, condition assessment photographs and readings for structural analysis.

4.1.6.1 Metric survey dataset

The exporting set should include all the 'raw dataset', consisting of the non-image based sources, such as wire-frame models, the point clouds generated, and other scanned hand-measured sketches and drawings. As well as the image-based sources, such as plan-parallel photographs, oblique photographs for photogrammetry or automatic modelling.

4.1.6.2 Other material

Other types of dataset can be extracted and exported from the object. This will depend on the needs of a specific case.

4.2 DATA ANALYSIS: MODELING AND PROCESSING

The implementation process described in these phases is characterized essentially by a selective procedure that deals with depicting the relevant information, which needs to be acquired, integrated, and assembled to generate simulations that allow a greater understanding of a building.

Therefore, the process of acquiring a 'measured dataset' is essential for the subsequent data-analysis phase, where information will be modelled and optimised

for the production of adequate visualizations of a monument. This last process is also the final step towards its dissemination, through the use of an information system to store, manage, and retrieve knowledge.

Emphasis at this stage should be placed on defining a set of geometrical representations which can illustrate the actual condition of a monument, including evidence of alterations and modifications which have occurred overtime (condition and structural assessments); as well as, identifying different phases by defining other geometrical representations undertaken during a building's phases of construction. These last representations will be based on the simulation of the building's condition and its relation to the available historical information.

Furthermore, these representations should take into account the context and setting of a monument particularly its setting both urban and in the landscape.

Subsequently, it is important to bear in mind that these models should aim to define the monument's authenticity, as a multi-dimensional concept involving the relationship with the values and dimensions of the subject that makes it credible or truthful. Such an approach has already been explained in Chapter II – part I, when defining the 'measured dataset' in the framework of this research.

At the same time, the analysis of the values and dimension is not an explicit task of this research. Nevertheless the processing methods explained here deal with these definitions in terms of their ability to generate adequate representations.

These models have entities that are expressed using multiple levels of abstraction, simplifying the visualization for real-time displayed and pre-defined scale.

In this framework, the correct manipulation of computer tools to simulate the Geometry of the fabric is of paramount importance. Taking into consideration that the geometry is composed by components (entities) that are organized in hierarchies and that have common attributes and share functional and spatial relations.

Furthermore, this research encourages the application of computer agents that emulate the action of 'modifying elements in architecture', such as light, colour, temperature, orientation, ventilation, texture, scale and time. They are related not only to environmental conditions, but are also inherent to the shape and material of the building. These factors will have an important final influence what the building looks like in reality.

These issues have already been explained in chapter II – part I, when dealing with the description of a building's geometry in architecture.

The adequate use of either two- and/or three-dimensional modelling systems in processing the dataset will enable the correct simulation of an historic building's complexity. This immense work might appear trivial, difficult or unnecessary to be simulated by the computer, but it is the only path to ensure a correct documentation of the monument and to ensure the correct exchange and transfer of knowledge is achieved.

Data analysis is developed using the following phases of work (see chart 14):

- Storage and identification
- Processing and modelling
- Verification
- The potential assembling and integration of other complementary sources of information (e.g. condition assessment)
- Optimisation
- Exporting

IMPLEMENTATION
DATA-ANALYSIS: PROCESSING AND MODELLING

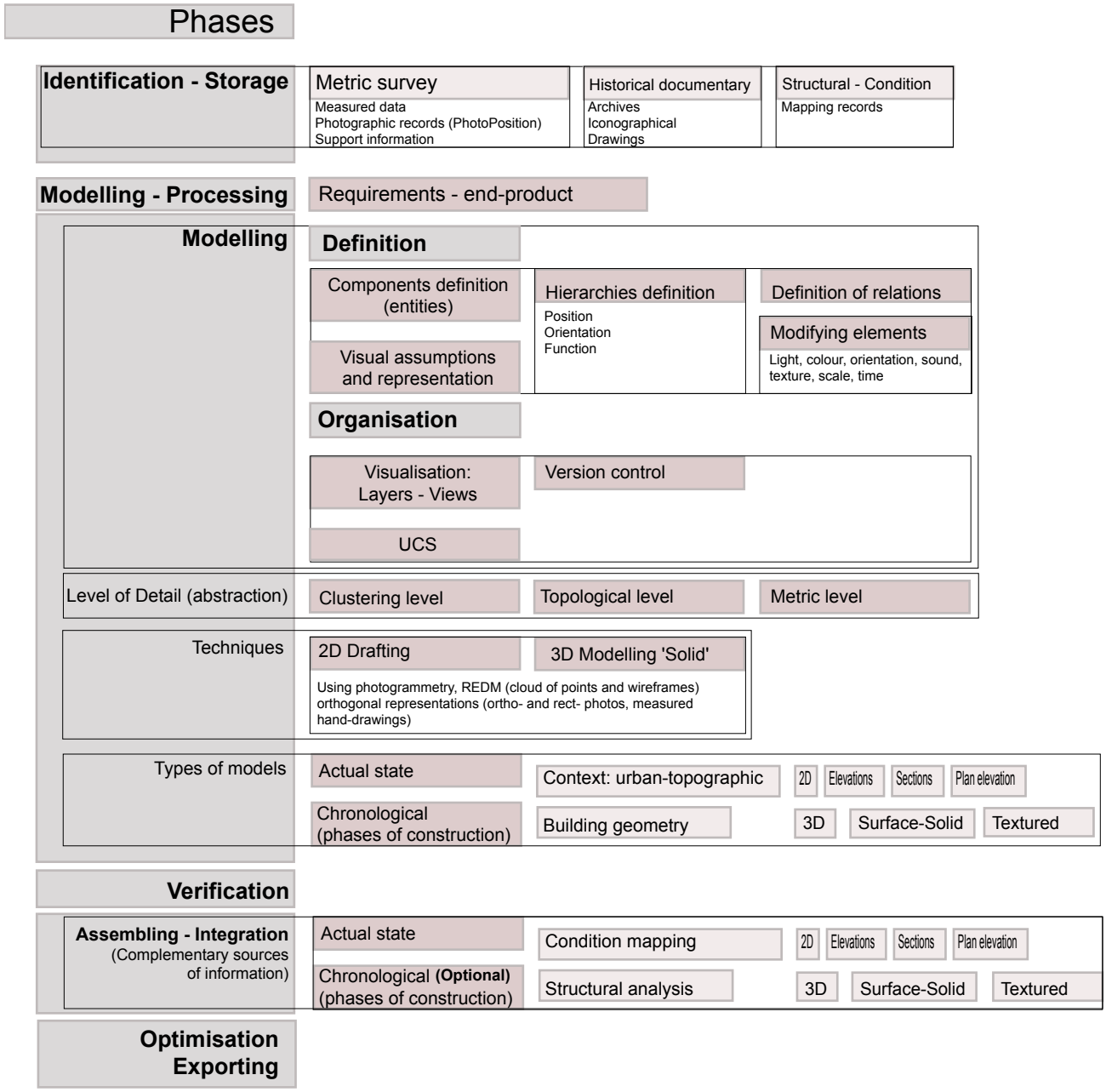


Chart 14: phases - data analysis

4.2.1 IDENTIFICATION AND STORAGE

The identification and storage of the records should be essentially state the relationship between 'time and space' described before when naming the files using protocols. Other information will be added according to the specific record used, relating to sources of information.

4.2.1.1 Metric survey

A full record of the metric survey file should be identified by the '*description of the data collected*' (e.g. description of collected entities), the '*absolute location*' of the measurements in relation to the local site grid and the 'date of collection' when the

reading has been executed. As well as, an absolute and/or approximate 'precision statement' of the instrument or technique used.

Furthermore, the record can also identify the thematic information of the surveyed information similar to the protocol, such as the '*site identification*', the '*activity area*', and the '*discipline code*'.

Finally, each record should state the type of a measured file stored, depending on whether it is a 'measured drawing' or a 'photographic record'. In some case the 'scale' and drawing technique should be included.

Measured drawings correspond to '*digital vector drawing*', '*cloud of points*', '*text file with coordinates files*', and '*digitalized hand-measured drawings*' (this last should also include the drawing scale and reference points to merge with other files).

A photographic record corresponds to plan parallel photographs used for rectification, overlapping stereo-pairs for photogrammetry (oblique photography), referential photography, and texture mapping acquisition. Each file should include the previous fields mentioned, as well as the 'type of media used' (analogue – Digital) for collection and storage (scanning parameters: resolution, image quality and scale).

Furthermore, other complementary on-site support information, such as remarks from the survey notebook and reference sketches should be digitised and stored according to the fields described above, perhaps excluding scale and '*precision statement*'.

Referential database for photo-orientation and position

An interest storage possibility for the vast amount of photographs collected in the site is to store them in a local geographic information system, describing the orientation, location, and date where the photographs were taken and linking them to maps of the site.

4.2.1.2 Historical documentary database

The records in the database should be identified using fields showing '*the original and digitised document'* (Bertels, I., Van Balen, K. et al, 2001, p.14)[57], a description of the of the event in relation to the 'absolute or approximate location' of the source in relation to the local site grid and the 'absolute or approximate dating' of the source.

Furthermore, the records should consist of a '*minimum fiche contains the inventory number, title, type of document, relative date and repository*' (Bertels, I., Van Balen, K. et al, 2001, p.14)[58].

At the same time, a reference to the source used should be described in protocols, stating the '*site identification*', the '*activity area*', and the '*discipline code*'; as well as, '*date*' (campaign) that relates to the time at which the source has been included in the study.

Finally, a complementary field should be added to '*vectored drawings and word-processing documents*' from historical sources that have been subjected to '*shape-character recognition and/or tracing*', which describes the '*processing parameters*' and a link to the original bitmap image captured during the digitalisation process.

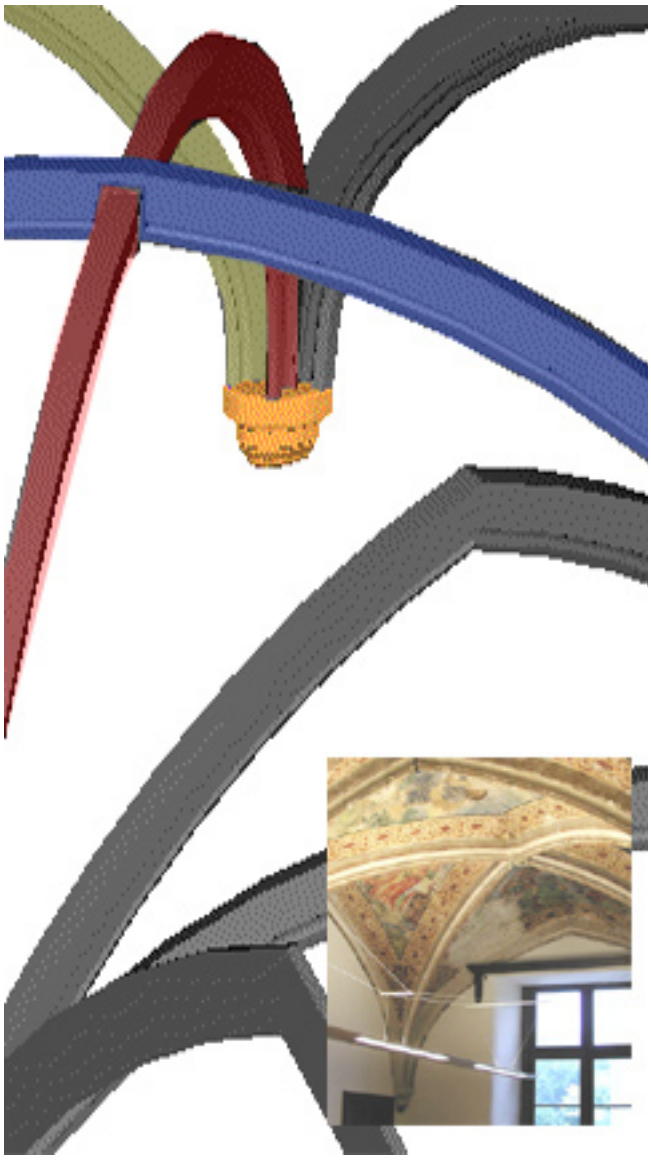


Figure 39: example of a set a vault's ribs, which have been modelled as independent 3D entities, Salle Heraldique, Castle of Arenberg, Heverlee, Belgium. Author.

Condition assessment: structural and weathering forms mapping records

The Metric survey dataset output is used for preparing condition assessments. Thus, the fields explained before will apply to these records. However in certain cases, a non-metric record at this stage will be used for preliminary assessments for these studies, such as sketches and oblique-photographs.

In this case, the sketches and non-metric photographs are to be digitised. They should be identified in the database using fields showing a description of the application, an 'absolute location' of the source in relation to the local site grid and the 'absolute dating' when the source was collected.

4.2.2 PROCESSING AND MODELLING

The phase of processing and modelling implementation are related to the transformation and manipulation of the geometric and textured information collected in the Metric survey for the preparation of models simulating the actual state of conservation of the monument and preparation of different models showing the different phases of construction.

The representation of these stages (states) is executed using orthogonal two-dimensional visualizations (vertical sections, plan.) and measured three-dimensional models.

This research encourages the end product be a set of three-dimensional models, where the user can extract other pertinent two-dimensional visualizations.

4.2.2.1 Entity definition: knowledge necessary in understanding the modelling of architectural elements

The Geometry of the object is composed of entities, which are the basic units, and a group of entities composing a component, these correspond to a '*basic unit of storage in a geometric database*' (Mitchell, W.J. & Mc Cullogh, M., 1995, p.471)[59], corresponding to an irregular and complex unit or a group of two- or three-dimensional geometric primitives (e.g. arch, window, door, beam, etc).

Moreover, entities containing a set of elements (e.g. where the masonry is composed of bricks, stones, joints, wooden frames..). The simulation of these entities and components with their elements, as either single or composed units will depend

on the required level of abstraction used; as well as the available information in the dataset collected (see figure 39).

Entities and component elements are described not only by geometric primitives, but also by other types of attributes, representing '*a property shared by one or more entities'* (Mitchell, W.J. & Mc Cullogh, M., 1995, p.468)[60].

4.2.2.2 Hierarchies and relations: position, orientation, and function

The hierarchies and relations are linked to the modelling of all the elements associated to their position, orientation, and function in the component and in the whole Geometry. Their definition is based on available data, which will not only provide information on the shape of the object but also the exact position according to the datum and local reference system used.

Moreover, the hierarchies group the components in horizontal and vertical organization levels, depending on the type of representation and level of abstraction used. These hierarchies can be identified using typologies or realistic three-dimensional representations.

4.2.2.3 The simulation of 'modifying elements in architecture'

At this stage of work, modelling elements are only referential for creating the simulations. These components will be of further use in the dissemination instrument.

These elements consist of agents or elements that are used to modify the characteristics of a place, affecting the perception of the entities and the object. These factors are light, colour, temperature, orientation, ventilation, texture, scale and time. In the case of the modelling of entities, it is important to take into consideration that these elements relate not only to environmental conditions, but they are inherent to the shape and fabric of the monument.

Furthermore, these elements can have an impact in the analysis of the authenticity of the object, related to their utilization in modifying the perception of the object and therefore having an impact in the way values and dimensions are understood.

Light

Simulated light is used to provide a different level of clarity to enhance the quality of a space, if this element is not manipulated according to the original purposes of the designer the message will be lost, and the public is mislead into believe something else (see figure 40).

Colour

Colour is associated with light, meaning that light itself can be any colour (Unwin, S., 1999, p.29)[61] or it can be a representation of the decay of the fabric, or as an abstract tool for coding the pathologies in the condition mapping or traces of different interventions and modifications during the time.

Orientation

The correct orientation of the model is important to understanding issues dealing with religious or philosophical beliefs. Furthermore, it can be used for generating a type of light, ventilation and other factors.

Sound

Sound relates to the acoustics of a building and/or site. It is a property used in design by the selection of specific forms and materials, a space can be of an unique function according to its sound characteristics (e.g. a concert hall or a church).

Texture

Texture contributes to the use of specific materials and forms for producing colours, and other elements modifying the perception of the object. It can also be associated with a fabric's decay.

Scale

Scale is used for producing a certain perception of space, being the generation of a specific human behaviour and/or for environmental needs. It is modelled in dimensions and sizes. The senses are manipulated by the use of scale.

Time

Time in modelling is linked to a chronology of a building's construction and deals with the identification of modifications and/or alterations on the fabric, and where relevant the generation of a patina.

4.2.2.4 Graphic scale and level of detail (LOD) or abstraction

The level of detail of abstraction is a visualization tool used for object representation. It ranges from schematic use of geometric primitives to very detailed, realistic, and textured mapped models.

They are most commonly used to optimise the visualization of an object from a macro to a micro view, and to speed up the efficiency of computer engineering time (execution time) to generate realistic and real-time experiences, whilst bearing in mind the need of observational accuracy and for the need to avoid misleading visualizations.

Thus, in this framework, they have been classified in three categories (see chart 15):

- Location or clustering level
- Topological level
- Metric level



Figure 40: example of the simulation of 'Light' in a 3D model (modifying elements in architecture), Fiat Lux (Debevec, P., 2000), St. Peters, Rome, Italy.

These categories are based on the literature available that deals with the representation of architecture according to modelling simplifications. The reasoning to produce such representations is based on the simplification of the object using reasonable scientific assumptions; such a process of reasoning should be attached to the representation for required verification.

Location or 'clustering level' (Tzonis, A. & Oorschot,L., 1987, pp)[62]*:* a schematic level of Abstraction, where the objects are visualized as '*the atomic parcel of space where a*

IMPLEMENTATION - LEVEL OF DETAIL
DATA-ANALYSIS: PROCESSING AND MODELING

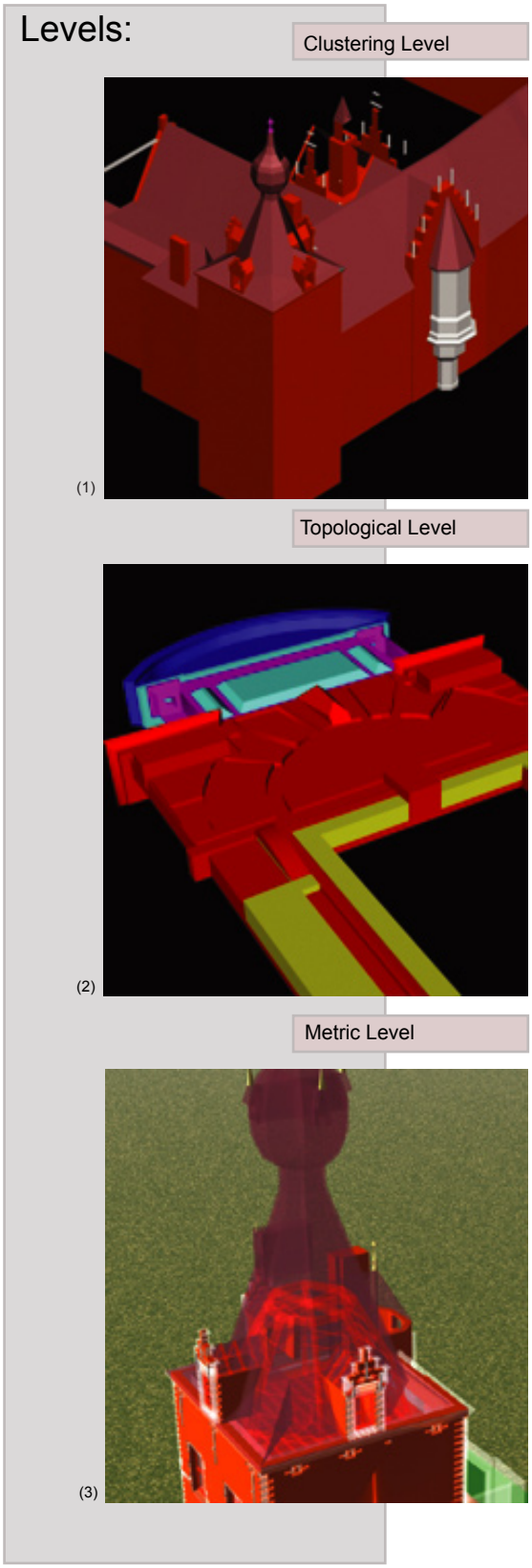


Chart 15: examples of different level of details in 3D modeling. (1) - (3) Castle of Arenberg, Heverlee, Belgium. (2) Chinon, France. Author.

distinct activity can take place' (Koutamanis, A., 1996, p. 31)[63].

In 3D dimensional representations of monuments, the entities are represented using basic geometric primitives based on regularization and assumptions, such as cube, sphere, etc. The voids have a reduced amount of polygons producing regular volumes with depth and where the observational accuracy is limited to providing information about their orientation, and location, relation.

Topological level (Fang, N., 1993, p.)[64]: an articulated level of abstraction, where the components of a building's features are visualized as "*massing volumes*" (Ching, F., 1995, p. 52)[65] using regularized and common geometric primitives. The inner and outer relationship between the different volumes and their relations are visualized. The number of polygons is simplified, but the inner and outer relation is maintained.

The result of such a level of detail is colour voids displaying the components using nodes and links.

Metric level (Fang, N., 1993, p.)[66]: detailed level of abstraction, realistic and verifiable. The components are visualized using their original appearance and irregularities. Complex polygon counts are expected, and the models should be textured. Each component is depicted in their different elements (e.g. the masonry of a wall, with the joinery). The observational accuracy is of primary importance.

Subsequently, each level of abstraction is based on the requirements described in the data-collection Phase in dealing with the definition of the application and target audience. As well as, to the type of Information System used for dissemination.

4.2.2.5 Visual assumptions and representation

The end product is the use of different levels

ASSUMPTIONS IN 3D MODELLING

DATA-ANALYSIS: PROCESSING AND MODELLING

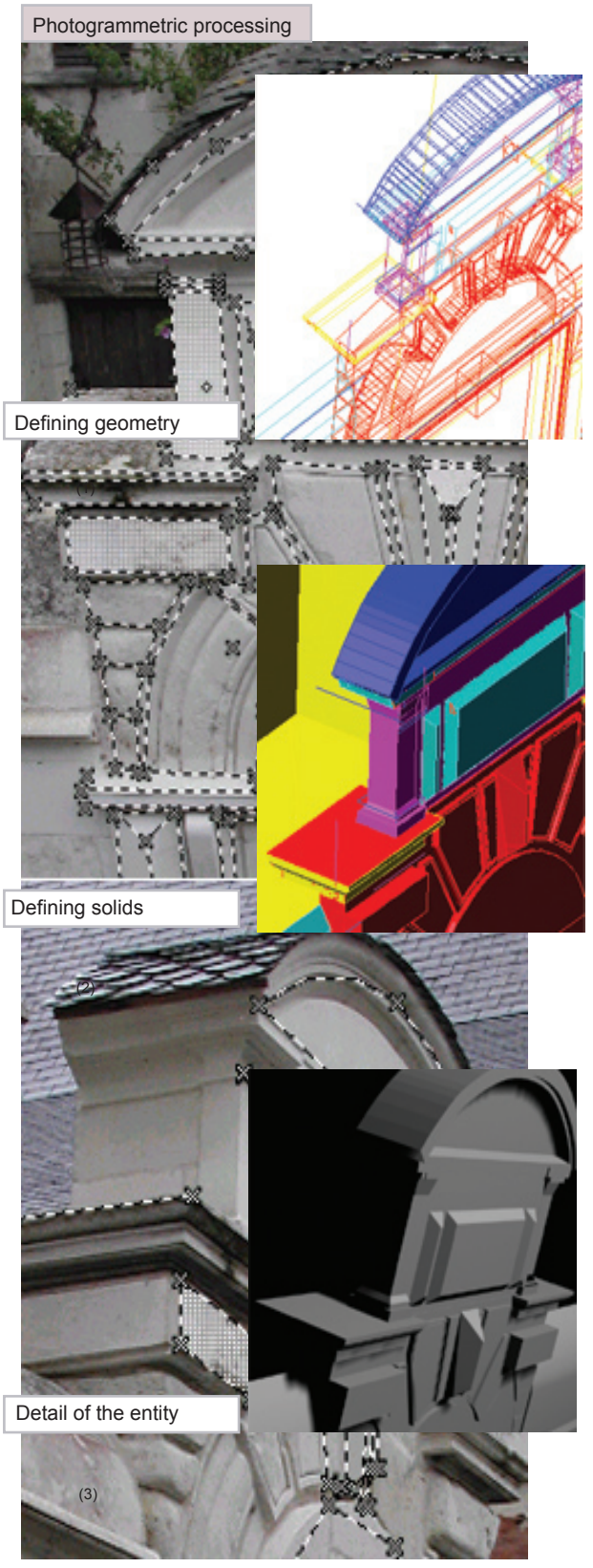


Chart 16: Examples of the process of modeling in the assumption of the object's geometry, using a Photogrammetric dataset, Chinon, France. Author.

of detail to represent the entities composing a building's features. This process of simplification consists of combining the whole or partial selection of the set of available measured-data from the metric-survey and finding a coherent matching single unit or multiple complex geometric primitive(s) to express the appearance of the entity. This process is called visual assumption (see chart 16).

For example, a set of regular voids can be used in representing the whole site, meaning that a 'topological level of detail' has been used for the visual assumption.

Visual assumptions are used for providing an adequate geometric modelling applied to the efficiency of the navigation of the model.

This research recognizes that the Metric level used is the most precise and accurate method of simulating a monument. However it is impossible to reach this level by using current off-the-shelves tools. The selection and matching process are the most effective method for adapting the subsequent modelling to the needs of the representation.

4.2.2.6 Layering: information levels

Layering is used in modelling for in order to have control over the *'visibility and manipulation'* of a single or set of entities. It can be also used for manipulating various attributes.

> *'Layers: Logical groupings of geometric entities, usually for visibility purposes, in which the member entities remain individually addressable' (Mitchell, W.J. & Mc Cullogh, M., 1995, p.475)* [67].

Layers can be used in the coordination of the modelling process and for grouping the entities in common relations or attributes.

A consistent and transparent method for naming the layers should be implemented before starting modelling, these protocols should described the 'site identification', the 'activity area', and the 'discipline code', and if necessary the 'date', when they have been used and collected.

4.2.2.7 Version control

A computer drawing can easily be edited, upgraded and changed. Consequently, a strict version protocol for a 'document management' concerning the naming of computer files should be implemented to avoid confusion in the construction of the simulation. Especially when the drafting is used for representing the various phase of the work in the study a built heritage site.

4.2.2.8 Generating geometric shapes simulating the entities

At this stage of technological development, 'computer-aided drafting' (CADR) packages provide a set of proven methods for modelling. They are powerful for manipulating a set of tools when wishing to transform the 'measured dataset' to two-dimensional geometric primitives or into more complex three-dimensional models. This research in particular has used solid and surface modelling techniques.

These tools deal with the 'definition of a single or multiple planes' relative to an '***absolute three-dimensional coordinate system***' (Mitchell, W.J. & Mc Cullogh, M., 1995, p.477)[68] or 'alternative coordinate systems' for viewing and/or to project the objects parallel to the plane for construction of 3D entities or generating orthogonal representations with vectors.

Furthermore, '*navigation tools*', such as zoom, pan, and 3D view rotation assist in constructing and modifying a specific element without affecting the whole object. A tool associated to this type is the so-called '*snapping object*' that enables the accurate picking of the object's edges, middle point, or other functions for drafting.

The inherent '*drafting tools*' now available allow the user to construct complex geometric primitives and to set complementary '*geometrical transformation functions*', such as translation, rotation, reflection, shearing, subtraction, intersection, extruding, and scaling. This enables the user to construct complex shapes and three-dimensional models, without having to rely to complex trigonometrical operations.

At the same time, modelling packages provide libraries of primitives and other shapes, but the utilization of these pre-defined solids should be avoided in this particular application working with built heritage.

4.2.2.9 Modelling techniques

Two- or three-dimensional simulations can be used for studying built heritage. In the framework of this research both are explained. The use of two-dimensional modelling techniques can be used for further developing three-dimensional simulations and vice-versa.

<u>Two-dimensional representations: orthographic projections</u>

The construction of two-dimensional representations is executed by defining a parallel view plane to the required orthogonal projection (e.g. elevation, vertical section, plan elevation, or plan section); this process is called '*Clipping*' (Mitchell, W.J. & Mc Cullogh, M., 1995, p.175)[69].

Furthermore, the universal coordinate system (UCS) should be adapted to a new alternative coordinate system parallel to the defined parallel view plan. This operation seeks to adapt the drafting tools and geometric transformation functions to the plane.

In the case of constructing built heritage features, the measured dataset is used as the base data to model the entities by defining polygons with polyline. Other drafting functions, such as arches, circles, and pre-defined primitives will be randomly used due to the irregularity of the construction fabric (e.g. a dense number of polylines defining an arch is preferable to the use of only three points).

The dataset should be introduced in the drawing prior to commencing with the definition of new plane views and UCS's avoiding the displacement of the wire frame and point of clouds in other locations of the scene.

Critical issues in two-dimensional drafting of built heritage

The use of two-dimensional vectors and polygons in the representation of built heritage should consider the adequate use of various '***line weight***' (Andrews, D., Blake, B., et al 1999, p. 3)[70] for improving the clarity of the drawings, displaying the part sectioned with a thicker line weight and assigning in a view sequence the different use of line weight to the different elements.

Furthermore, a dense '***point density***' should be available for the definition of the lines; this feature should be adapted to the output scale desired. The '*default **text** fonts in many CAD packages are often crude and can devalue the presentation of a drawing. It is now easy to add good quality fonts to CAD drawings and where possible these should be used*' (Andrews, D., Blake, B., et al 1999, p. 3)[71].

On the other hand, for the adequate use of orthogonal representations, the drafting parameters should be adapted to the plotting '**scale**' to obtain a good tolerance in the precision and observational accuracy.

Three-dimensional modelling

Three-dimensional modelling techniques are designed to produce a correct simulation of the entity according to the required Level of Detail and the Visual Assumptions assumed, the most adequate technique for integrating for this purpose is the assembly of solid models, these representations are capable of carrying far more information about the attributes of the object that any other technique (e.g. calculation of volume, shape, and attributes).

Ideally, in a built heritage site, each entity is modelled as an independent element, in order to assign different attributes (e.g. condition mapping, geometric properties, cultural, material) and linked other types of sources of information (e.g. Historical Documentary documents or Iconographic items) or other more detailed models. This exercise is a laborious task and is not achieved in most of the current applications of three-dimensional modelling.

Furthermore, other constraints to this technique are the engineering time required for the computer to display, navigate, and interact with these solids.

The current state of the arts in three-dimensional modelling is explained in chapter III (part I), reviewing the use of solid-modelling, surface-modelling and wireframes.

Three-dimensional modelling using photogrammetric applications

Part of the processing phase and modelling is to interact with the overlapping stereo pairs captured during the collection phase.

Specialized and cost-effective photogrammetric applications are capable of extracting three-dimensional points, vectors, and textures from photographs (photogrammetric processing have been already explained in chapter III – part I).

The dataset of measurements extracted from these applications can be further processed using the techniques described below (see chart 17).

Three-dimensional modelling using cloud of points and wire frames

The production of three-dimension solids using a set of cloud of points and/or a wire frame for simulating the entities consists in defining a two-dimensional profile or shape using 'editing operations' and 'drafting tools' and an 'extrusion' path or height for the extruding operation.

Furthermore, the resulting extruding solid can be further transformed using tools called 'Boolean operations' (Geebelen, B., 2001)[72] (e.g. union, subtract and intersect) for reaching a higher level of detail. The resulting solid can be an irregular and complex solid simulating the original entity.

Three-dimensional modelling using orthogonal representations, rectified or ortho- photographs, and digitised measured hand-drawings

Prior to starting modelling, all the rectified photographs, ortho-photographs, and digitised measured hand-drawings should be positioned according to the orientation of their plane and the local system of coordinates defined.

Later, these sources will be used for digitalisation. The operator traces the most important features and creates a new set of wireframes consisting of two-dimensional vectors. These are parallel to an auxiliary plane, which has already been defined.

From this point, the method is similar to the one described above, where the measurements are used for defining a two-

MODELLING TECHNIQUES

DATA-ANALYSIS: PROCESSING AND MODELLING

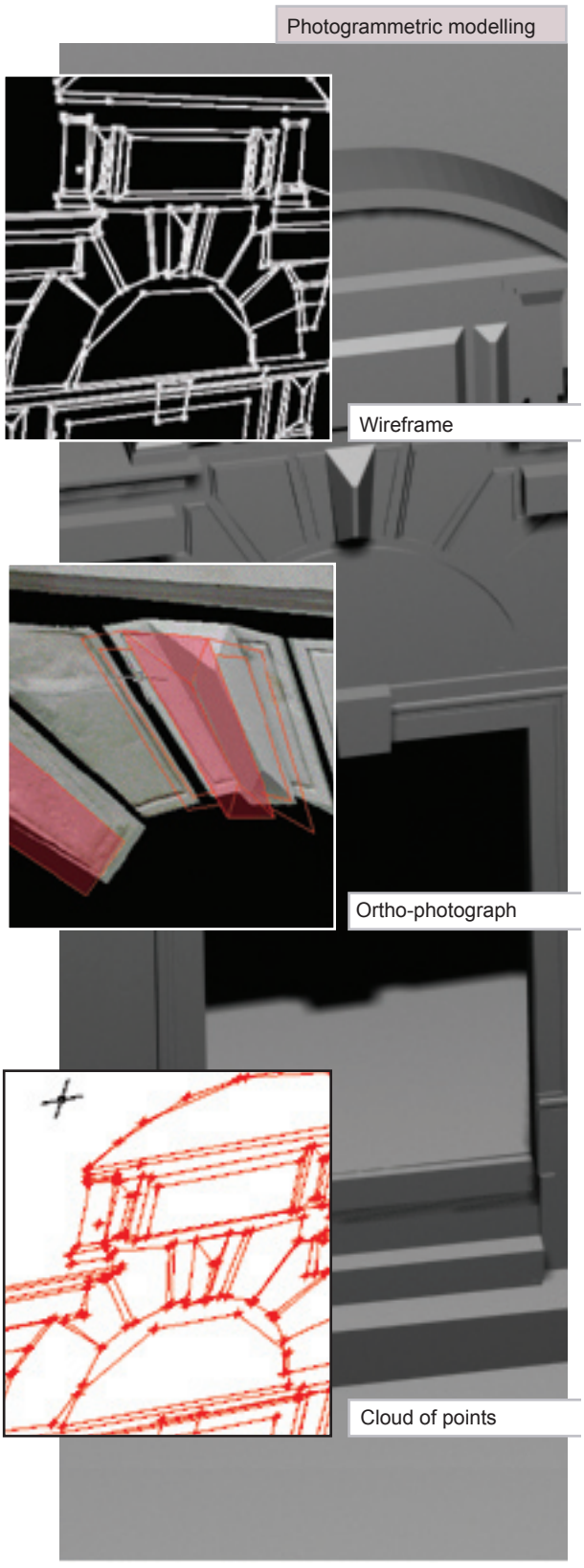


Chart 17: examples of the process of modeling using Wire frames, Cloud of Points & Ortho-Photographs, Chinon, France. Author.

dimensional profile or shape and extrusion path or height as mentioned previously in the use of 'boolean operations'.

Three-dimensional modelling using textures

Textures can be used for mapping the three-dimensional solids and creating more realistic views. However in recent software developments, textures can be used to actually to construct three-dimensional wireframes and cloud of points.

These new applications represent a revolutionary approach to create three-dimensional models using a more intuitive GUI.

Remarks on solid-modelling in simulating a built heritage site

This research prefers the use of solid-modelling techniques to other three-dimensional modelling methods (e.g. surface, NURBS) because it allows one to obtain a quantifiable entity.

This entity can provide information on attributes associated to it, such as material, volume, cost, energy, history, structural behaviour, etc.

On the one hand, surface modelling, texture mapping, and NURBS can demand less computer processing effort and realistic representations. On the other hand, it cannot deal with quantifiable issues.

Noise, what does this means to a conservation specialist?

Noise in terms of computer graphics is those points that are dropped or reduced in the process of modelling three-dimensional entities by the use of regular geometric primitives. However in conservation this noise is part of the actual reality of the imperfect and irregular state of the fabric.

Consistent and transparent description of the methodology in reduction of noise in modelling should be properly documented in the report. These points can give important information on the condition of the object and therefore the possible cause of decay.

Actual geometric and texture fabric model

Under normal conditions the simulation of the building's features is executed using existing a 'measured dataset' that was captured during the metric survey, without relaying on existing measured drawings and/or other sources of geometric measurements.

However, most models rely on fulfilling an existing survey, merging existing dataset of measurements with selective measurements. In this case, it is important to first verify that the dataset is correct.

The merging should be recorded for obtaining transparency and consistency with the newly combined dataset.

Context modelling (urban – topographic)

The simulation of the object's environment should include the correct modelling of the existing topography and urban characteristics.

The level of detail used for urban context can be limited to a location of clustering level, displaying the 'basic massing of space' (Laseau, P., 2000, p. 88)[73], which describes basic relational issues, such as the different heights of objects, occupancy, orientation, and other relevant issues according to the three-dimensional perception of the surroundings and needs of the representation.

Furthermore, the topographic modelling or landscape should be represented using a correct contour interval in two-dimensional representations and for three-dimensional

models of a good density of points for calculating a dense 't*riangular irregular network*' (TIN)[74].and therefore an adequate surface-mesh simulating the relives of the topography.

Equally, the vegetation should be included in the model, perhaps using a similar location or clustering level (LOD) through massing representation, displaying the occupancy, location, and orientation of these entities.

Building geometry

Similar to the context, the building geometry modelling is based on the actual metric survey carried out, or merging previously verified datasets from other sources.

The level of detail in a building's geometry is certainly higher than with its context, however it should be adapted to the representation and needs explained previously in the phase of data-Collection when discussing the purpose of documenting.

The modelling technique should be transparent and consistent, using the highest possible amount of detail in simulating the fabric. All the entities should be defined using the same LOD and independence.

The final set of representations, meaning a two-dimensional set of orthographic maps or a three-dimensional open should have an adequate observational accuracy to be used in assigning new attributes corresponding to other studies carried out in the fabric ob the object, such as the a stratigraphical research for historical documentary verification by defining the different phases of construction, condition mapping, and structural analysis; as well as, other applications adapted to the context and application.

Chronological models (phases of construction)

The phases of construction are modelled on the resulting output from the actual condition model and the stratigraphical verification of the historical documentary sources describing and/or illustrating the changes.

This simulation combines multiple sources of information; in some cases a dataset of previous states will be available and can be digitised to fit in the actual condition of a representation.

Furthermore, the identification of the different stages to be modelled is a multidisciplinary action, involving a 'process of organising evidence for change through time into a series of intellectually coherent temporal units or phases. Phasing involves tying the relative sequence for a site to any independent date through the idea of the terminus ante quem[75] and the terminus post quem[76]' (Clark, K., 2001, p.113)[77].

This research does not deal with the actual identification of this phasing but with the methodology for simulating the phase of construction according to the available direct information from the metric survey and existing evidence both in the stratigraphical study and historical documentary research.

The final models and representations of this application are hypothetical, they are based on interpretations, assumptions, and uncertainties that are very difficult to verify. This is due to the non-existent of a vast number of sources and traces in the fabric of the monument for control. Therefore, the process of simulation, in this case, should be documented and presented along with the output.

Moreover, it is recommended to preset more than one representation for each phase of construction, providing the end-user with the choice of judging the relevance of the interpretation process and the amount of



Figure 41: Example of Hypothetical Reconstructions: (1) Romanistic Church (circa 1400), (2) a Project (Circa 1505), (3) Current State, St. Peters Church, Leuven, Belgium (Neuckermans, H. Van De Vijver, H. 1998)

existing uncertainties.

Other more alternative visualisation techniques can be of use in these applications. The various phases of construction can be represented by using existing transparent models and comparing them with previous models, or with the use of different colours for the subtracted parts.

In this type of representations the building's geometry cannot be isolated to the modifications suffered by due to its urban or landscape location.

The urban context should be modelled in each of the phase of construction extracted form the history of the structure. If there is no information available the building could be isolated from its context, but documentation should be prepared along with the representation explaining the circumstances of the decision.

Furthermore, the building's geometry will be modelled using techniques according to the historical documentary material available and its actual condition. The geometry of the new entities can be of less observational accuracy that the actual state, but this is an issue that is difficult to verify. Therefore all procedures should be documented and explained.

4.2.3 VERIFICATION

All of the resulting representations should be verified 'in situ'. The verification procedure should be carried out by checking the level of details of the model or maps, as well as correcting any discrepancies and uncertainties encountered during the computer processing phase.

The final product should be a simulation of the actual state of the building. An interdisciplinary approach to the 'documentation product' is advisable. The revision of the representations by

multiple experts is important to provide a homogenised set of tools adapted to the needs of the application.

4.2.4 THE ASSEMBLING AND INTEGRATION OF OTHER COMPLEMENTARY SOURCES OF INFORMATION

This research has so far proven the need to create a 'measured dataset', which transmits the actual condition and chronology of the built heritage site being studied. This, in order to reach the ideal point where the monument is simulated to the highest possible extent using adequate precise tools and observation accuracy.

This involves not only describing a building's history and geometry, but also studying the issues affecting its conservation. In this sense the final output or 'core data' should integrate the condition mapping of the fabric and the structural behaviour of the building.

On the other hand, this research acknowledges that there are other intangible issues to be studied. However this dissertation concentrates in the building's fabric itself and not with other social, philosophical or legal issues affecting it.

Actual state: condition assessment (weathering mapping and structural analysis)

Condition assessment is carried out in order to diagnose the state of a building's conservation. This requires the definition of a weathering forms classification for registration purposes.

This registration is executed by mapping observation about the surface on-site with optimises records (e.g. colour optimise photographs). These techniques are non-destructive and highly efficient.

Conventionally, these techniques are based on a two-dimensional output of the actual condition study carried out using the metric survey. This technique consists of mapping the weathering forms in print-outs of the elevations, cross-sections and plan elevation of a site, by either using hatching patterns or colours.

Moreover, in more advanced applications, the mapping can be digitised or directly carried out using CADR packages. In this case a library of hatching patterns is defined according to the weathering forms and is applied to the orthogonal views by defining polygons in different areas. This technique can be seen as being more consistent than conventional mapping methods, which use colours, since the pattern library is a unit and the application can be homogenous to all the views of the object. Further, it can be quantified by defining queries to the CADR dataset.

On the other hand, this research acknowledges the existence of more advanced techniques, which can be used for investigating the fabric of the monument. The approach is nevertheless concentrated in those that required the observational mapping of the fabric using the documentation produced in the metric study.

Three-dimensional techniques for condition mapping and structural analysis

Three-dimensional approaches to mapping the condition of an object are more complex and less effective than two-dimensional mapping at this time of development, however structural behaviour of the building can be simulated with higher accuracy using these approaches, such as Finite Element Analysis and other techniques.

A promising track for the application of three-dimensional condition mapping techniques is the automatic acquisition of three-dimensional textures mapped to the model.

In this application, a high-resolution image

is used for identifying a 3D area that is mapped by querying the texture directly with a previously defined set of attributes (similar to the hatching library used in two-dimensional applications) using a sort of three-dimensional hatching or colour.

Subsequently, a real three-dimensional quantification can be executed by querying any of the attributes. The potential of these technique look very promising. They could provide the highest ever precision in simulating the state of conservation of the monument.

Chronological models (phase of construction): condition assessment

The definition of the condition assessment during the different phases of construction is a challenging task; it is of course subject to a high level of uncertainty by the lack and gaps in the historical dataset.

However, it can be hypothetically executed by combining different representations from the various phases of construction and incorporating the final output by simulating the actual state of conservation of the building, including condition assessment.

Furthermore, historical accounts, blueprints, and other iconographical sources which have been documented and which relate to a building's condition should be reviewed and subsequently modelled.

4.2.5 OPTIMISATION AND EXPORTING

Optimisation consists in the preparation of a package, which combines the variety of representations prepared for simulating the monument's actual condition and different phases of construction, and in a later stage other thematic information, such as the building's condition.

This package is the optimal 'measured dataset' according to the needs of the dissemination tool. The critical issue of the optimisation phase is the technical and scientific compatibility of the models with the contents linked to it to the information system selected.

Technical issues deal with the models being optimal performance of the model, in terms of real-time navigation and interaction with the end-user, depending on the engineering specification of the media, Graphic-User interface, and operational systems or platform used.

Furthermore, this optimised product will be later used during the next phase of work, ensuring that the optimisation process has been consistently documented.

4.3 DATA-SYNTHESIS: INFORMATION SYSTEMS AND DISSEMINATION

Synthesis is the phase, which presents the 'measured dataset' of representations. It seeks to enhance one's knowledge of a site as well as encouraging its future conservation.

This phase employs use of a '*prototype, replica, duplicate, facsimile, and reproduction*' (Fitch, J.M., 1998, p. 1)[78].

Prototype meaning the monument, while replica, duplicate, facsimile, and reproduction deal with reaching a simulation state with different levels of detail.

However, current dissemination techniques seek not only to make a physical replica of the monument using the computer, but also to find ways of enhancing one's understanding of it. Looking at the prototype or replica alone does not give enough information about its history and state of conservation. Moreover, it is impossible to predict its remaining life.

Information systems are of great use,

precisely because they 'enhance the experience of knowledge by displaying interactive visualizations linked to other sources of information, which help us to understand its authenticity. It advocates the notion of a multi-layered approach of values and dimensions, which make a monument relevant.

The critical issues of this last phase are the consistent and transparent spread of information through interaction with the end-user.

> *The distribution of digital images over communications networks will make our cultural heritage available to a wider audience than ever before. Creative use of digital-imaging technology has the potential to change the nature of teaching and research. For these transformations to take place, however, a critical mass of digital information about works of art must exist, and it must be available in standard forms. A common understanding of the principles and issues that pertain to the creation and distribution of digital-image archives is required for this new field of activity to move ahead as a whole. In an area where the terminology and procedures are unfamiliar and where technology evolves rapidly, a basic outline of the issues and practices involved in creating a digital-image database is essential (Besser, H. & Trant, J., 1995, p. 6)* [79].

Synthesis is the production of the dissemination tool(s) to present the measured dataset of the monument to a wider group of people for a specific application. It is the result of the interpretation and analysis of the information gathered across the different phases. However there are many issues that should be take into account prior to transmitting, commencing, based on all available evidence and clear interpretation, as well as the proper documentation of the process, including its limitations.

This research acknowledges the need to examine issues dealing with copyright and ownership in the distribution and accessibility of records.

Furthermore, at this stage, preliminary ideas of an Online Information System are presented, which have the idea of giving a referential and updateable system that provides access to specific or wider groups of people.

4.3.1 SYSTEM CONCEPTION

The system proposed is a storage tool in which information about a built heritage site is retrieved using a single or multiple 'geometry-based representation(s)' (Heylighen, A., 2000, p. 67) [80] as graphic user interfaces.

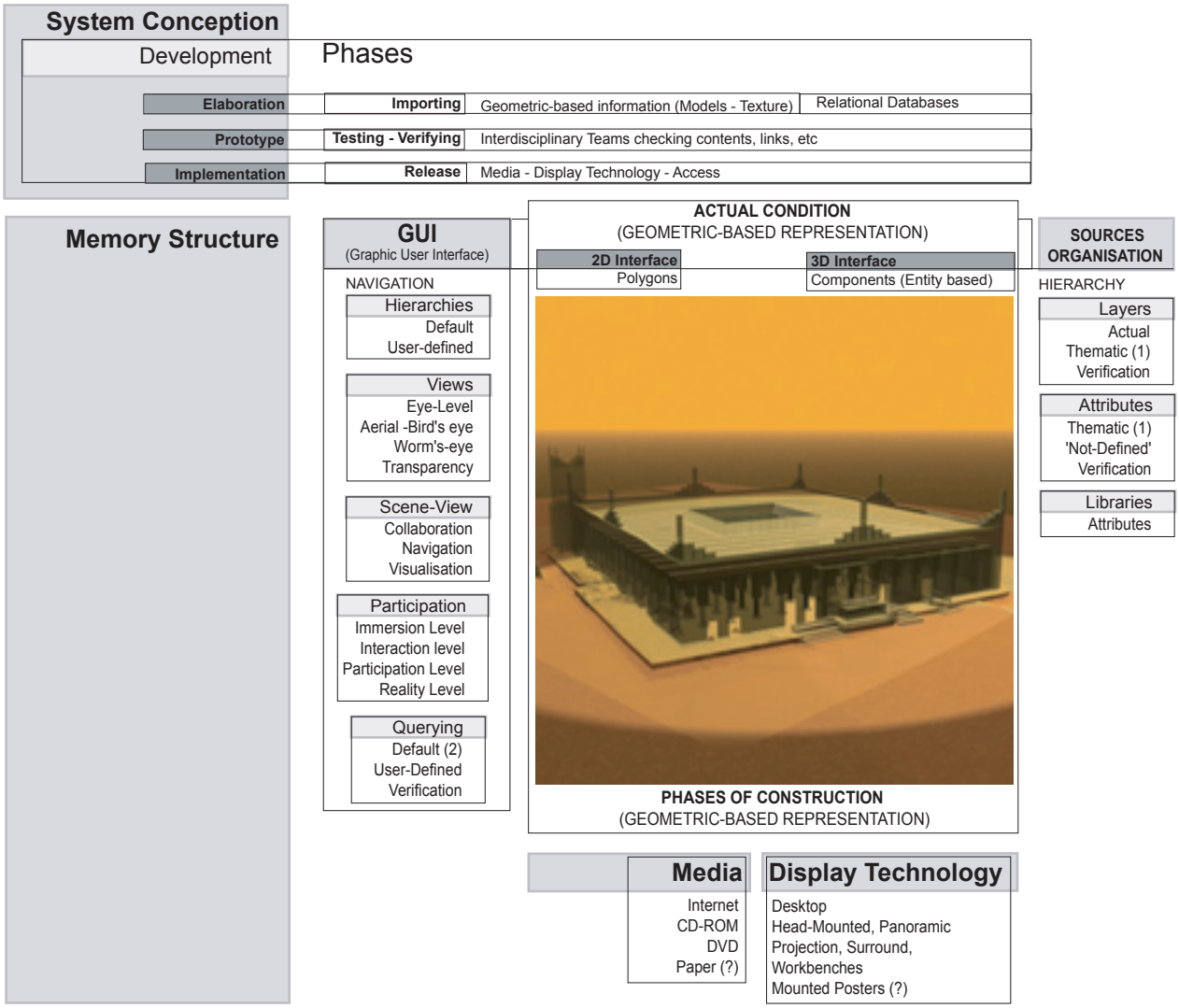
The representation will be depicted in its basic components, consisting in entities in 3D models and/or polygons in 2D representations.

These units are grouped in components, which are stored and organized in different user-defined hierarchical orders (horizontal and vertical).

The users can then customize the entire systems for evaluation, navigation, collaboration, and maintenance of the dataset. However, it is not intended as a modelling tool, the geometric-based interface remains non changeable, only the users defined as administrators can import a new entity replacing an old one in case that more evidence is found, or surveying techniques allow better metric survey results.

Furthermore, the interface involves the comprehensive utilization of '*relation databases*' (Mitchell, W.J. & Mc Cullogh, M., 1995, p.479) [81], which can be created by assigning thematic attributes to the entities displayed in the User-Interface.

IMPLEMENTATION
DATA-SYNTHESIS: INFORMATION SYSTEMS AND DISSEMINATION



(1) Thematic: Condition (Weathering forms, Geometry, Historical Documentary, Colour, Material, ..)

(2) Default: Condition (Weathering forms, Geometrical inquire, Colour, Material, ..) - Historical Documentary

Chart 18: data-synthesis 'a proposal' - an Information system for disseminating knowledge of historic buildings. Author.

The system should provide the possibility of customizing different views and levels of details (location or clustering: displaying clusters-bounding boxes, geometric primitives, full detail with or without texture mapping) depending on the needs.

At the same time, the system should be used for different applications in studying built heritage. The following studies have been defined:

- Inventorization
- Historical research
- Conservation of built heritage, including standing buildings and archaeological sites
- Monitoring of built heritage
- Broader audience presentation

4.3.1.1 Phase of development

The system conception is developed through a series of phases:

Elaboration phase: the dataset for the geometric-based interface and relational databases is imported and implemented. The user assigned as administrator defines the hierarchies used for linking the relational databases to the geometric-based representations by assigning attributes to each or grouped components (entities/ polygons).

Prototype phase: the GUI and databases are available for testing purposes. A group of interdisciplinary experts check the contents, links, and real-time capabilities of the system.

Furthermore, at this stage the administrator will define the access restrictions for each other user-group.

Implementation phase: the system is released using a specific media, display technology, and maintain.

4.3.1.2 Hierarchies

Hierarchies are defined for a proper navigation and visualization of the components of the geometric-based user-interface.

Default hierarchies

The system proposes pre-defined hierarchies (Horizontal and Vertical) for the preliminary stages of elaboration and prototype, where the management of the information is more critical. In this phase the geometric-based interface is fed and updated with the contents of the relational databases.

Horizontal hierarchies organize the components in rooms or spaces, and relates to the movement and functional relations of the object (e.g. entrance's hall, kitchen, living room, etc).

Vertical hierarchies are organized in terms of vertical levels (e.g. ground floor, first floor, mezzanine, etc).

User-defined hierarchies

The system should be capable of defining other hierarchies using attributes defined by the 'professional user', such as dividing the object by historical chronology, 'activity number' sequences in Archaeology, structural behaviour, weathering forms, etc.

This grouping can be executed at a stage where all the entities and/or polygons are defined by a set of attributes in the databases.

4.3.1.3 User-definition

The need of defining users is important to control the manipulation and management of the system, and customize it in terms of '*what should or should not be portrayed*' (Kantner, J., 2000, p. 47)[82].

Several user-groups can be defined, but at this stage a professional and educational classifications are established, according to restrictions and assigned functions.

Professional-user: They are responsible for organizing the dataset and linking it to the graphic user Interface and defining an 'administrator', who's role is to access, create, modify, and customize the system, and a 'collaborator' defining the user feeding system only.

Educational-user: is defined as a 'Guest', his/her role is restricted to navigation, customizing the pre-defined views, and providing feedback of the system and contents to the Professional-Users.

4.3.1.4 Memory organization (Heylighen, A., 2000, p. 85)[83]

The platform of the systems is based on a Geometric-based navigation system; these representations can be two-dimensional through elevation plans, elevations, vertical sections, or any other orthographic projection.

It should include, three-dimensional models, where the system should be capable of being customized to shift from two-dimensional to three-dimensional views.

As mentioned previously, the system is composed of a single unit called entities in 3D and polygons in 2D. A set of these can be grouped geometrically in its components.

Furthermore, these elements will be enriched with thematic information using attributes, which are grouped in its layers of information and navigation hierarchies.

4.3.1.5 Graphic user interface (GUI)

The default GUI should be the representation of the 'actual geometrical condition' of the Geometry of the monument and its context.

The interface will be linked to other graphic interfaces called 'Hypothetical Interfaces', dealing with representations showing the different proposals for reconstruction of the phases of construction, as well as, stability studies and condition mapping models.

However, it is recommended that the system entities be single and not repeated in each representation, in order to create a scientific consistency in the information. Therefore, some of these hypothetical visualizations can be displayed only as a whole referential attribute, without contents.

Real-time navigation

Real-time relates to the smooth navigation, rendering, and general performance of the system to avoid any 'perceptible delay' in the data being visualized.

Therefore, the system proposed should have the possibility of customisation according to user needs, and especially in relation with to devices for store and retrieval.

Type of views

Views are related to the level of detail and the approach of the building. However some default views could be defined using Laseau's[84] classifications (see chart 19):

Eye-level view: the person interaction with the three-dimensional environment is adapted to real situations. The position of the viewer is set to a normal height and distortion is not used. This type of view is the most akin to the real situation.

Aerial view or bird's-eye view: most humans would not have the chance of experiencing this type of view in a real life situation. They would either use a balloon or helicopter to achieve this. However, it is very useful to show to the spectator the whole scene.

Worm's-eye view: this view is unrealistic, the building can be partially sectioned and it is possible to observe the interior. It is very useful to show the modification of the space and relations between the exterior and interior.

Furthermore, it is possible to add more classifications, such as:

Transparency views: whereby the building and its components are transparent giving the audience the ability to see the entire inside elements. It can create confusion, but can be particularly useful when needing to reconstruct a building in the absence of more accurate information.

Alternative view: user defined view, it can be stored in the system, similar to the possibilities provided by most CADR packages.

Scene navigation and the spectator

Computer limitations affect the full performance of this proposed application. Particularly, the use of three-dimensional representations, where real-time and rendering quality can be affected. Therefore, it is alternatively possible to establish a set of changeable scene views and navigation, similar to those used in rendering packages. These views will change depending on user need and the engineering capacity of a computer.

Collaboration scene: consists of a working task mode, where information is being added and updated. In this case the scene display is customized to show bounding boxes representing the entities and this will be displayed in detail, when the object is selected, and the textured mapping subsequently set off.

Navigation scene: this view is customized to the needs of the user in the particular area and scale. The level of detail is improved by the approach of the user. This particular view demands high performance.

Visualization scene: this view is customized only for viewing the objects without interacting with the databases. The quality of visualization can be customized by the selection of light, zooming or panning the view, creating rendered or photo-realistic images. Other applications can include the use of augmented rendering, such as transparent models, the used of un-realistic colours and views.



Chart 19: examples of different types of views, Castle of Arenberg, Heverlee, Belgium. Author.

4.3.1.6 Layers, attributes and library (databases)

These annotations are used for organizing the data into groups that share particular and common attributes, which can be accessed by navigating the Graphic User Interface or querying the system.

The functional hierarchy structuring the memory of the system is the sequence entity/polygon annotation using the grouping forms: layer as the highest grouping form and attribute the unit, where the library is an alternative element that can be inserted after an item has been defined as an attribute.

Layers

There are two main types of layers, the actual condition layers, thematic, and verification. Subsequently both are divided in different categories.

Actual condition layers: textured mapping and geometric entities (e.g. a primitive, a complex shape, etc).

Thematic layers: historical stratigraphy, condition assessments, and others complementary layers.

Verification layers: these provide information about the information used to assign an attribute in general lines, they are mainly associated with historical documents, weathering mapping, structural notes, spatial analysis, and other relevant information describing the process. This layer is used to verify the precision of the information and review the various processes.

Subsequently, it is important to include the role of a 'non defined' layer, where the scientist can review the components and entities in cases where information is not available or found, or possibly restricted.

Attributes

The Thematic layers provide a general overview of the component, and the attributes will provide the unit identification to the entity. For example a thematic historical stratigraphy layer can display all the components having similar dating or which simply have a historical document assigned. While attributes will be the carriers of all the information assigned to the entity.

Attributes can deal with colour, material, type of weathering form, historical documents, verification information, spatial conception process, quality of the material, particular properties, etc.

Furthermore, a 'non-defined attribute' is defined as a situation where no information about the weathering form, historical fact, or any other information is available. An attribute call will also be called a field when associated with databases.

Libraries

Although libraries are associated with geometrical-based representations of pre-defined objects (e.g. doors, windows..), in this context they consists of colours, hatching shapes, and other repetitive thematic elements used to define attributes of the entity/polygon, such as weathering forms, historical dating, etc.

4.3.2 MEDIA SELECTION

The good conception, contents, customisation, and navigation tools in an information system is not the only problem when encountering visualizations of large-scale datasets as is the case with built heritage.

These systems provide the user with advanced information. Therefore the selection of a media and computer system to store, manipulate, and manage the system,

and to offer the user access, is a critical aspect.

A good media should be able to offer the user the ability to retrieve and share information in a dynamic way.

Internet is the best-known digital media, since it targets and is accessed by a broad audience, which can easily find and retrieve information. It can be defined as a broad information source, giving rapid and dynamic access to published information. However, it is dependant to the user's hardware ability to download the data or to manipulate it in real-time using a specific connection.

However, connection problems and problems with downloading can be avoided by using CD-ROM or DVD. These though, are also limited to distribution; as well as the end-user's type of computer.

Furthermore, the application can reside in an environment accessible to a broader audience, only such as a museum or library. Or it could be restricted to a government office for the management of locally built heritage.

The ideal system is the one that resides in an accessible location, but which has several user definitions and customisations to provide access to professional users and visitors.

4.3.3 DISPLAY TECHNOLOGY

Display technologies can provide a higher level of immersion and interaction to the end-user. However there are constraints due to the high investment necessary to obtain a highly immersing and interactive experience.

The system is probably adapted to the use of a desktop display, which is the most widely used device. It is highly cost effective and accessible, although it is limited to the size of a computer screen and the rendering capacity of the video card.



Figure 42: example of the view customization to visualize a detail of the vault, Salle Heraldique, Castle of Arenberg, Heverlee, Belgium. Author.

Other systems, such as head mounted displays, panoramic projection, surround projection or Workbenches are being considered, but their application is limited because of economical constraints (see chart 20).

4.3.4 PARTICIPATION LEVEL

The level of participation not only relates to user restrictions and customisation tools to visualize the scene, but also to the actual immersion and interaction of the user with the environment. An interactive system allows the user to navigate in real time a specific

model.

According to Kerlow and Rosebuch, these levels can be defined by describing the immersion, interaction, participation, and reality level, which compose these types of visualisations (Kerlow, I.V. & Rosebuch, 1994, p. 244-245)[85].

In the case of the '***immersion level'*** , the system variable enables the user to have a partial immersion experience. The view is limited to the size of the computer or a LCD projector screen.

Next, the '***interaction level'*** and '***participation level'*** are described as having restricted access and allowing a single use or multiple users to browse the system without being able to communicate to each other.

Finally, the user itself determines the '***reality level'***, and the performance of the devices used for navigating the system.

4.3.4.1 Database querying

Part of the interaction level and participation of the end-user with the system is the possibility of 'enquiry'. This alternative consists of defining queries to the attribute or layer ordered database and getting the results displayed in the visualization, mapped onto the geometric-based representation.

Furthermore, the user can either use the 'default queries' or new user 'defined queries'.

The default queries will deal with 'geometric properties' of the object itself (dimensions, colour, volume) in relation to others; as well as, 'thematic contents', such as chronological dating, weathering forms, and structural function.

Furthermore, these queries can be used for actual quantification and measurement

DISPLAY TECHNOLOGY
DATA-SYNTHESIS - EXAMPLES

Examples:

Head-Mounted



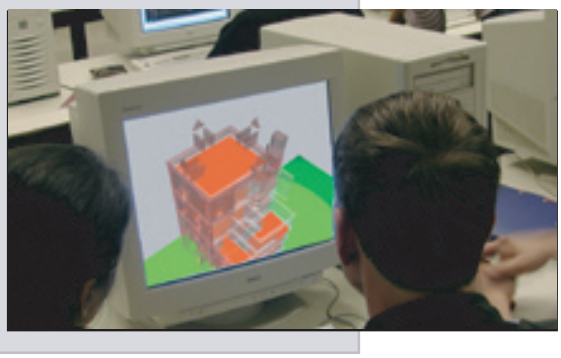
Desktop (Alternative) **(1)**



Surround (CAVE) **(2)**



Desktop View



(1) Ename Park (Virtual Reality display) , Belgium
(2) Fakespace product: www.fakespace.com

Chart 20: examples of Display Technologies in Visualization. Author.

methods. For example the system can implement tools to define distances between points, obtained in the 3D location in space of an object (using local, regional, or international coordinate systems), or perhaps the amount and effect of weathering forms in the fabric.

Alternatively, they could be implemented to generate visualization simulations of atmospheric conditions, light effects, and other important modifying elements in architecture that provide insight about the artistic and religious dimension of the object.

Moreover, the participation level of the user is defined on the one hand in the navigation of the model. On the other hand, in querying the information to get it visualized. Queries are the basic 'exploration' and 'scientific' navigation and experimenting tool.

At the same time, the queries can also obtain 'verification' information about the person that has contributed to the investigation defining the entity, the sources, the modelling process and metric survey dataset used.

The queries can be combined to obtain different results and compare and examine the output.

4.3.5 REMARKS ABOUT THE INFORMATION SYSTEMS PROPOSAL

This system has been described on along general lines. It is an approach to implementing a methodology to obtain an information system adapted to the three-dimensional study of built heritage.

4.4 CLOSING REMARKS

This chapter has dealt with the idea of introducing a proposal, which was developed by merging techniques, variables, and the most recent literature. This methodology, it may not be economically viable. However it should be used as a guideline.

Furthermore, this part has discussed a number of elements vis-à-vis documentation, such as the relationship between the scope and those enjoying built heritage (target audience). This research acknowledges the existence of specific needs for specific groups of people.

The correct definition of the 'target audience' can have a great impact in the understanding of protecting heritage.

Subsequently, each phase of this methodology, and especially the dissemination of an Information Systems should incorporate variables, which make the process transparent and consistent, which allows for precise verification, observational accuracy and relevance of the information shared, selected, and interpreted.

The careless use of capturing, processing, and dissemination tools can mislead the operator and the user. The later could be encouraged to believe non-existent values relating to a monument.

This problem is relevant to the nature of this field, where a substantial amount of knowledge is available and correct storage, management and retrieval tools can make the difference in the perception of the object.

'Accuracy pertains not only to the design of the model but also to conventions of representing degrees of certainty and hypothesis', such as the visual conventions corresponding to the relationship between the words of 'definitely, probably, and possibly' (Frischer, B. & Abernathy, D., 2000)[86]. Such terms allow merely for hypothetical representations.

These assumptions play not only a role in the definition of phases of construction, but also the use of other techniques where the observational judgement and interpretation is implemented in creating a 'Replica' of the object.

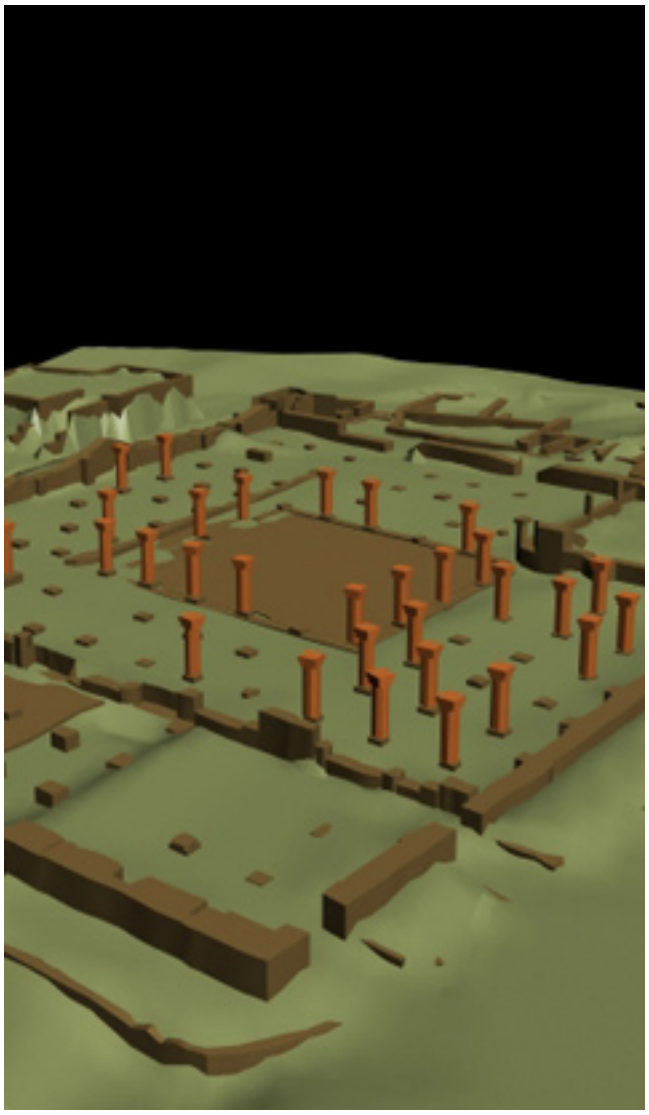


Figure 43: example of the view customization to visualize a number of columns that have been restored, Great Mosque, al-Baleed, Sultanate of Oman. Author.

Moreover, perhaps without any prejudice the term 'not defined' should also be included, to identify those entities, where there is no evidence, or where missing information is too great.

During the implementation of this methodology, it is important to review the problems dealing with 'obsolesce', when ever it deals with scientific guidelines for dealing with the methodology and the computer formats used for storing, managing, and retrieval.

Public awareness is a very important issue in promoting the conservation of built heritage, especially when information systems are used to decide when monuments will be protected. In this application the correct use of visualizations is of relevance to obtain positive reactions.

Globally, heritage is under threat and the industry and academic communities should react. Swiftly to protect this heritage

The merging of concepts, such as 'sustainable' and 'optimised techniques' should be adopted. It is of the utmost importance thus that adequate methodologies for documenting built heritage are used.

For, it not only contributes to the creation of a permanent record of our heritage, past and present. It also helps us to understand its importance in order to encourage its future conservation.

Notes:

[1] **Anamsesis** (sometimes named analysis) corresponds with the phase of the research to acquire significant data and information on the different dimensions of the heritage. It is essentially multi-disciplinary.
Diagnosis corresponds with the phase of the identification of the values (aspects of authenticity), causes of damage and decay. It is the synthesis of the gathered information and their confrontation. Diagnosis should lead to definition of objectives and aims, based on deliberate and clear choices that on their turn are based on generally accepted restoration principles.
Therapy corresponds with the phase of the choice of the remedial measures and their execution.
Control refers to the phase of checking the efficiency of the interventions. In order to achieve minimal impact on architectural heritage, using funds available in a rational way, it is usually necessary that the study repeat these steps in an iterative process. The different fazes are following each other but frequent loops to previous phases have to guarantee that each step is only made when enough and validated information is available. K.Van Balen 'RILEM TC old and new Mortars: Report on External Requirements', Preliminary draft, Leuven, 2000.
[2] Searls, C.L., L. Binda, J.F. Henriksen, p.W. Mirwald, A. Nappi, C.A. Price, K. Van Balen, V. Vergès-Belmin, E. Wendler, and F.H. Wittman, 1997. Group Report: How can we diagnose the condition of stone monuments and arrive to suitable treatment

programs? Saving Our Architectural Heritage: the conservation of historic stone structures. Eds. N.S. Baer, and R. Snethlage, pp. 199-221. Chichester: J. Wiley and Sons Ltd.

[3] Historic American Engineering Record 'Chapter IV: Recording Historic Structures & Sites for the Historic American Engineering Record' http://www.cr.nps.gov/habshaer/haer/manual/chapter4.pdf (Last visited: 16/07/2001)

[4] Schofield, W. 'Engineering Surveying', Butterworth & Heinemann, London 2001, p.21.

[5] Ibid 4.

[6] Fitzner, B., Heinrichs, K. & Kownatzki, R. 'Weathering forms – classifications and mapping', Denkmalpflege und Naturwissenschaft: Natursteinkonservierung I, Ernst & Sohn, Berlin 1995. P. 41.

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[8] Ibid 7

[9] Historic American Engineering Record 'Chapter IV: Recording Historic Structures & Sites for the Historic American Engineering Record' http://www.cr.nps.gov/habshaer/haer/manual/chapter4.pdf (Last visited: 16/07/2001)

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[21]Ibid 20. P. 41.

[22,23] Ibid 20. P. 44.

[24] Ibid 20. P. 48.

[25] Ibid 20.

[26] Ciciarelli, J.A. 'A Practical Guide to Aerial Photography', Van Nostrand Reinhold, New York 1991, p. 38.

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[28] Ibid 27. P. 249.

[29] Clark, K. ' Informed Conservation: Understanding historic buildings and their landscape for conservation' English Heritage, London 2001. p. 111.

[30] Staff of Research and Education Association 'Handbook of Field Surveying', Research and Education Association, New York, 1983. P. 249.

[31,32] Ibid 29 P. 36.

[33] 'True or Grid meridian: the first deals with the longitude calculated by the 'astronomical observation', and the last by 'drawing a plane parallel lines to form the north-south lines of the national grid'. Hewitt, R.; Guide to Site Surveying; Architectural Press, London 1976. p. 132.

[34] 'Magnetic north is often sufficient orientation for architectural surveying'. Hewitt, R.; Guide to Site Surveying; Architectural Press, London 1976. p. 20.

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CHAPTER V

APPLICATIONS

FRAMEWORK FOR THE SELECTION OF METRIC SURVEY TOOLS FOR THREE-DIMENSIONAL DOCUMENTATION AND DISSEMINATION OF BUILT HERITAGE

CHAPTER V:
APPLICATIONS

The objective of this chapter to present a number of applications when studying built heritage, providing guidelines for the 'metric survey study' in the selection of three-dimensional documentation and to examine various dissemination tools.

Moreover, the application framework aims to define the intensity and spectrum of the metric survey study.

In this respect, the metric survey study is related to the preparation of the 'measured dataset' and involves the collection and mapping of the sources associated with the subject's geometry and texture, which can yield information for future studies, such as spatial-typological analysis, condition assessment, historical assessment, and other relevant investigations.

Applications are defined by their purpose (scope and target audience) and their expected quality requirements and which deal with the degree of completeness and reliability of a 'measured dataset' (metric survey output).

This research emphasises in the following applications. They have been classified as the:

- Historical research of built heritage
- Conservation of built heritage
- Broader audience presentation

Furthermore, other applications, such as monitoring and inventorying of built heritage are briefly mentioned for referential purposes.



Figure 44: recording tools - REDM Total Station and a camera, Stupa 1, Sanchi Hinayana Buddhist site 2001, India. Author.

5.1 APPLICATIONS FRAMEWORK

An application is a decision-making process, which seeks to define a set of parameters. It involves describing the different constraints embedded in the application's objectives and the restrictions posed by the subject. It will involve physical, social, and legal aspects.

Specifically, it means the identification an 'application purpose', in order to consider the scope, the target audience, and the quality of information, which will be presented to the public. Moreover, it is a process of defining the site's limitations and what it means when selecting documentation tool(s).

The parameters set by studying these variables enables one to understand the monument within its context, and subsequently to define its importance.

This framework of applications involves two decision-making processes or phases of work (see chart 21):

- **Definition-framework:** this process involves the non-thematic dataset (metric survey study), in terms of its expected quality and is extent or 'intensity' (Boehler, W. Heinz, G., 1999)[1].
  - Further, it also takes the needs of the thematic studies into account, to be used in the analysis of the subject and context.
  - **Selection-framework:** the process of selecting a combination of metric survey tools (documentation and dissemination) according to the parameters described in the definition-framework.

5.2 DEFINITION-FRAMEWORK PROCESS

This process involves identifying the needs and tasks of a specific application, which is based on variables dealing with 'purpose' (target audience – scope) and expected quality (precision, observational accuracy, and completeness) of the expected non-thematic study dataset (metric survey study) in recording these activities.

Subsequently, the parameters of this framework are defined by considering:

- **Identification of the non-thematic dataset (metric survey study) requirements**: the applications are defined by variables associated with the application and the tasks derived by these parameters, and which need to consider the requirements of the non- and thematic content studies.
- **Identification of variables associated with practical restrictions**: is the study of limitations associated to the subject and its context, consisting of the actual situation of the subject--context and the parameters and potential required by the metric survey tool(s) to overcome these obstacles.

5.2.1 TYPE OF STUDIES REQUIREMENTS: NON- AND THEMATIC CONTENT

Understanding the importance and relevance of built heritage deals with studying its authenticity, which is translated into values and dimensions. This investigation mentions a sequence of studies, which seek to authenticate the monument. The study begins by preparing a 'measured dataset' of the building, containing two-dimensional maps or three-dimensional models, which are then used as a base data for other studies leading to a final 'core data' to

FRAMEWORK OF APPLICATIONS IN DOCUMENTATION AND DISSEMINATION TECHNIQUES FOR STUDYING BUILT HERITAGE

(FRAMEWORK - VARIABLES IN THE PROCESS OF DOCUMENTATION AND DISSEMINATION TOOLS)

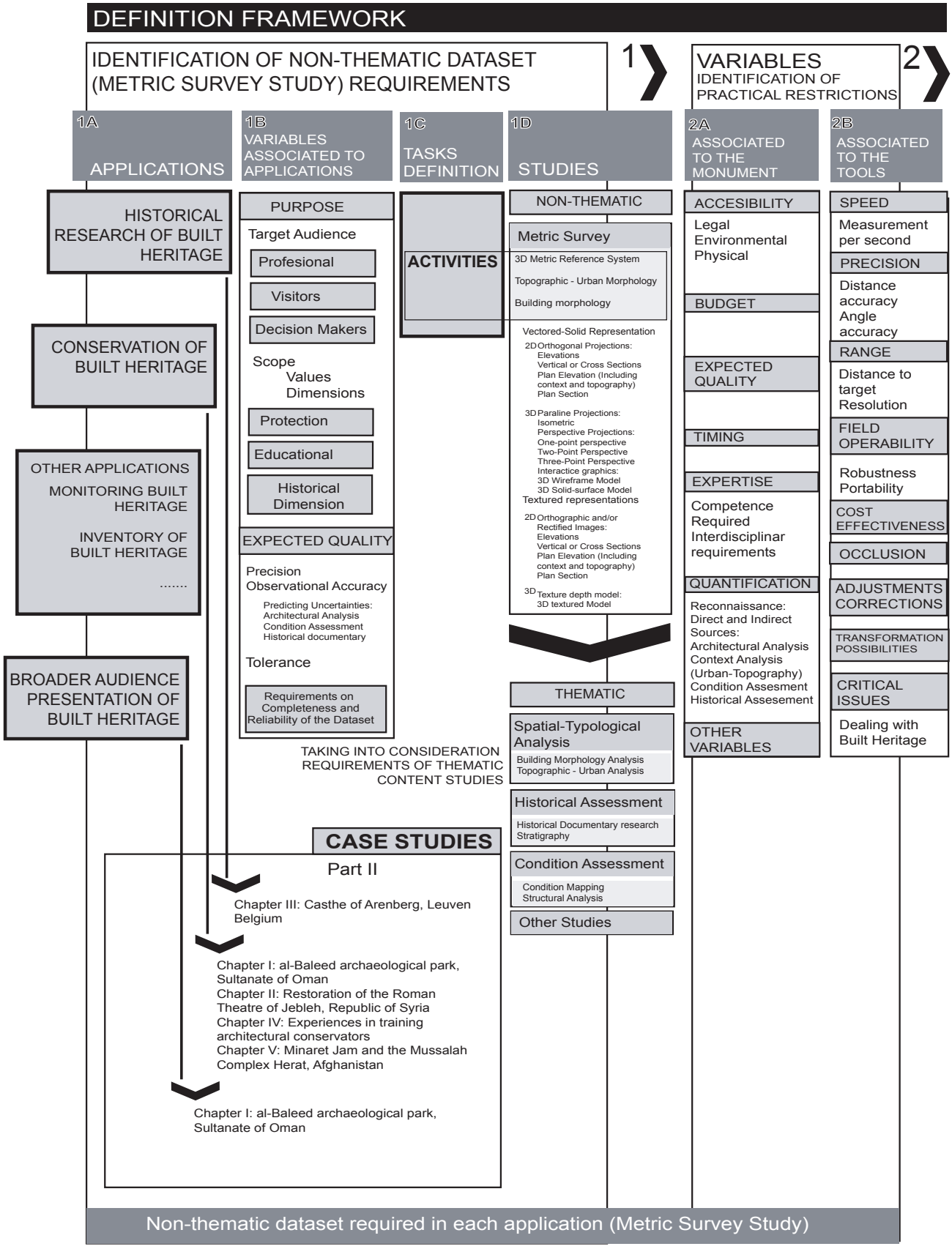
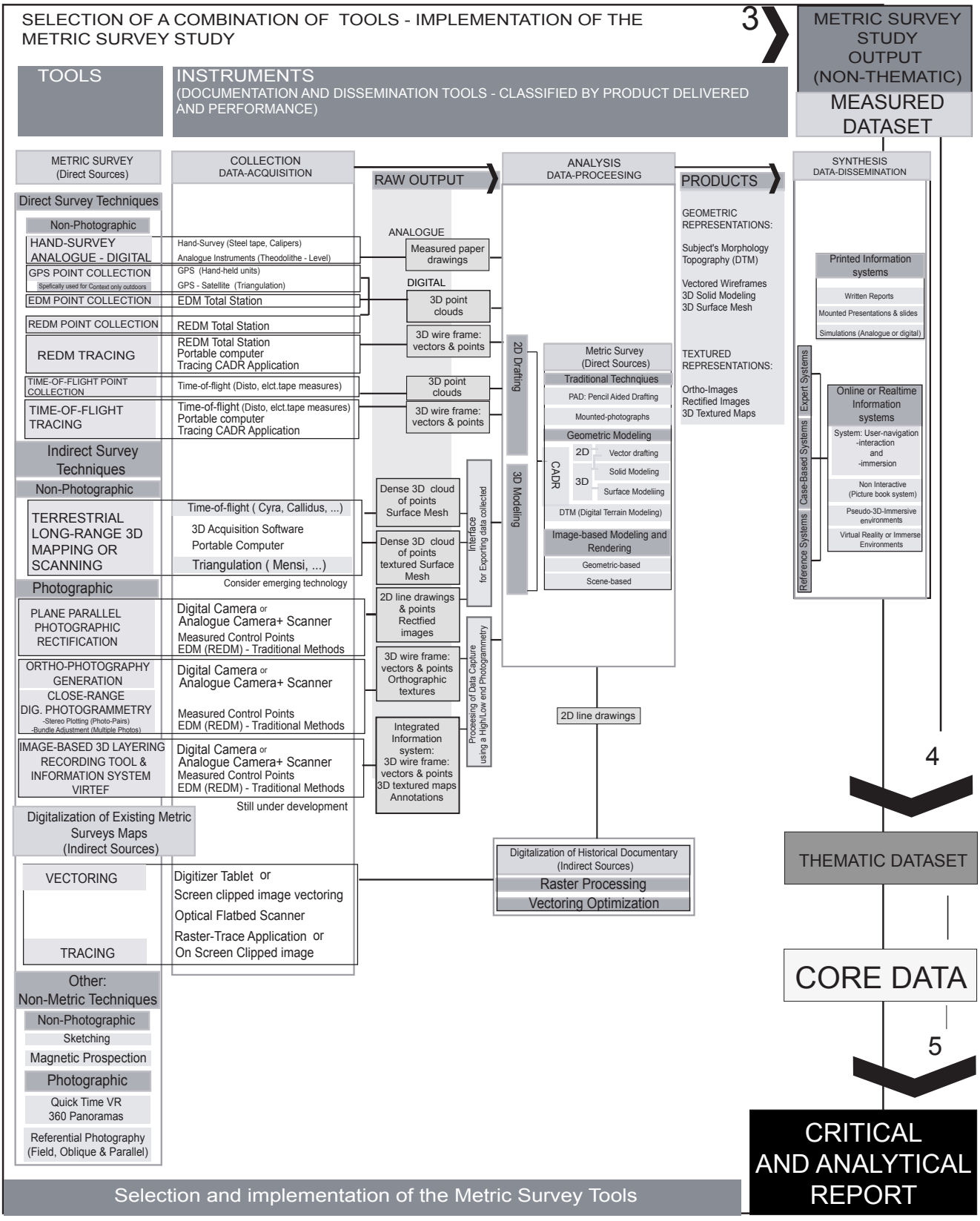


Chart 21: framework of applications

SELECTION FRAMEWORK



STUDIES IN DOCUMENTING AND DISSEMINATING
RESEARCH STRATEGY FOR STUDYING BUILT HERITAGE

Type of Study

NON - THEMATIC

Metric survey

Study aimed at acquiring a measured 'Dataset' of the building and context Including the study of the geometry and texture of the fabric.

- Context (landscape - urban)
- Building geometry and texture

DATASET: FOR USE IN THEMATIC STUDIES CONTENT

THEMATIC

Spatial - typological analysis

Study aimed at understanding the spatial and typological characteristics of the object and its emplacement

- Building morphology analysis
- Topographic - urban analysis

Historical assessment

Study aimed at understanding the phases of construction and modifications carried out to the object. Collection of documents from archives and other historical sources. Important relation with the Metric Survey for Confirmation

- Historical documentary research
  - Archival and bibliographical research
  - Iconographic research
  - Map regression
- Stratigraphical research (relational to other studies)

Condition assessment

Study aimed at understanding the current state of conservation of the object's fabric by investigating the type of construction materials present and alteration pathologies associated to these types of material and environmental conditions.

As well as, to understanding the construction systems, quality of the grounds, and cracks, in order to determine the causes of decay for possible operation to improve the stability of the structure

- Condition mapping
  - Materials analysis
  - Analysis of weathering forms
    - Loss of material
    - Discoloration/deposit
    - Detachment
    - Fissures/deformation
- Structural analysis
  - Construction systems
  - Technical -scientific analysis
  - Fissure mapping

Other studies

Complementary studies aimed at understanding issues adapted to specific projects and situations, where other type of analysis are required

- Impact assessment
- Dendrochronology
- Sampling

DATASET WITH THEMATIC CONTENT FOR FURTHER ANALYSIS

Chart 22: studies in documenting and disseminating built heritage

prepare an 'analytical and critical report'.

This initial study is identified as a '**metric survey study**', which has already been extensively explained in chapter IV – part I. It consists of a set of measured and verified geometric and textured representations of the building with its setting, and which have been recorded using a combination of acquisition and dissemination tools. It is characterized by the absence of any thematic content, such as the identification of construction materials mapping, historical layering or phasing definition.

Furthermore, although the metric survey is initially prepared independently, it should take into account the requirements of other thematic content studies (spatial and typological analysis, the condition assessment, historical assessment of the object, and other studies), in order to ensure a useful set of information for the mapping, assessments, and further analysis.

Thematic studies:

Thematic studies are implemented simultaneously in order to conceive a complete and reliable set of information for the interpretation and subsequent analysis of the monument within its context, its actual state of conservation, and certainly its past.

Spatial and typological study (context and architecture): deals with the analysis of a building's geometry set within its context (topographic – urban geometry). The analysis basically uses the 'measured dataset' prepared in the metric survey study.

This study is associated with the recognition of a hierarchy, functionality, circulation, and building's qualities.

Furthermore, it is also the analysis of 'modifying elements in architecture', such as light, colour, temperature, orientation, ventilation, texture, scale and time.

Historical assessment: this deals with the comparative study of historical documentary facts and the answers to be found in the stratigraphy of the fabric, in order to clarify the historical chronology of the monument, the history of the building and its surrounding environment.

In this case, the metric survey is used as a mapping instrument to identify the construction phases, which can be found in documents and in the fabric of the subject. It is a comparative study that analyses and verifies a monument's fabric.

This assessment makes use of different techniques, such as historical documentary research (map regression, iconographical research, and archival-bibliographical research) and the study of the fabric's stratigraphy.

Historical documentary research

This involves carrying out investigations into the iconographical sources, as well as available archival and bibliography sources. Lastly, it also involves techniques of 'map regression'.

Iconographical research is related to the collection of 'Topographical or other drawings, published views and historic photographs' in order to acquire information about the 'building function, patterns of alteration, and perhaps ideological intentions of the original' (in case of illustrations) (Clark, K., 2001, p.73)[2].

Archival and bibliographical research: comparative research conducted in national or international institutions, libraries, and other related bodies, where documents on a monument's present condition and past can be found.

Map regression: this technique involves the collection of 'all relevant maps' (Clark, K., 2001, p.76)[3] of a site in order to create a

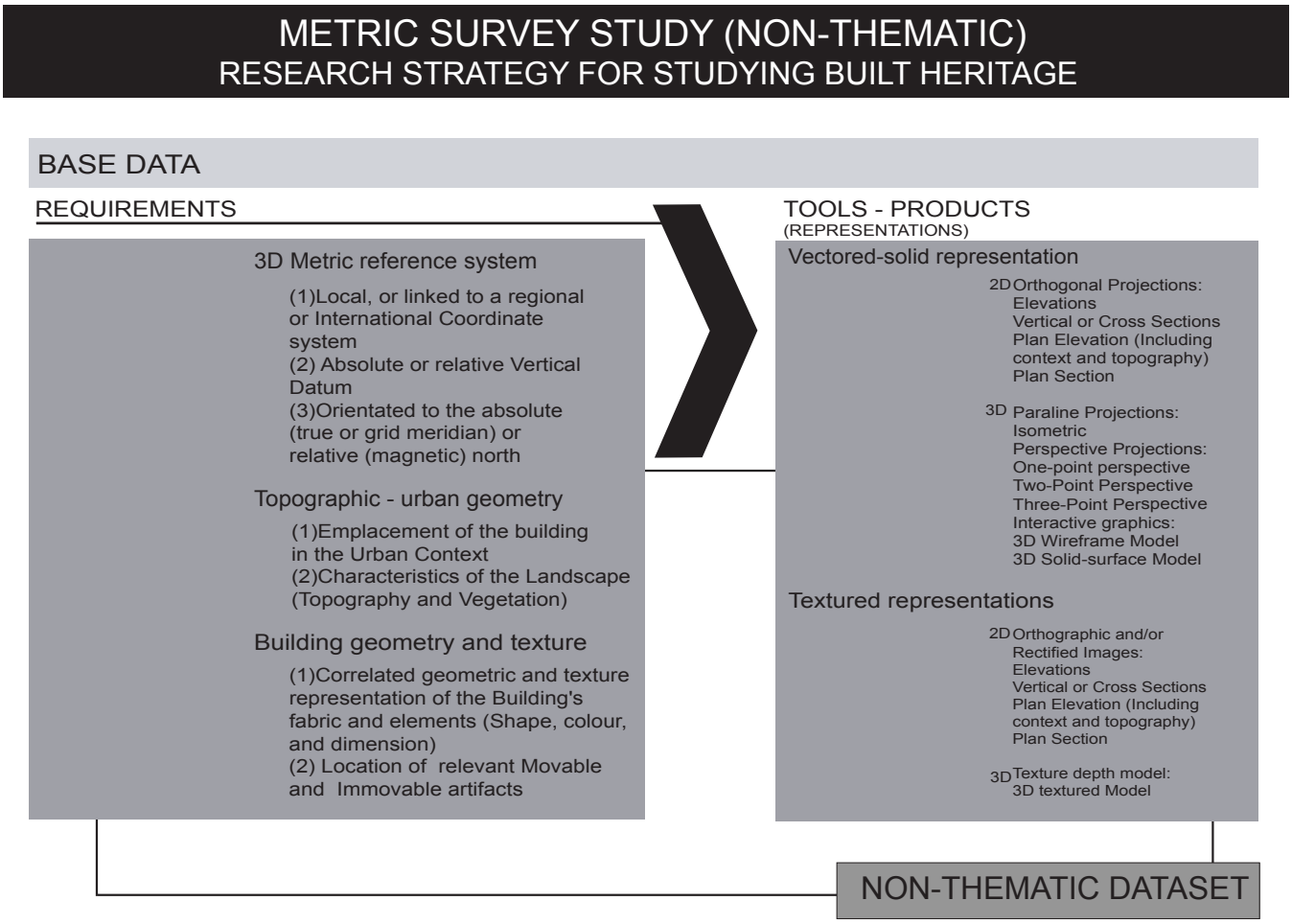


Chart 23: metric survey study

complete or partial sequence of the building's development over time.

Stratigraphy

This is a non-intrusive analytical technique. It is an application, which is based on the observation of a building's fabric in order to find evidence supporting the historical documentary research (map regression and historical images). These have been collected in order to assess the '*structural sequence*', '*logic of construction*' (also studied in Condition Assessment), and '*evidence for absolute dating'*, (ICOMOS, 1990, p. 43)[4].

It also seeks to examine, the nature of the material used, which should provide further evidence of 'social organization, the time, the energy consumption and effort that went into the acquisition, manufacture or transportation of the material' (Conway, H. Roenisch, R., 1994, p. 69)[5].

This research also involves the use of 'comparative and contrasting' tools to 'reveal similarities and differences' (Conway, H. Roenisch, R., 1994, p. 34)[6] with other related existing or documented buildings or sites.

Condition assessment: studies a monument's fabric by mapping the materials and weathering forms and its causes (condition mapping); as well as the structural analysis (deformation, crack analysis, stability, etc). The metric survey dataset is used as a base for this mapping process, monitoring of the mechanism of change in the fabric of the building and to study the anatomy of the structural design.

Studying a monument's anatomy involves analysing its joinery, structural support design, masonry sequence, the material employed,

and other relevant subjects associated with its construction.

At the same time, there are other types of studies which can be used depending on levels of decay, and the characteristics of a site, such as dendrochronology (study and dating of wooden structures), petrographic sampling, mechanical strength, ultrasonic tests for discontinuities or fractures in the fabric, etc.

5.2.2 TASKS DEFINITION: ACTIVITIES

A thematic assessment involves the implementation of a series of tasks in order to gather relevant sources of information. These tasks can be defined in terms of 'Activities'.

These Activities aim to define the parameters of a 'metric survey' tool(s).

5.2.2.1 Activities in the non-thematic dataset: metric survey

This non-thematic study consists of a series of 'measured and controlled dataset' relating to the geometry and texture of a Building; as well as, the topographic-urban geometry of the building being studied. The dataset should include:

Three-dimensional metric reference system: covering the whole site. It should include: (1) a local or absolute three-dimensional coordinate system. (2) an absolute (true or grid meridian)[7] or relative north (magnetic north)[8] orientation. (3) 'vertical datum' elevation linked to absolute or relative systems.

Later, the system of coordinates should be linked to regional or international systems. The precision of fixpoints is crucial. A close traversing[9] technique should be applied for improving the accuracy of the 3D coordinates.

Topographic and urban geometry: the building's location within an urban context (shape and dimension) and the characteristics of the landscape (topography and vegetation). In order to establish relations between the specific orientation of the building (relation design and environmental conditions), location in the terrain (level, projection, water system, drainage, etc) and other physical objects yielding historical facts.

Building geometry: correlated geometric and textured representation of the object's fabric (shape, colour, and dimension), with emphasis on the '*original form*' of the monument and any historical phasing, which may have occurred, '*materials and construction' (ICOMOS, 1990, p. 31)*[10]*.* The location of artefacts and other movable objects is important for thematic assessments.

The metric survey study should serve as an information system, which links other graphic, textual, or visual sources of information, such as photographic recording, analytical sketches, etc.

This type of study seeks to lay the ground for historical interpretations, bearing in mind '*the accuracy of any historical interpretation is always open to reinterpretation* (Conway, H. Roenisch, R., 1994, p. 29)[11]'. Nevertheless, this dynamic change or reinvention could not be produced without the existence of an adequate metric documentation describing a building's actual geometry and its unique characteristics.

The data acquired during a metric survey can consist of a multiple set of different types of representations. These can be classified in vectored-solid representations (geometric) and textured-based representations. The metric survey has been extensively described in chapter IV – part I.

Vectored – Solid Representations:

These types of representations correspond to the use of two-dimensional vectored drawings, or three-dimensional models using vectors, surfaces and/or solids.

Two-dimensional representations:

Orthogonal projections: elevations, vertical or cross sections, plan elevation (including context and topography), plan section

Three-dimensional representations:

Paraline projections: isometric
Perspective projections: one-point perspective, two-point perspective, and three-point perspective.
Interactive graphics: 3D wire frame model and 3D solid-surface model

Textured representations:

These types of representations are produced by acquiring the texture of the monument by means of photographs, sketching, or other image-based techniques. The output can be a two-dimensional orthogonal representation or a rectified representation.

Two-dimensional representations:

Orthographic and/or rectified images: elevations, vertical or cross sections, plan elevation (including context and topography), and plan section.

Orthogonal textured representations are related to the use of close-range digital photogrammetry or other image-based applications for the generation of a perfect orthogonal projection of the object, where all the planes are presented in an absolute position and without distortion.

Rectified textured representations are related to the use of plane parallel photography and associated applications for correcting the image distortion using control points lying in the desired plane. The output is a single plane corrected image.

Three-dimensional representations:

Texture depth model: 3D textured mesh surfaces or coloured point clouds.

Three-dimensional textured representations, showing the depth and texture of the fabric generated either by manual correlation of surfaces or by automatic processes. The later is still under development, but appears to offer great potential present a great potential.

5.2.2.2 Expected quality in metric survey studies

Graphic representations prepared using a metric survey tool are evaluated not only for the type of representation presented but for its quality and reliability.

Quality deals with specifying a scale (in relation with digital resolution) this also applies to 3D reconstructions and texture generation. The quality of a digital image with higher resolution will always be better than one with lower resolution.

Completeness deals with the precision and uniformity of the set of measurements. It also includes, the density of measurements collected (observational accuracy), dealing with the irregular nature of built heritage, where a higher number of measurements is advisable to simulate an entity better.

5.3 DEFINITION FRAMEWORK: APPLICATIONS

A fundamental question posed when seeking to define an application is whether the level of quality of the information collected and processed can yield useful knowledge about the history and actual state of the site.

This level of quality depends on the definition of the purpose, consisting in the scope of the investigation and its relation with the needs of the target audience.

The level of quality combines the evaluation of the level of completeness and reliability of the dataset, which will be used in both non-thematic and thematic assessments.

These different studies or assessment will provide the grounds for further analysis aimed at achieving the objectives defined by the application chosen.

5.3.1 BASIC CONSIDERATIONS

The metric survey study should always be performed 'as best as possible'. In other words, the recording process of the monument's geometry should be done to the highest standards so that it can be used in different applications.

On the other hand, the dissemination media of the metric survey study depends on the type of visualizations required by the target audience.

Furthermore, all the applications presented in this research relates to the study of values and dimensions of the building in order to understand its relevance and to give grounds for implementing interventions that will ensure its protection.

Each application should be adapted to the specific nature and needs of the site being studied. Although these applications are based on first-hand experience and literature, the objective is to present a methodology that provides guidelines for the adequate selection of documentation and dissemination techniques for recording, managing, and presenting information on built heritage.

5.3.2 HISTORICAL RESEARCH OF BUILT HERITAGE

The main thrust of this application is to elucidate through the use of publications, the relevant historical and social dimension of a building in association with a specific period of time or a past event of particular importance, such as (ICOMOS, 1990, p. 10)[12]:

- Sites with an innovative structure or design.
- Sites of historical, though non-architectural importance (e.g. the places associated with great events or people).
- Sites that pose or answer historical problems.

The case study explained in chapter IV – part II, dealing with the historical research of the castle of Arenberg in Leuven (Belgium), provides an example of the application of digital three-dimensional modelling techniques for the creation of a historical information system. In which a virtual environment is used as platform to browse, consult and understand the relevant sources of an historic building, including its history and its actual state of conservation

5.3.2.1 Purpose

The study of a building is associated mainly with an event and/or individual, emphasizing its social and historical dimension.

Target Audience

The audience for this application is defined as professionals or specialists, consisting in art historians, archaeologists, architects, and visitors.

Scope

This application concentrates on the '*critical study of the widest possible range of*

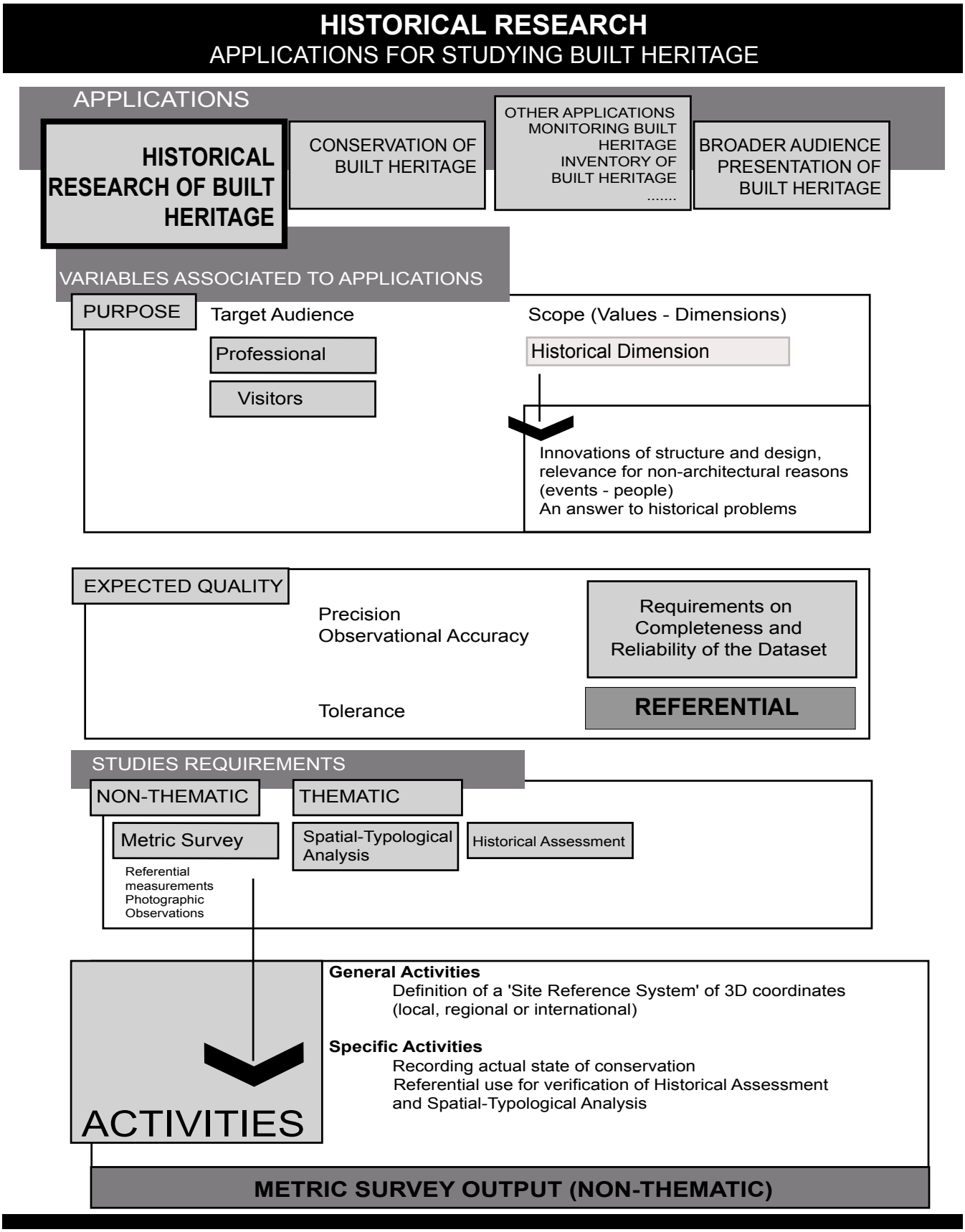


Chart 24: applications: historical research of built heritage

relevant sources' (Marwick, 1989, p.13)[13] to provide the social and historical dimension of the object.

> *'Historical study involves collecting facts, but facts by themselves tell us nothing. In order to make any sense of those facts they must be selected, ordered, evaluated, interpreted and placed in context' (Conway, H. Roenisch, R., 1994, p. 29)[14].*

Moreover, this study deals with the comparative investigation of historical documentary research and the evidences presented in the fabric of the object and context.

5.3.2.2 Expected Quality

In this case, the historical assessment requirements play an essential role in determining the level of completeness required in the metric survey.

The quality of the 'measured dataset' is defined by the '*degree of engagement with the fabric*' (Clark, K., 2001, p.76)[15] of the site and the level of verification required from historical documents.

This base record will be used in 'analytical representations' to illustrate the chronology of the site, such as '*phase plans, 3D reconstructions, and cut away drawings*' (Clark, K., 2001, p.83)[16].

5.3.2.3 Task definition: Activities in Historical Research of Built Heritage

A fundamental difference in this application is the degree of intervention in the monument's fabric to find evidence.

> *Historical research alone is rarely sufficient to inform the conservation process. There must be some degree of engagement with the fabric of the site or building, which is, after all, what we are seeking to conserve (Clark, K., 2001, p.76)[17].*

In historical research, this level of intervention is limited to the observation of the fabric to find traces of its historical development and to make a comparative study with the historical documentary sources.

Role of the metric survey in this activity

This application concentrates on recording the actual state of a site's conservation, whilst emphasising the need to assess its history.

Similarly, the measurable base record generated will be used of the analytical observation in stratigraphy, which in turn will add weight to the documentary research. In this case, the building's fabric is used as a 'potential historical document'.

General activities

> Definition of a 'Site Reference System' of 3D coordinates
> (Local, regional or international)

Specific activities

> Recording actual state of conservation
> Referential use for verification of Historical Assessment and Spatial-Typological Analysis

In this case, other thematic studies, such as condition assessment are not used for this type of application.

A metric survey is used specifically for observational purposes, to review and map the 'stratification', thus determining the

CONSERVATION
APPLICATIONS FOR STUDYING BUILT HERITAGE

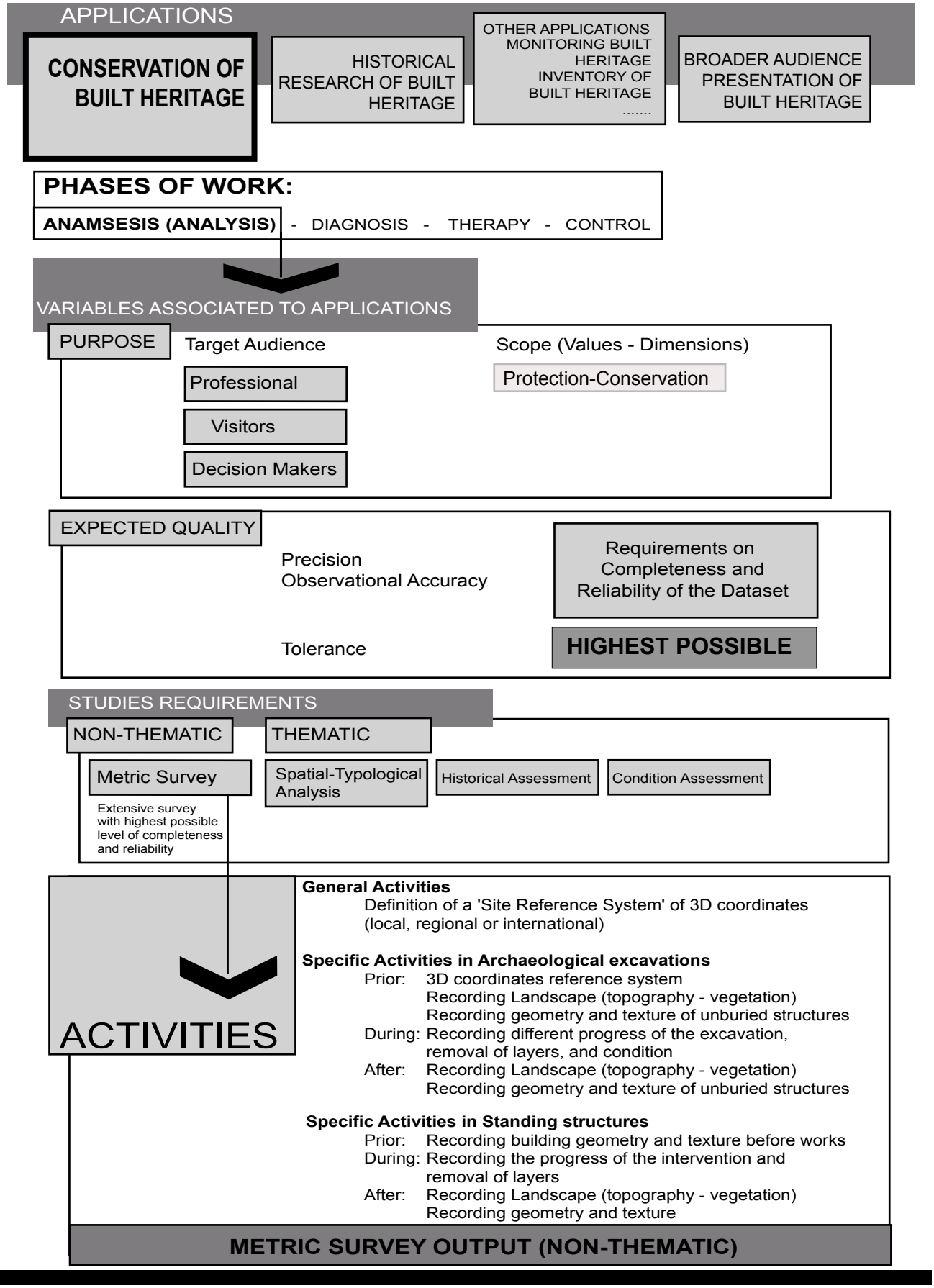


Chart 25: applications: conservation of built heritage

various phases of a monument's history.

5.3.3 CONSERVATION OF BUILT HERITAGE

The conservation of built heritage is the mainstream of this research. There is no doubt that under this heading the use of modern registration techniques for the protection of built heritage represents a challenge.

> *Conservation emerges as a hybrid discipline dedicated to safeguarding cultural heritage by observing and analysing the evolution, deterioration, and maintenance of material culture; conducting investigations to determine the cause, effect, and solution of problems; and directing remedial and preventive interventions focused on maintaining the integrity and quality of the existing historic fabric and its attending practices and associations (Matero 2000)*

Primarily, the use of measured representations (metric survey studies) is to record a complete dataset of the geometry and texture of a monument where destruction has occurred.

Furthermore, the measured representation as a 'base data' for mapping the different layers of information embedded in the fabric and literature of the site and its context in order to understand the different values of its architectural heritage (Van Balen, K., 2000)[18].

The process of documentation in conservation is carried out using a '*cumulative*' '*analytical recording*' (ICOMOS, 1990, p. 2)[19] whereby a number of tasks are carried out to understand the actual condition of the building's fabric, in relation to its geometry and texture.

This application is illustrated in the following chapters in part II:

Chapter I: case study: conservation and broader audience presentation of Built Heritage: al-Baleed Archaeological Park, Sultanate of Oman.

Chapter II: case study: conservation of built heritage: preparing a proposal for the restoration of the roman theatre of Jebleh, Republic of Syria.

Chapter III: case study: experiences in training architectural-conservators in the use of metric survey methods: master students at the R. Lemaire International Centre for Conservation, Almaty Workshop (Republic of Kazakhstan), Sanchi Workshop (India), and Université d'été in Chinon (France).

Chapter V: case study: the use of metric survey tools in urgent recording: Mussalah complex site in Herat and minaret Jam, Afghanistan.

5.3.3.1 Purpose

The framework of this application consists in the study of built heritage for its protection, including the use of documentation techniques in both archaeological sites and standing structures.

In this application, the target audience is primarily professional and the scope is protection. The scope is to determine the relevance and authenticity of the monument. This is performed by considering and defining all the values and dimensions embed in the monument's past.

The understating of its authenticity involves the participation of an interdisciplinary team of experts capable of analysing data relating to a site's condition and relevance, they

should seek to offer solutions to safeguard its future. In addition, they should suggest with measures for 'emergency treatment, preventive care, and long-term safekeeping' (GRI-AAT, 2000)[20].

Moreover, in conservation works, including urgent/preventive maintenance, rehabilitation, infill, and restoration, the resulting analysis can be used for defining the interventions required for 'making changes to an object or structure so that it will closely approximate its state at a specific time in its history' (GRI-AAT, 2000)[21].

Target audience

The interdisciplinary group of professionals analysing and preparing projects to ensure conservation of the monument, such as art-historians, architects, conservationists, civil engineers, archaeologist and other related professionals.

Furthermore, politicians and decision makers (investors and promoters) should also be included in the target group for this application, since they make funding available for the execution of studies relating to conservation.

Scope of the metric survey (non-thematic study) in conservation: recording the 'activities'

Metric surveys are used in conservation to provide a highly complete and reliable set of measured representations. Later, they are used for mapping the actual condition of the monument and its history to understand the relevance of the site and weathering factors affecting its fabric.

The geometry and texture recorded should consist of measured representations displaying masonry details (joinery and material display).

This process is limited not only to offering information prior the works, it is also used in a dynamic process, which involves recording the whole process of conservation.

5.3.3.2 Task definition in conservation of built heritage

The Conservation of Built heritage is developed following a series of work phases, involving '***anamnesis, diagnosis, therapy and controls***' (Searls, C.L., L. Binda, Van Balen, K. et al, 1997, p. 199-221)[22].

> ***Anamsesis*** *(sometimes named analysis) corresponds with the phase of the research to acquire significant data and information on the different dimensions of the heritage. It is essentially multi-disciplinary.*
>
> ***Diagnosis*** *corresponds with the phase of the identification of the values (aspects of authenticity), causes of damage and decay. It is the synthesis of the gathered information and their confrontation. Diagnosis should lead to definition of objectives and aims, based on deliberate and clear choices that on their turn are based on generally accepted restoration principles.*
>
> ***Therapy*** *corresponds with the phase of the choice of the remedial measures and their execution.*
>
> ***Control*** *refers to the phase of checking the efficiency of the interventions. In order to achieve minimal impact on architectural heritage, using funds available in a rational way, it is usually necessary that the study repeat these steps in an iterative process. The different fazes are following each other but frequent*

> *loops to previous phases have to guarantee that each step is only made when enough and validated information is available (Van Balen, K., 2000)[23].*

This research focuses on the 'anamsesis' phase, specifically in the use of a measured dataset (Metric Survey) prepared to record the activities carried out in the study of the building's geometry.

Furthermore, this study deals not only with registering the current state of the building prior to work begins. It also is a dynamic process whereby all the tasks are carried out. It consists of a series of 'Activities' undertaken during the investigation of inaccessible information hidden inside the monument or buried underground.

These tasks or interventions are undertaken when acquiring information on the monument, they may include: (ICOMOS 1990)[24]:

> Differences in material (but may indicate only a repair, or the employment of a material better suited to a particular location in the building).
> Breaks in masonry.
> Adjoining parts of a building structurally independent of each other.
> Differences in wall alignment.
> Differences in wall thickness.
> Differences in structural techniques.
> Stylistic differences in architecture and decoration.
> Evidence for the demolition of part of a building.

Furthermore, these observations can be used for evaluating and correlating the facts in the study of '*documentary sources*' (ICOMOS 1994)[25] by researching documents and analysing the stratigraphy.

'Anamnesis' activities examine works implemented in 'archaeological excavations', as well as the use of semi- or destructive tools when studying the fabric of 'standing structures'.

The registration of these tasks deals not only with acquiring data, but also ensuring that evidence, which may have been removed and possibly destroyed, has been properly recorded.

General Activities

Definition of a 'site reference system' of three-dimensional coordinates (east, north, height), according to local, regional, or universal systems.

Specific activities in archaeological excavations

The registration when metric survey study considers activities in archaeological excavations considers:

Recording the object's and context's geometry and texture prior to, during and following the excavation of a site is carried out, in order to prepare a record, where the 'distinction between horizontal "slices of time" and vertical sequences through time that forms the basis of most excavation methodology '[26] (Renfrew, C. & Bahn, P., 1996, p.97) or also called stratification. It also seeks, to record any disturbances in order not to lose important information and to safeguard evidence of past activity on the site.

The data acquired as a result of this process is used to assess evidence of 'human activities at a particular period in the past; and changes in those activities from period to period'[27] (Renfrew, C. & Bahn, P., 1996, p.97).

Moreover, the metric survey seeks to provide a geographic referential system that is used for comparisons and associations among removable artefacts and structures

found in distinctive parts of the site. The attributes of these elements will also be recorded when dealing with 'aspects of form, style, decoration, colour, and raw material' [28] (Renfrew, C. & Bahn, P., 1996, p.539).

Activities:

Prior to excavation:

Using the 'Site Reference System' as a base, implementing of a 'Site Surface Survey' (Renfrew, C. & Bahn, P., 2000, p.89)[29] for recording under ground deposits, unburied or visible ruins, the landscape, and collecting artefacts, taking into consideration the building's geometry and texture; as well as setting out excavation grids for trenches and recording the position of moveable artefacts.

During excavation:

Recording the different stages of excavation, updating the geometric geometry and texture of immovable object (structures), modifications in the landscape (topography in relation with quantity of earth removed), parts dismantled or removed (artefacts, structures, etc).

After excavation:

Recording the actual state of the uncovered remainings (updating the geometry and texture) and modifications in the landscape (topography).

Specific activities in studying standing structures:

Recording the various stages of work during investigations into the fabric of standing structures is of paramount importance, because it establishes the building phase to ensure 'reversibility' of actions undertaken that *'can be replaced or improved in the future'* (Croci, G., 2000, p.79)[30].

At the same time, areas that might be removed as a result of the ongoing analysis should be recorded.

The removal and subsequent destruction of information should be translated into a permanent record.

Activities:

Prior performing destructive intervention test, partial removal, demolition of 'substantial elements' (Clark, K., 2001, p.41)[31] in the fabric in order to find sources of information:

Prior works:

- Implementation of the 'Site reference system' (defined previously).
- Recording the actual state of the building, including is geometry and texture, especially areas where destructive interventions will be carried out.

During works:

- Recording the different stages of works, registering the geometry and texture of parts being dismantled or removed (structures), and findings (artifacts, structures, etc). As well as, updating the geometry and texture of the object in following its removal.

After works:

- Recording the current state of conservation of the building and context geometry after completion of the works.

The combination of these recorded activities forms the metric survey study, which, in this case, is used during all stages to serve as a 'base data' for the preparation of other thematic studies.

The 'core data' combining the non- and

thematic assessments are used in the following phase of 'Diagnosis', where the analysis and confrontation of the dataset serves to understand the values and dimensions embedded in the monument and it's setting. This synthesis will offer various options to safeguarding the monument's future.

5.3.4 BROADER AUDIENCE PRESENTATION OF BUILT HERITAGE

This application is associated with the preparation of a presentation instrument for enhancing the knowledge of built heritage to a broader audience of people for cultural tourism and promotion.

It is characterized by a photo-realistic display of 3D models of the actual, on-site, situation; as well as, models explaining the historic sequence of events relating to a monument's construction.

This application is crucial, to the study of built heritage. It is a situation where the 'cultural heritage field, we speak of historical value, aesthetic value, and social value –values that contribute to the meaning of these material remains. These values exemplify why we, as individuals and societies, believe that these remains should be stewards for future generations. They are the driving force behind the very definition of these things as "heritage", influencing their interpretation and physical conservation' (Avrami, E., 2000, p.19)[32].

> *'Preservationist should also guard against the pitfalls of creating « instant history, that is, historical reconstructions insufficiently related to the heritage of people, their possessions and the historic sites associated with them' (South, S., 1976, p.40)[33]*

The place of this activity in built heritage applications is based on the idea of presenting a digital or virtual reconstruction or restoration of the monument being studied to a 'specific date or point in time' without actually intervening in the fabric of the building and allowing the visitor to interact with different types of information at the same time without entering in direct contact with them.

In addition, the metric survey study can serve to create virtual displays of a site that cannot be partially or totally visited, because of the level of deterioration, should they be located in remote areas where they have being destroyed. A metric survey study can help avoid huge investments in the protection of a site.

5.3.4.1 Purpose

This application deals with preparing the ground for an 'intelligible' dissemination tool for the general non-specialized public and decision makers (governmental or sponsors).

The tools should be used as an educational instrument, the purpose of which is to enhance the knowledge of a heritage site. A particular application is devoted to so-called 'Heritage tourism' (Godfrey, K., 1998, p.31)[34], which promotes knowledge and the subsequent participation of the community (national or international) and which helps to ensure the protection of built heritage.

<u>Target public in this category</u>

Visitors (the general public): people visiting an interactive, highly visual and three-dimensional representations exhibition.

Politicians, decision makers, investors and promoters: an interactive, visual and two- or three-dimensional representation is prepared for authorities and/or sponsor

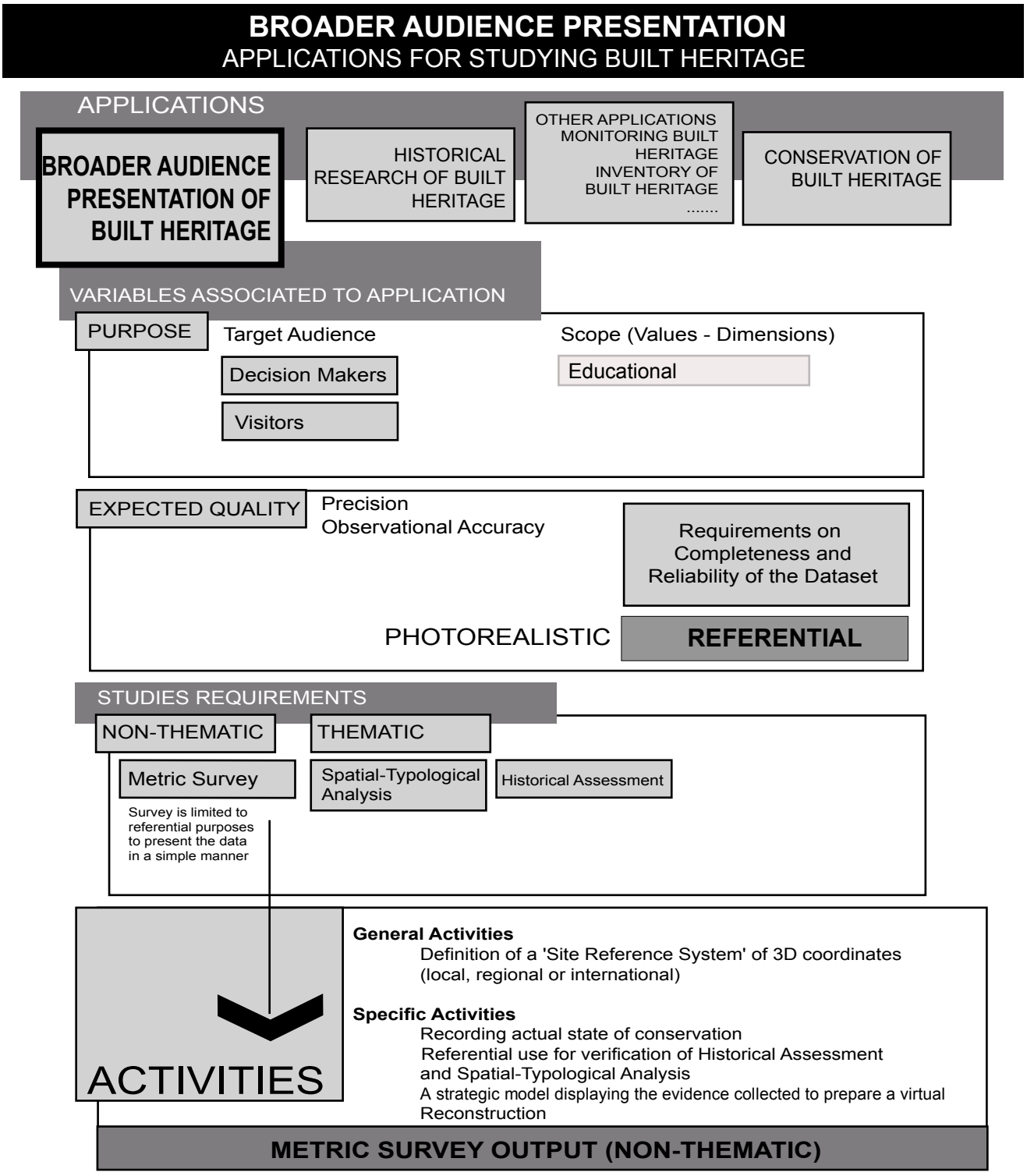


Chart 26: applications: broader presentation of built heritage

dealing with the protection, management and execution of conservation projects.

Scope of the metric survey (non-thematic study) in broader audience presentation of built heritage

In this case, the metric survey studies are used to either create the base data for an independent presentation of the monument

or to develop the site '*as a historical exhibit*' (South, S., 1976, pp39)[35]. Later, this material will be used for producing interpretations about the past.

The dataset should provide a high density of information, so the expert is capable of creating an interpretation based on factual data close to the real geometry of a building. Therefore, making it easier to deduct the historical sequence of construction and modifications to its fabric.

5.3.4.2 Task definition in broader audience presentation of built heritage

The main task of this application is to ensure that the dataset resulting from the metric survey study provides information on the correct correlation between the geometric-texture reality of the site and the 'explanatory exhibition' prepared, even if more emphasis is given to photo-realism, which characterises of these presentations.

In this case, it is possible to approach the different angles through different activities for the metric survey:

General Activities

- Definition of a 'site reference system' of 3D coordinates (local, regional or international)

Specific activities

An actual state of conservation of the subject, including its geometry and texture in order to clarify the level of interpretation when preparing reconstructions.
A strategic model displaying the evidence collected to prepare a virtual reconstruction of the object: based on the historical assessment study.
A realistic reconstruction.

The level of realism in a broader audience application is of importance, but the product of the processing and modelling phase should indicate what is a hypothetical reconstruction, the result of speculation, and what is supported by factual data collected 'in situ'. This allows others to evaluate the results of the reconstruction.

5.3.5 OTHER APPLICATIONS: MONITORING OF BUILT HERITAGE, INVENTORYING BUILT HERITAGE

Inventorying of built heritage: this is a systematic procedure to locate, identify, and record a large number of historic buildings and sites for further protection. The studies carried out during this type of investigation are limited to a rapid-assessment of the subject according to a general framework prepared by specialist before undertaking the inventory. This guide should containing a minimum of characteristics, which describe the sites and should include photography.

> *'The role of inventories in the management of the cultural heritage has long been recognized. They are indispensable, for purposes of identification, protection, interpretation, and physical preservation of movable objects, historic buildings, archaeological sites, and cultural landscapes (Thornes, R. Bold, J., 1998, pp; 1)*[36]

Furthermore, '*documentation should be assembled by both the locally (old photographs, postcards, municipal planning permits etc) and, ideally, regionally and nationally (old maps, general and specialized bibliographies, archives, records, etc)*' (Génicot, L., 1998, p. 10)[37].

This application should be viewed as

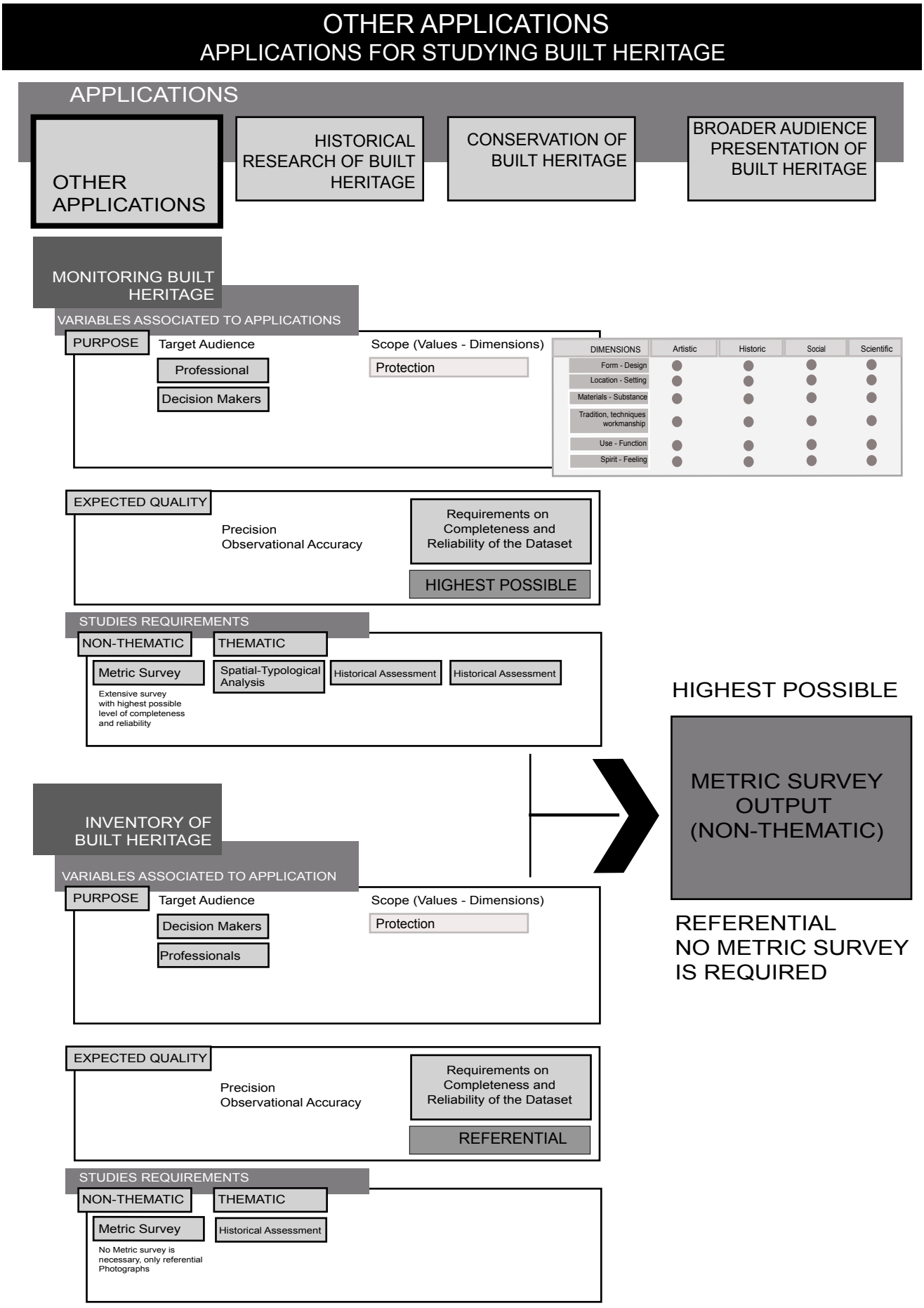


Chart 27: applications: other applications (inventorying and monitoring of built heritage)

a first step towards the identification of monuments in need of conservation, but its intensity should be estimated in terms of the time frame and budget needed to carry out the studies. It also needs to take into account what material is available for study purposes.

Moreover, an intensive investigation based on the objectives of a 'Structural plan' (Génicot, L., 1998, p. 11)[38] following a preliminary inventory on the fabric conservation needs, historical research, or other applications when studying built heritage should be considered before conservation work is carried out.

This 'structural plan' is consider the estimates the extent of the existing heritage of a location, consisting of different levels of priorities.

Monitoring of built heritage: this application evaluates the actual structure of the site being studied, includes the study of '*resistance, stability, and rigidity, very often stability will be the determining criterion*' (Smars, P., Derwael, J. et al, 1998)[39].

Monitoring is implemented by observing the subject's deformation by applying punctual sensors systems for acquiring data on vibrations, foundations, and environmental factors affecting the structure are applied over an extended period of time.

The resulting 'deformation model' and 'Mathematical model' from the sensors provides a picture of what is affecting the structure being studied.

Further, the conclusions of these studies expertise will be able to deduct the need of urgent remedial works or maintenance procedures to conserve the object and to implement a system of regular inspection of the site.

Impact assessment: this application is closely linked to the conservation of built heritage. It is associated with the study of the actual condition of the monument to assess the impact of a restoration project.

5.4 DEFINITION FRAMEWORK: VARIABLES

Variables are filters defining the current situation being studied and the subsequent selection of the type of documentation to be used.

5.4.1 VARIABLES ASSOCIATED TO THE MONUMENT

There are legal aspects, budget available for the metric survey, timing, and the expected quality or '*intensity*' (Boehler, W. Heinz, G., 1999)[40] (quantification) of the project, needs to be taken into account.

5.4.1.1 Accessibility

This variable deals with legal aspects, environmental conditions, and physical problems, which could, when combined, limit the availability of relevant documentation.

Ranging from the access ownership issues to a high level of occlusion, physical boundaries, and the nature of the object's fabric.

Furthermore, legal limitations dealing with the use of a specific technique, such as the use of aerial photography, GPS readings, etc.

5.4.1.2 Budget

The amount of funding available to carry out a metric survey study in a specific application, will influence what technique is selected.

A 'Greater precision requires a quite disproportionately greater amount of work' (Hogg, A., 1980, p. 13)[41] and could imply

higher costs. However, in recent technological developments higher precision might be reached in a shorter time frame. Unfortunately these techniques are expensive.

5.4.1.3 Expected quality

The level of quality deals with the expected completeness and reliability of the representation(s) resulting from the metric survey study, which will be used to compare and map other thematic assessments.

Furthermore, the level of reliability depends on the level of precision and observational accuracy. The later is used to predict any uncertainties when collecting the relative positions of the site's components and its unique characteristics

5.4.1.4 Timing

This variable deals with the time available for on- and off-site work. The selection of a tool for documentation and dissemination is affected by the amount of time available for performing the task.

5.4.1.5 Expertise

Expertise deals with the skills and experience required to operate the documentation tool selected and the 'interdisciplinary' participation required for analysing the results of the metric survey study.

A lack of experience will affect the 'rate of progress' (R.E.A., 1993, 4-5)[42] of the survey.

5.4.1.6 Quantification

This variable deals with quantifying the density of work required to produce the set of representation composing the metric survey Study.

5.4.1.7 Other variables

Other filters associated with specific problems of the site being studied.

5.4.2 VARIABLES ASSOCIATED TO THE METRIC SURVEY TOOL

These variables relate to the use of tools to collect, analyse, and disseminate data. The combination of the tool and monument's variables provides the guidelines for the selection of a technique(s).

This list of variables should be used as a guideline to evaluate the selection of the most convenient combination of tools. Nevertheless, this evaluation should be carried out based on previous knowledge of the variables associated to the site and requirements of the metric survey study.

5.4.2.1 Speed

The speed is expressed in terms of the time that it takes a tool to perform a measurement records (points, vectors, photographs, etc) in a specific period of time (second, minutes, hours, days, etc.). As well as, the time required for work off- and/or on-site.

5.4.2.2 Precision

Precision is expressed in the accuracy (distance, position, and angle measurement) of a single measurement recorded or a combination of measurements recorded.

5.4.2.3 Measuring Range

The range is associated with the maximum distance capacity of the tool to collect a measurement record.

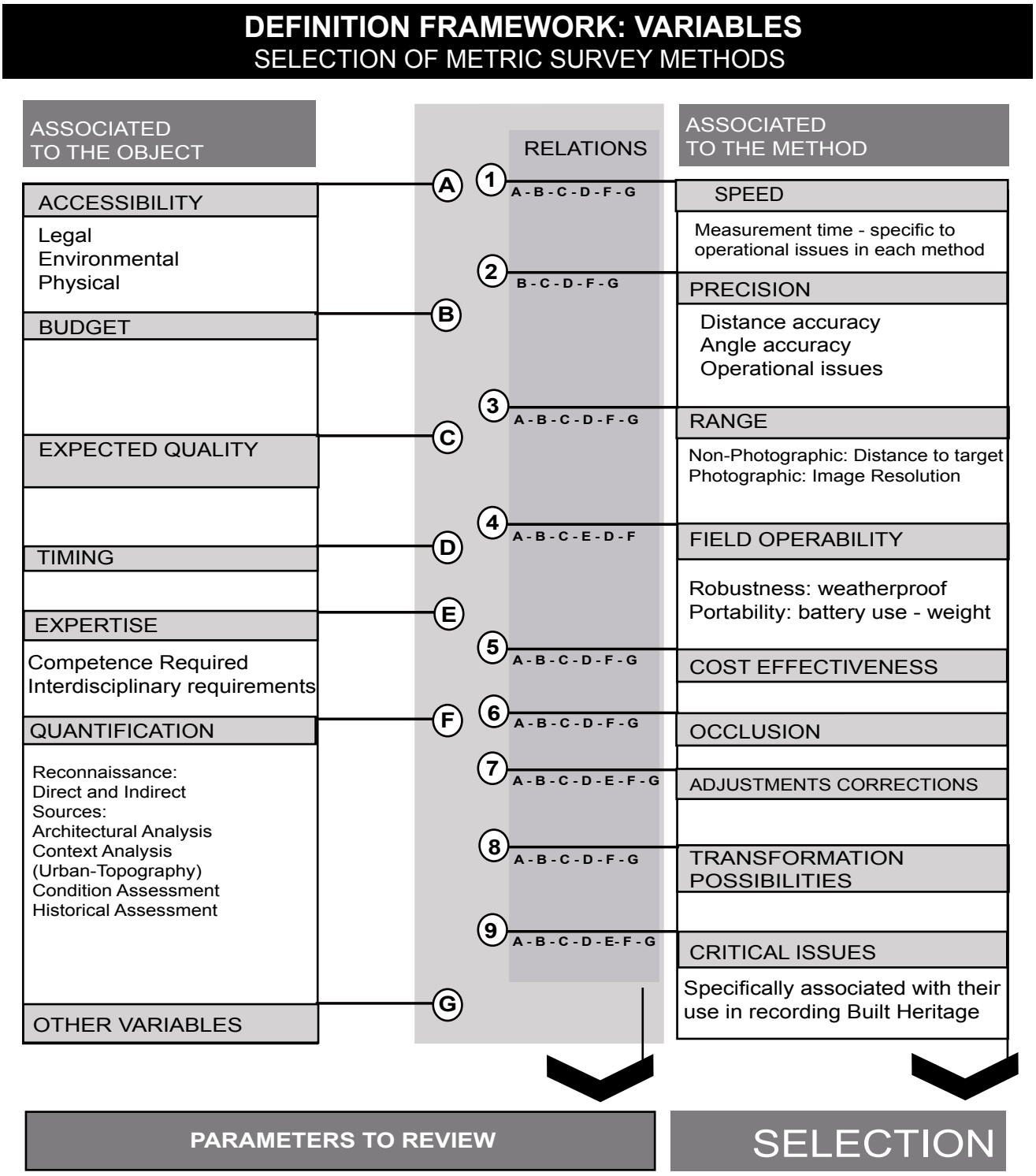


Chart 28: variables - definition framework

5.4.2.4 Field operability

The capacity of a tool to be transported and its robustness to operated under extreme atmospheric conditions. As well as, the available local facilities requirement to ensure proper performance and the effects of the 'adjustments and corrections' (Hewitt, R., 1976, p. 81)[43] required when operating in the field.

Robustness

Deals with the actual instrument's weight, sensitivity to atmospheric conditions, such as temperature, rain, humidity, sunlight, and

illumination. As well as, sensitivity to unstable floors (vibration).

Portability

Deals with the level of portability, independent operating time (power supply: batteries), fragility, and weight when transported.

Adjustment and corrections

The procedures required to adjust the instrument each time it is used will have an impact on the selection of the tool. This field also deals with the variable 'expertise' mentioned in variables associated to the object. This type of adjustment should be controlled and repeated during the whole process of surveying.

Furthermore, corrections will deal with adjustments dealing with atmospheric conditions.

5.4.2.5 Cost effectiveness

The budget of a tool is considered by the relation between the cost of the equipment and the cost of the operation. The equipment cost is related to the unit price.

Similarly, the operation cost deals with the speed, robustness, occlusion operability, and precision in collecting measurements. This record can be a vector, point, orthographic texture, or 3D textured map.

5.4.2.6 Occlusion

This variable deals with the tool operability in areas with severe occlusion from vegetation, urban characteristics, lighting, and other variables affecting the collection of measurements records.

5.4.2.7 Transformation possibilities (Lagerqvist, B., 1996, p.35)[44]

This variable relates to the degree of transformation of the dataset acquired by the tool to be used in different applications. It 'Implies the possibility to let the data from one recording technique, be used without loss of information within frames of other techniques' (Lagerqvist, B., 1996, p.35)[45].

Furthermore, it deals with the potential of storage, retrieval, and conversion of the stored media of the dataset to be read in future by other devices.

5.4.2.8 Other critical issues dealing with documenting Built heritage

Among other critical variables associated with documenting built heritage are problems dealing with instruments having a poor response to construction materials, weathering forms and the safety of the operator to use an instrument.

5.4.3 COMPARISON AND EFFECTS OF VARIABLES

In principle all the combination of parameters from both the monument and tool's variables will yield restrictions to the selection of a metric survey tool(s).

However, a number of relations can be subtracted from the combination of the variables in both subjects.

Accessibility: this has effects is most of the variables associated to the operation and therefore selection of the tool, however it does not have a relevant role in the specification of the 'precision' has other variables such as the expected quality, quantification or the budget available.

Budget, expected quality, timing, expertise available, and quantification: these variables will yield effects in all the parameters for selecting the tool, because they are directly linked with the operational issues of the instruments chosen.

Expertise: although this attribute has possible effects in all variables, especially in those dealing with operational issues. Its influence has the most impact on:

- Field Operability: dealing with the level of expertise required to implement the tool on- and offs-site in an effective manner or the time required to understand the use of the instrument.
- Adjustments and corrections: dealing with the expertise required by an ability of the operator to carry out the number of procedures to apply the tool correctly.
- Critical Issues: this issue goes beyond the knowledge of adjustment and corrections to use correctly the tool, but includes the expertise needed to wisely apply the tools to yield effective results adequate to the needs of studying built heritage.

5.5 SELECTION FRAMEWORK: METRIC SURVEY TOOLS

A general explanation of 'state of the art' technology for surveying buildings has been presented in Chapter III. The contribution of this research is to integrated and described these 'tools' as a technique rather than isolated instruments.

A technique combines the use of surveying instruments (collection), processing tools (analysis), and representation tools (synthesis).

Furthermore, this research presents an overview of all the available techniques with an emphasis on those which are effective in providing three-dimensional measurements for studying built heritage, reviewing the potential and limitations of each of them and proposing adaptive measures to improve their performance.

The selected tools are:

Electronic distance measure instruments: point collection and tracing
Reflectorless electronic distance measure instruments: point collection and Tracing
Terrestrial long-range three-dimensional mapping or scanning
Plane parallel photographic rectification
Close-range digital photogrammetry (stereo and bundle restitution)
Automatic 3D geometric and textured model generation from images

5.5.1 GENERAL GUIDELINES

The instruments exposed in this research are associated to the use of 'Plane Survey' (R.E.A., 1993, p. 1)[46], which assumes that the surface of the earth is plane. It is important to remember that this type of survey is used for relatively small areas. When the survey size is increased, the precision will drop considerably.

All the tools described deal with specific deductive mechanism to extract and define a selected number of measurements to define an architectural entity. The degree of measurement density acquired is based on the morphological characteristics (regularity and depth) of the shape collected and the level of detail required.

Finally, tools such as Aerial Photogrammetry or remote sensing from satellite are not covered by this research.

5.5.2 CLASSIFICATION

The use of documentation and dissemination tools in recording built heritage can be classified using different characteristics, ranging from the following parameters:

- Classified by product delivered (3D output: vectors, points or textures)
- Classified by performance (speed, precision, field operability)
- Classified by cost

However, they should be classified by combining the different characteristics in order to find the best, most efficient tool in its totality, possibly by classifying them in terms of delivery and performance when recording built heritage.

The idea exposed above is obviously very complex and aleatory considering that each subject has a different reality and context. Therefore a preliminary classification is presented in the following chart. Further, in the complementary explanations presented are based on the on-site performance. In relation with the level of engagement or contact required with the subject's fabric and the extent of fieldwork time required for recording.

Moreover, direct and indirect tools are differentiated by the level of intervention of the operator in making decisions concerning of the subject's geometry and texture to implement the survey and the product delivered.

Subsequently, these two branches, direct and indirect recording, are divided in non-photographic techniques (or measured building survey) and photographic techniques (or image-based techniques).

5.5.3 TOOLS FOR METRIC SURVEY STUDY

5.5.3.1 Direct survey techniques

Non-Photographic

These tools are characterized by their ability to offer geometric information about the building. Textured mapping is executed by colouring the vectored and wire frame models prepared.

Conventional hand-survey (digital or analogue)

Conventional hand-survey tools are associated with the use of instruments such as steel tape, calliper, plumb, and other analogue-optical devices, such as theodolithes and levels, as well as, complementary structures, such as scaffolding to cover the entire subject's fabric. These tools have already been explained in Chapter III, although they are covered in the chart, they will not be discussed here.

They are characterized by a limited range, time constraint and without specialized knowledge they are ineffective. However, the level of engagement with the fabric is remarkable, because the operator experiences the conception directly by observing and recording the fabric. This contribution should not be ignored by the use of more advance tools but integrated into the control and improvements of the measurements prepared.

Analytical sketching is integrated in this tool and should be considered by other tools used for understanding the fabric of the building.

GPS (Global positioning systems) point collection

These tools are used in collecting measurements by sophisticated or hand-held global positioning system receivers. These systems are largely used for large areas of

terrain; they are limited to outdoor use (for satellite capture). Their precision can range from centimetres to meters. In studying built heritage (close-range application) their use is advisable in order to define the location and orientation of the site reference system.

Electronic distance measurement (EDM) point collection

This tool uses an 'electronic distance measurement' device also called 'total station' for data-collection, which is capable of recording measurements by projecting an infrared beam to a reflective prism rod (reflector).

This action permits the machine to calculate the three-dimensional co-ordinates of a point using the geodetic information recorded, which includes the horizontal and vertical angles, horizontal and absolute distance to the measurement, and the different of heights between the station and the targeted point.

The phase of work of this tool consists of: data-collection, data-processing, verification and exporting.

Example of the field application of this technique can be found in the case study dealing with al-Baleed archaeological park (chapter I-part II).

Data-collection: involves preparing a network of fixpoints (bench-mark or standpoint), which covers the entire site to establish a 'site reference' system.

Later, the network points are measured and a least square calculations performed for increasing the precision of the fix points.

Once the EDM device has been properly levelled to a fixpoint measuring point and orientated using a base bearing angle to a second known station from the network just created, recording starts by defining and measuring a series of points (density of the survey) aimed at defining the targeted entity for the further processing of off-site work. These measurements are stored in the memory of the machine and later transferred to the computer off-site.

Furthermore, a sketch or photographs of the site should be prepared to mark the measurements made with the instruments, the marking should correspond to the Point ID (alphanumeric or numeric characters) inserted into the memory of the machine. In more advanced applications a code can be assign to the Point ID that will be later interpreted be the CADR application to produce a 3D vector.

Data-processing: the measured points stored in the memory of the Total Station are transferred to the computer using communication software that delivers them into different formats containing 3D coordinates that can be read by a CADR or DTM application (e.g. DXF).

Subsequently, this cloud of points is identified in the CADR application space and 3D vectors are used to define the targeted entities conforming the subject.

In more advanced applications, the readable coordinate file format contains codes appointed and predefined previously to the survey that can be read by the CADR and DTM application and generate automatically vectors connecting the points measured.

The resulting product is a wire frame of vectors and points that can be further used in photographic techniques, such as rectified photography to further digitise the geometry of the object.

Verification: the processes of controlling the measurements can be performed by checking the output on-site and using analogue theodolithe or photogrammetry.

ELECTRONIC DISTANCE MEASUREMENT - DIRECT SURVEY METHODS

(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: POINT COLLECTION

PROCESS

1 DATA-COLLECTION

SITE REFERENCE

A set of Fix points are defined covering the whole site, they are accordingly measured and 'least square calculations are used to increase the precision of the network

MEASURING ENTITIES

A number of measurements are executed, taking into consideration the quality requirements of the survey (point density) Simultaneously the points surveyed are marked in a sketch or photographs of the subject being studied, each surveyed point should have a Point identification

ON-SITE WORK

Points stored in the EDM's memory are transfered to the computer

2 DATA-PROCESSING: CONSTRUCTING A WIREFRAME AND TOPOGRAPHIC MODEL

(1) The point of clouds acquired from the EDM device is processed by linking points with 3D vectors defining the different targeted entities (this process can be automatic if measurements codes are used.
(2) Terrain measurements are used to create a Digital Elevation Model

3 VERIFICATION

(1) The resulting wire frame and Digital Elevation Model is verified 'in-situ', modification and corrections are introduced by adding more measurements

4 RESULTS

(1) A 3D points wireframe of Vector to be exported to the CADR application for further processing work
(2) A 3D Digital Elevation Model (contour lines and/or 3D mesh)

EXPORT TO OTHER APPLICATIONS

INSTRUMENTS

EDM DEVICE

PRECISION		PRICE
HIGH	Projecting an Infrared beam to a prism rot	+++++
MID		+++
LOW		++

PROCESSING APPLICATIONS

TYPE		
PROFESSIONAL	Computer Aided Drafting Application	++++
MID-RANGE		++
LOW-END		+

TYPE		
PROFESSIONAL	Digital Terrain Modeler Application	++++
MID-RANGE		++
LOW-END		+

PRODUCTS

GEOMETRIC DATA: WIREFRAME: POINTS AND VECTORS AND DIGITAL ELEVATION MODEL (CONTOUR LINES AND/ OR A 3D MESH

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Average 0,15 p/s Depends on speed operator - eng.time	~0.01 - mm. Depends on correct visualisation of the targeted point	2 - 5000 m. High areas are difficult to measure, where the operator does	Robust , need 2 operators Highly Portable on-site Involves extended off-site work and verification only on-site	Advanced Knowledge of surveying	Output is produce in a compatible format: (1) ASCII list of coordinates (2) CADR format

BUDGET	OCCLUSION
In Average Suistanable	Multiple Measuring Positions are required to overcome obstacles high areas are difficult to measure (see range)

CRITICAL ISSUES DEALING WITH BUILT HERITAGE

Time Consuming
Generally the precision and observational accuracy depends in the density points collected on-site
The data collected is generally limited (time constraint)
The range in High points is limited to the hand of the operator holding the prism rot
Suitable for topographic and archaeological sites documentation

SUMMARY

THIS METHOD IS SUITED FOR RECORDING ARCHAEOLOGICAL SITES AND FOR MAPPING TOPOGRAPHY
IT IS NOT ADEQUATE FOR STANDING STRUCTURES IF IT IS NOT USE IN COMBINATION WITH OTHER PHOTOGRAPHIC METHODS

Chart 29: EDM point collection - process

Improving the survey's data can be perform by adding a higher density of point collected, with more measurements in situ or by implementing complementary techniques.

Exporting: the output consists of a 3D point cloud and wire frame CADR drawing format and a 3D digital elevation model (contour lines and/or 3D mesh) if a DTM application is used.

Furthermore, an ASCII file containing a list of coordinates from the measured records can be obtained.

Variables associated to the use of Electronic Distance Measurement (EDM) Point Collection tool

Speed: the speed of a system is associated with the time that it takes a person holding the prism rod to reach the desired measurement, the operator to find the point with the telescope, mark the point in the referencing sketch, and the actual engineering time it takes the machine to collect the measurement. This can vary from case to case; a referential time has been suggested by Addison, A. and Gaiani, M. of 0,15 point/second[47]

Precision: this can range from between 0.005 m. to 0.05 m. for point acquired. Nevertheless the precision can be affected by the levelling when using a prism rod to measure a point in the ground.

Measuring Range: the range is limited by two factors. The first factor deals with the physical range of the device, normally up to 2 to 5 km. On the other hand, range can be associated with the actual reach of a higher point with the prism rod.

Field operability (Robustness and Portability): An important feature of these tools is that they require at least two people '*to operate them effectively--a transit operator and someone to mark a*

EDM POINT COLLECTION METHOD

PROCESS EXAMPLE

PROCESS:

A useful number of Measurements are recorded of the object using the EDM device, these records are documented in a sketch for further processing



The measurements are use to defined vectors representing the entities recorded. The topographic records are used to calculate a DEM and contours lines are generated.

Archaeological excavation
House L. 930, al-Baleed, Oman

Figure 45: EDM point collection - example. Author.

REFLECTORLESS ELECTRONIC DISTANCE MEASUREMENT - DIRECT SURVEY METHODS

(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: POINT COLLECTION

PROCESS

1 DATA-COLLECTION

SITE REFERENCE

A set of Fix points are defined covering the whole site, they are accordingly measured and 'least square calculations are used to increase the precision of the network

MEASURING ENTITIES

A number of measurements are executed, taking into consideration the quality requirements of the survey (point density) Simultaneously the points surveyed are marked in a sketch or photographs of the subject being studied, each surveyed point should have a Point identification

ON-SITE WORK

Points stored in the REDM's memory are transfered to the computer

2 DATA-PROCESSING: CONSTRUCTING A WIREFRAME AND TOPOGRAPHIC MODEL

(1) The point of clouds acquired from the EDM device is processed by linking points with 3D vectors defining the different targeted entities (this process can be automatic if measurements codes are used.
(2) Terrain measurements are used to create a Digital Elevation Model

3 VERIFICATION

(1) The resulting wire frame and Digital Elevation Model is verified 'in-situ', modification and corrections are introduced by adding more measurements

4 RESULTS

(1) A 3D points wireframe of Vector to be exported to the CADR application for further processing work
(2) A 3D Digital Elevation Model (contour lines and/or 3D mesh)

EXPORT TO OTHER APPLICATIONS

INSTRUMENTS

REDM DEVICE

Projecting an Infrared beam to a prism rot or directly a laser beam to the surface

PRECISION/ RANGE	PRICE
HIGH	+++++
MID	+++
LOW	++

PROCESSING APPLICATIONS ++++

Computer Aided Drafting Application

TYPE	
PROFESSIONAL	++
MID-RANGE	+
LOW-END	

Digital Terrain Modeler Application

TYPE	
PROFESSIONAL	++++
MID-RANGE	++
LOW-END	+

PRODUCTS

GEOMETRIC DATA: WIREFRAME: POINTS AND VECTORS AND DIGITAL ELEVATION MODEL (CONTOUR LINES AND/ OR A 3D MESH

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Average 0,15 p/s Depends on speed operator - eng.time	~0.01 - mm. Depends on correct visualisation of the targeted point	2 - 5000 m. EDM 2 - 200 m. REDM	Robust Highly Portable on-site Involves extended off-site work and verification only on-site	Advanced Knowledge of surveying	Output is produce in a compatible format: (1) ASCII list of coordinates (2) CADR format

BUDGET	OCCLUSION
In Average Suistanable	Multiple Measuring Positions are required to overcome obstacles high areas are difficult to measure (see range)

CRITICAL ISSUES DEALING WITH BUILT HERITAGE

Time Consuming
Generally the precision and observational accuracy depends in the density points collected on-site
The data collected is generally limited (time constraint)
The range is limited to the reflectorless mode and it is sensitive to the material brightness
Suitable for any application in recording built heritage

SUMMARY

THIS METHOD IS SUITED FOR ALL APPLICATIONS IN RECORDING BUILT HERITAGE
GOOD RESULTS CAN BE ACHIEVE IF IT IS USE IN COMBINATION WITH OTHER PHOTOGRAPHIC METHODS

Chart 30: REDM point collection - process

point, or hold a measuring tool or prism rod in alignment with the telescope' (HAER, 2000)[48], the collecting work is carried out mostly on-site.

EDM devices are normally robust against extreme environmental conditions (rain, heat, etc). They can operate in bright sun light. Extreme care should be taken with the telescope in case of direct sun light. More advanced machines have integrated a thermometer to compensate for variations in temperature. If this is not available the temperature and air pressure should be indicated when measuring.

Furthermore, they are portable and can be operated using batteries for an extended period of time.

Adjustment and corrections: advanced knowledge of surveying is required for correct levelling and for orientating the instrument. Also require is, the use of least square calculations to increase the precisions of the network of points in the 'site reference' system.

Cost effectiveness: the most common use electronic distance measurement device can cost around 4000 Euros. The cost effectiveness of these systems is measured in terms of range, precision, memory, and robustness.

Occlusion: multiple measuring positions are required to overcome obstacles and to cover the site; high areas are difficult to measure (see measuring range).

Transformation possibilities: the measurements output is produce in various standard formats, such as ASCII list of coordinates and DXF. Furthermore, a wire frame model and digital elevation representation can be exported in very common CADR formats. The data can be modified only by the collection of complementary points on-site.

Other critical issues dealing with documenting built heritage:

- It is a 'time consuming' technique, where the operator is confronted to the judgement of selecting each point to record.
- Generally the precision and observational accuracy depends on the density of points collected on-site.
- The data collected is generally limited and time consuming.
- The range in High points is limited to the hand of the operator holding the prism rod.

It is suitable for topographic and archaeological site documentation.

Summary in the use of Electronic Distance Measurement (EDM) Point Collection

This tool is suitable for recording archaeological sites and for mapping topography. It is not adequate for standing structures if it is not used in combination with other photographic tools.

Reflectorless Electronic Distance Measurement devices (Point collection or tracing)

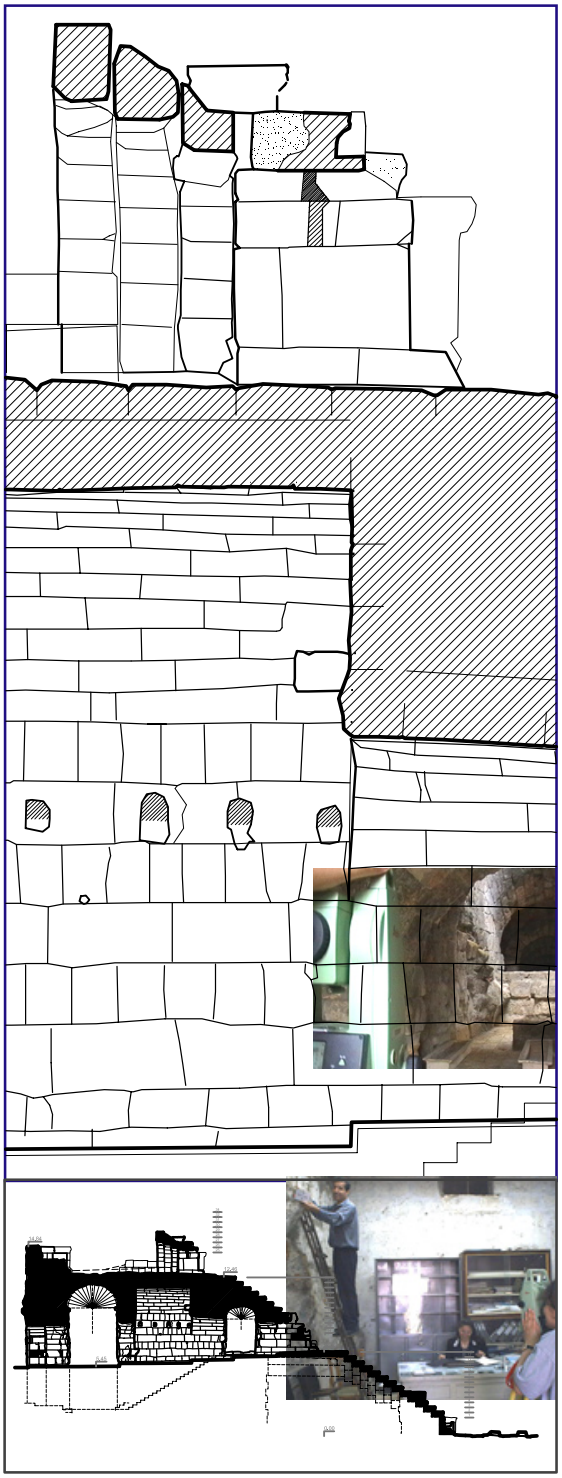
A 'reflectorless electronic distance measurement' device or 'total station' provides the traditional measurements 'mode' by projecting an infrared beam to a prism rod (reflector), as well as the reflectorless 'mode' by projecting a laser beam to a surface up to 80-200 m. from it.

A REDM device or total station operates without the use of a reflector and *'has the advantage of rapid targeting and access to remote targets*' (Clark, K., 2001, p.82)[49].

REDM POINT COLLECTION METHOD

PROCESS EXAMPLE

A useful number of Measurements are recorded of the object using the Reflectorless EDM, these records are documented in a sketch for further processing



The measurements are use to defined vectors representing the entities recorded. The topographic records are used to calculate a DEM and contours lines are generated.

Conservation of Built Heritage
Section - Cavea, Roman Theatre Jebleh, Syria

Figure 46: REDM point collection - example. Section by T. Stevens. Author.

Furthermore, this action permits the machine to calculate the three-dimensional co-ordinates of a point using the geodetic information recorded, which includes the horizontal and vertical angles, horizontal and absolute distance to the measurement, and the different heights between the station and the targeted point.

Reflectorless Electronic Distance Measurement (REDM) Point Collection

In this application a 'reflectorless electronic distance measurement' device or 'total station' is used to record points in order to define an entity.

An example of the field application of this technique can be found in the case studies dealing with the restoration of the roman theatre of Jebleh-Syria (chapter II-part II) and the use of metric survey tools in urgent recording at the Mussalah Complex Site in Herat and Minaret Jam – Afghanistan (chapter V-part II).

The phase of work of this tool consists of: data-collection, data-processing, verification and exporting.

Data-collection: involves preparing a network of fixpoints (bench-mark or standpoint) covering the entire site to establish a 'site reference' system.

Subsequently, network points measured and a least square calculations are performed for increasing the precision of the fixpoints.

After the REDM device is properly levelled to a fixpoint measuring point and orientated to a the base bearing angle to a second known station from the network just created, recording starts by defining and measuring a series of points (density of the survey) aimed at defining the targeted entity for further processing off-site work. These measurements are store in the memory of the machine and later transfer to

the computer off-site.

Furthermore, a sketch or photographs of the situation should be prepared to mark the measurements, the machine permits the operator to insert a Point ID (alphanumeric or numeric characters) or in more advanced applications a code.

Data-processing: the measured points stored in the memory of the Total Station are transferred to the computer using communication software that delivers them into different formats containing 3D coordinates that can be read by a CADR or DTM application (e.g. DXF).

Subsequently, this cloud of points is identified in the CADR application space and 3D vectors are used to define the targeted entities conforming the subject's geometry.

In more advance applications, the readable coordinate file format contains codes appointed and predefined previously to the survey that can be read by the CADR and DTM application, in order to generate automatically the vectors connecting the measurements and produce a wireframe.

The resulting product is a wire frame of vectors and points that can be further used in photographic techniques, such as rectified photography to further digitise the geometry of the object.

Verification: the processes of controlling the measurements can be performed by checking the output on-site and using analogue theodolithe or photogrammetry techniques

The improvement required to the dataset of the survey can be performed by adding a higher density of point collecting adding more measurements in situ or implementing complementary techniques.

Exporting: the output consists of a 3D point cloud and wire frame CADR drawing format and a 3D Digital Elevation Model (contour lines and/or 3D mesh) if a DTM application is used.

Furthermore, an ASCII file containing of a list of coordinates from the measured records can be obtained.

Variables associated to the use of Reflectorless Electronic Distance Measurement (REDM) Point Collection tool

Speed: the speed of a system is associated with the time that takes the operator to find the point with the telescope, mark the point in the referencing sketch, and the actual engineering time it takes the machine to collect the measurement. This can vary from case to case; a referential time has been suggested by Addison, A. and Gaiani, M. of 0,15 point/second[50]. The speed can be affected by the brightness of the material being surveyed.

Precision: it can range between 0.005 m. to 0.05 m. in acquisition of points, however the precision can be affected by the correct instrument set-up and the accurate selection of the point to be measured by looking at the telescope.

Measuring Range: deals with the physical range of the device, normally up to 2 to 5 km in infrared mode and from 2 to 200 m. in laser mode (reflectorless).

Field operability (Robustness and Portability): An important feature of these tools is that it can be operated with only one person, the collecting work is carried out mostly on-site.

REDM devices are generally speaking robust and can withstand extreme environmental conditions (rain, heat, etc). They can operate in bright sun light. Extreme care should be taken with the telescope in case of direct

sun light. More advanced machines have integrated a thermometer to compensate for variations in temperature. If this is not available the temperature and air pressure should be indicated when measuring.

Furthermore, they are portable and can be operated using batteries for an extended period of time.

Adjustment and corrections: advanced knowledge of surveying is required for correct levelling and for orientating the instrument. Also require is, the use of least square calculations to increase the precisions of the network of points in the 'site reference' system.

Cost effectiveness: the most common use reflectorless electronic distance measurement device can cost around 7000 Euros. The cost effectiveness of these systems is measured in terms of reflectorless range, precision, memory, and robustness.

Occlusion: multiple measuring positions are required to overcome obstacles and to cover the site; high areas are difficult to measure (see measuring range).

Transformation possibilities: the measurements output is produce in various standard formats, such as ASCII list of coordinates and DXF. Furthermore, a wire frame model and digital elevation representation can be exported in very common CADR formats. The data can be modified only by the collection of complementary points on-site.

Other critical issues dealing with documenting built heritage:

- It is a 'time consuming' technique, where the operator is subjected to chose and records each point.
- Generally the precision and observational accuracy depends on the density points collected on-site and the adequate selection of measurements to define the entities.
- The data collected is generally limited (time constraint).
- The range of the laser-measuring tool might be affected by the reflective properties of the material.

<u>Summary on the use of Reflectorless Electronic Distance Measurement (REDM) Point Collection</u>

This tool is suitable for all applications in recording built heritage. Better results are expected if it is used in combination with photographic tools.

<u>Reflectorless Electronic Distance Measurement (REDM) Tracing</u>

This tool uses the REDM Total Station as a tracing device by linking the device directly to a CADR application 'on-site'. A portable computer equipped with a drafting tool or tracing plug-in application working with the CADR software is used.

Furthermore, this tool allows the operator to execute all the common features of a total station, such as instrument set-up, traverse (least square calculations), and all the commands available in the CADR application and that in combination can be used to generate a wire frame of vectors and points.

The case study dealing with experiences in training architectural-conservators in the use of metric survey methods: master students at the R. Lemaire International Centre for Conservation, Almaty Workshop (Republic of Kazakhstan), Sanchi Workshop (India), and Université d'été in Chinon (France) (chapter III-part II) presents some examples of the use of this technique in recording historic buildings.

REFLECTORLESS ELECTRONIC DISTANCE MEASUREMENT - DIRECT SURVEY METHODS

(NON-PHOTOGRAPHIC) **-** METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: TRACING

PROCESS

1 DATA-COLLECTION AND PROCESSING

SITE REFERENCE

A set of Fix points are defined covering the whole site, they are accordingly measured and 'least square calculations are used to increase the precision of the network

MEASURING ENTITIES

Instrument setup is performed using the Tracing Software
The REDM instrument is linked to a Portable computer equipped with a CADR software and in combination with the Tracing application:
A wireframe of vectors defining the targeted entities is recorded by measuring points (selecting the line command) in the fabric of the building

ON-SITE WORK

2 VERIFICATION

(1) The resulting wireframe of vectors is optimized using the CADR
(2) The resulting wire frame and Digital Elevation Model is verified 'in-situ', modification and corrections are introduced by adding more measurements

3 RESULTS

A 3D wireframe of Vectors to be exported to the CADR application for further processing work

EXPORT TO OTHER APPLICATIONS

INSTRUMENTS

REDM DEVICE

PRECISION/ RANGE		PRICE
HIGH	Projecting an Infrared beam to a prism rot or directly a laser beam to the surface	+++++
MID		+++
LOW		++

PORTABLE COMPUTER

PORTABILITY		PRICE
HIGH	For carrying the CADR and Tracing application	+++++
MID		+++
LOW		++

PROCESSING APPLICATIONS

TYPE		
PROFESSIONAL	Tracing Plugin for a CADR application	++

TYPE		
PROFESSIONAL	Computer Aided Drafting Application	++++
MID-RANGE		++
LOW-END		+

TYPE		
PROFESSIONAL	Digital Terrain Modeler Application	++++
MID-RANGE		++
LOW-END		+

PRODUCTS

GEOMETRIC DATA: WIREFRAME: POINTS AND VECTORS

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Average 1 p/s	~0.01 - mm. Depends on correct visualisation of the targeted point	2 - 5000 m. EDM 2 - 200 m. REDM	Robust Portable on-site Involves extended on-site work	Advanced Knowledge of surveying	Output is produce in a compatible format: CADR drawing format

BUDGET	OCCLUSION
In Average Suistanable Depends in the relation Precision/ Range and portability of the portable computer	Multiple Measuring Positions are required to overcome obstacles high areas are difficult to measure (see range)

CRITICAL ISSUES DEALING WITH BUILT HERITAGE

Time Consuming
Generally the precision and observational accuracy depends in the density points collected on-site
The data collected is generally limited (time constraint)
The range is limited to the reflectorless mode and it is sensitive to the material brightness
Suitable for any application in recording built heritage, results are produce on-site

SUMMARY

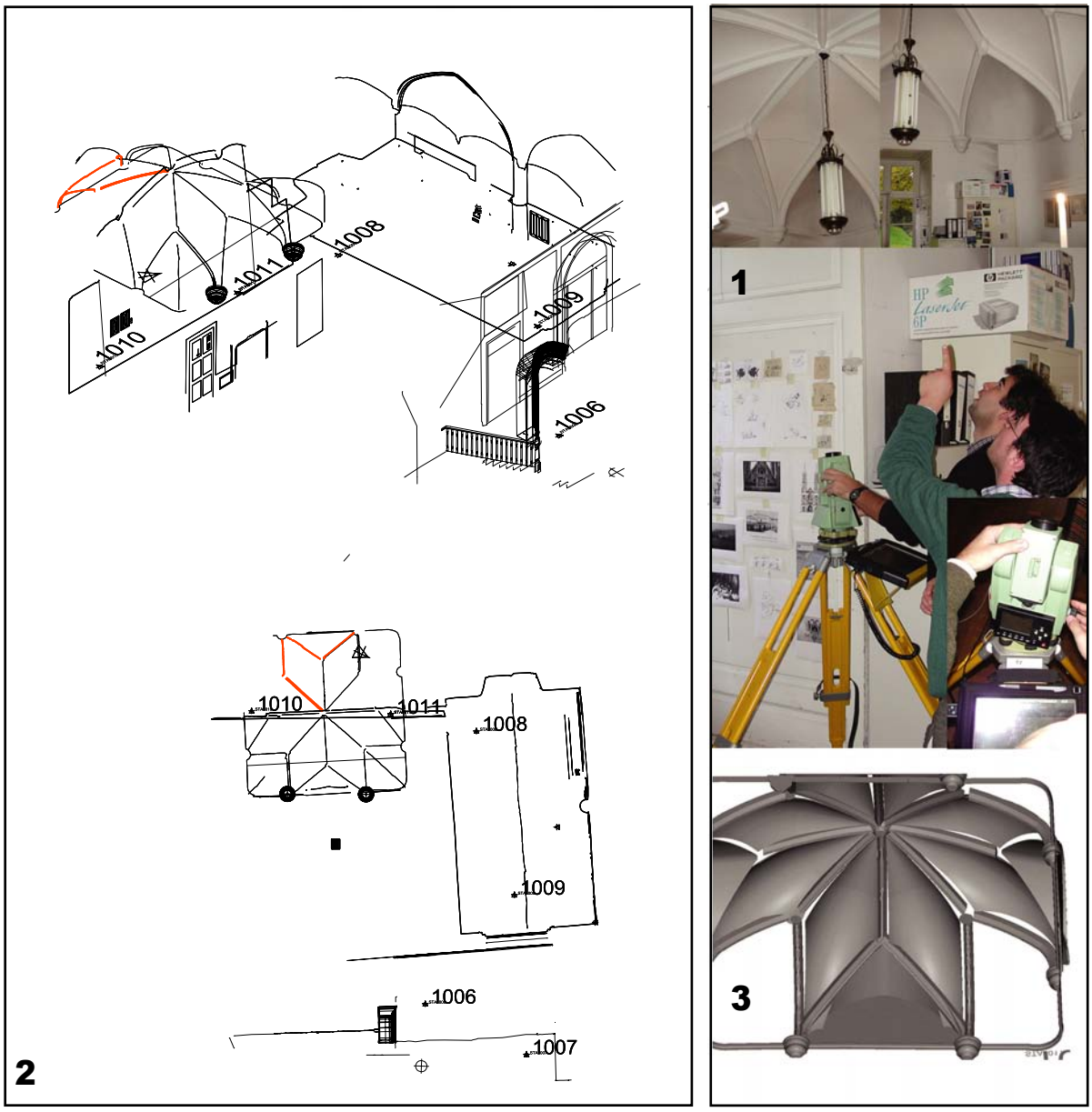
THIS METHOD IS SUITED FOR ALL APPLICATIONS IN RECORDING BUILT HERITAGE
GOOD RESULTS CAN BE ACHIEVE IF IT IS USE IN COMBINATION WITH OTHER PHOTOGRAPHIC METHODS

Chart 31: REDM tracing - process

REFLECTORLESS ELECTRONIC DISTANCE MEASUREMENT - DIRECT SURVEY METHODS
(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE
METHOD: TRACING

EXAMPLE

Instrument setup is performed using the Tracing Software The REDM instrument is linked to a Portable computer equipped with a CADR software and in combination with the Tracing application (1).
A wireframe of vectors defining the targeted entities is recorded by measuring points (selecting the line command) in the fabric of the building (2).



A 3D Solid model can be created, using as base data the wireframe prepare by the Tracing method (3)

Chart 32 REDM tracing - example. Author.

This tool is developed in three phases of work: data-collection and processing, verification and exporting. This tool involves mostly an on-site work.

Data-collection and processing: this tool saves time, acquisition and processing is real-time performed, since the result can be visualized in the screen of the portable computer.

Depending on the different needs mentioned

previously, the first part of this tool involves preparing a network of fixpoints (bench-mark or standpoint), which covers the entire site to establish a 'site reference' system.

Subsequently, the network points are measured and a least square calculations performed for increasing the precision of the fixpoints.

After the REDM device is properly levelled to a fixpoint measuring point and orientated using as the base bearing angle to a second known station from the network just created and using the tracing plug-in features, the recording starts by collecting segments (vectors), which are defined by measuring a series of points (density of the survey).

These measurements are transferred and fed real-time directly into the CADR application. Editing, transformation, and corrections can be made immediately allowing for the instant visualization of the site's measurements.

Furthermore, either a sketch or photographs of the site should be prepared for complementary control when checking the results off-site. Measured sketches and plane parallel photographs can be made which in turn can be further integrated into the CADR drawing.

Verification: the processes of controlling the measurements can be perform by checking the output on-site through the use of analogue theodolithe or photogrammetry.

Complementary measurements, modification, and corrections should be executed 'in-situ'.

The resulting product is a wire frame of vectors and points that can be use in combination with other non-photographic and photographic techniques, such as measured hand-survey of the site's features and rectified photography to further digitise the geometry of the building.

Data obtained from the sources can be performed by adding a higher density of point collecting more measurements in situ or implementing complementary techniques.

Exporting: the output consists of a 3D wire frame CADR drawing format.

Variables associated to the use of Reflectorless Electronic Distance Measurement (REDM) tracing tool

Speed: the speed of a system is associated with the time that takes the operator to find the points with the telescope to define a vector, mark the point in the referencing sketch (if necessary), and the actual engineering time it takes the machine to collect the measurement and transferred it to the CADR application. This can vary from case to case; a referential time is suggested of 0,17 point/second. The speed can be affected by the brightness of the material being surveyed.

Precision: it can range between 0.005 m. to 0.05 m. for point acquired, however the precision can be affected by the correct instrument set-up and the accurate selection of the points defining vectors measured by looking at the telescope.

Measuring Range: deals with the physical range of the device, normally up to 2 to 5 km in infrared mode and from 2 to 200 m. in laser mode (reflectorless).

Field operability (Robustness and Portability): the collecting work is carrying out on-site.

REDM devices are normally robust against extreme environmental conditions (rain, heat, etc), they can operative in bright sun light but extreme care should with direct sun light to the telescope. More advance machines have integrated a thermometer to compensate temperature, if this not

available the temperature and air pressure should be indicated when measuring.

Furthermore, although the REDM is portable, the portable computer attached to the measuring device can be less robust against environmental conditions and the batteries can have a shorter period of time that REDM device.

Adjustment and corrections: advanced knowledge of surveying and CADR application is required for correct levelling and orientated the instrument; as well as, the use of least square calculations to increase the precisions of the network of points in the 'Site reference' system and use the Tracing plug in combination with the CADR software.

Cost effectiveness: the most effective in price quality systems of Electronic Distance Measurement device can be around 12000 Euros (Including REDM device, portable computer, CADR application, an Tracing plug-in). In Average in depends on the relation between the precision and the range of the reflectorless mode; as well as, to the portable computer chosen, the price of this last equipment depends on its robustness and battery independence time.

Occlusion: multiple measuring positions are required to overcome obstacles and to cover the site; high areas are difficult to measure (see measuring range).

Transformation possibilities: the wire frame model with the measurements output is produce in various drawing formats, such as DXF or DWG, it mostly work with AutoCAD LT or full version. The data can be modified only by the collection of complementary vectors on-site.

Other critical issues dealing with documenting built heritage:

- It is a 'time consuming' technique, where the operator is subjected to chose and records each point.
- Generally the precision and observational accuracy depends in the density points collected on-site and adequate selection of measurements to define the entities.
- The data collected is generally limited (time constraint).
- The range of the laser measuring tool might be affected by the reflective properties of the material.

It is highly effective in providing real-time results while working on-site.

Summary in the use of Reflectorless Electronic Distance Measurement (REDM) Tracing

This tool is suited for all applications in recording built heritage. Better results are expected if it is used in combination with non-photographic (e.g. Hand-survey drawings) photographic tools (ortho- or rectified photography).

Time-of-flight point collection

This tool consists of using Time-of-flight hand held device, such as the known electronic tape measurement device that collects points using Laser beam projected to a surface. The measurements are either manually typed into the computer or sketched for in-situ for further work off-site.

This tool is more associated with the use of hand-survey techniques, it is potentially more powerful, giving a larger range to the surveyor to reach elements without the use of a scaffolding and in some cases the device can be linked to a portable computer making the measurements accessible to other applications for further processing.

Time-of-flight Tracing

This tool is the combination of a Time-of-flight hand held device (Disto, electronic tape measurement device) connected to a portable Computer that is equipped with a Tracing plug-in for drafting vectors using a CADR application

The vectors are defined by collecting multiple points with the readings of the measuring device; this line is automatically drawn in the CADR application

5.5.3.2 Indirect Survey Techniques

Non-Photographic

Terrestrial Long-range 3D Mapping or Scanning (Tool: Time-of-flight)

This Long-range Laser Mapping tool is capable of generating a large set of measurements from the fabric of the object. This system is implementing using the following phases: Collection, Matching-Merging, Generation of Models, verification, and Exporting to other applications. Currently this tool is consider as emerging technology in Built Heritage

The mapping system exposed here uses a 'pulse time-of-flight' tool, which generates a set of measurements or point cloud by calculating the time it takes to a laser beam to reach and return the scanned surface.

These devices are equipped with an active sensor that automatically acquires dense 3D sets of points (point cloud) using a previously specified interval in a short time. Subsequently, most of them provide a software application that is capable of matching and merging scans from different scan-positions using targets or similar surface matching techniques.

The different overlapping set of points that are collected and merged can be modelled into surfaces and/or solids using a library of pre-defined 3D primitives and tools.

Data-Collection: as in other tools, a site reference system should be established by measuring the external target system for the mapping device.

Furthermore, the system is placed in different viewpoints that allow multiple overlapping scans covering the entire subject, and at least covering two external targets for least-square calculations and merging of the data.

This can be executed by directing the head of the scanner to a specific area; in some cases the device is equip with a rotating head that enables one to record in a circular path close to 360o.

The resulting dense point cloud is automatically visualized instantly on-site and transferred to the scanner application for matching and merging. This phase is executed 'in-situ'.

Matching-merging process: the software accompanying the scanner will reduce the point cloud density and the modelling of the scanned points.

By matching relocated scanned positions the operator identifies the targets in each scan. Once they have been identified the multiple overlapping readings are automatically matched and the properties matching the surface verified.

Generation of polygons and models: the generation of a 3D model of the building is a time-consuming task using this system, taking into consideration the high amount of the scanned data. However, this system is certainly faster than any other remote sensing or indirect recording technique in obtaining the geometry of a surface.

TERRESTRIAL LONG RANGE 3D MAPPING OR SCANNING - INDIRECT SURVEY METHODS

(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: TIME-OF-FLIGHT

PROCESS — **CYRAX - CALLIDUS**

INSTRUMENTS

SCANNING SYSTEM

FEATURES	MAPPING DEVICE + PORTABLE COMPUTER + SOFTWARE	
PROFESSIONAL		+++++++
MID-RANGE		+++++

1 DATA-COLLECTION

CONTROL POINTS ARE MEASURED (TARGETS)

A set of control points are measured using a REDM Device, Analogues measuring devices or Hand-Survey methods

SCANNING - MAPPING

A sequence of scan are executed covering the whole object and with sufficient overlapping, covering at least three-targets and overlooking the interesting features

2a MATCHING - MERGING

(1) Reducing Cloud of Points Density for manipulation
(2) Matching relocated scanned positions: control points are identified in each scan - the scans are merged

2b POLYGONS - MODELS GENERATION

(1) Identifying and selecting a set of points which are either converted to a surface mesh or a similar pre-defined primitive is assigned
(2) Contour lines can be generated with Triangulate Irregular Network calculations

3 VERIFICATION

(1) The Cloud of Points can be verified on-site with other EDM devices or Photogrammetry
(2) Complementary scans should be executed on-site to improve the uniformity and density of the data collected
(3) The Site reference should be checked with other instruments

4 RESULTS

(2) The raw data is a Dense Cloud of Points that can be transform in polygons, 3D primitives, contour lines, and/or a surface mesh that can be exported to a CADR application for further processing

PRODUCTS

GEOMETRIC DATA: CLOUD OF POINTS - CONTOUR LINES
3D SURFACE MESH

EXPORT TO OTHER APPLICATIONS

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Average 1000 p/s[a]	~0.002 m. to 0.01 m. Depends on correct Square Least calculation and merge of scans	1 - 130[a] m.	Robust heat-humidity, Not rain, works with bright sun light	Advanced knowledge in Surveying and CADR	Output is produce in compatible formats

COST	OCCLUSION	CRITICAL ISSUES DEALING WITH BUILT HERITAGE
Very Expensive	Multiple scans are aim at overcoming obstacles, they are affected by blank and shadowed areas	On-site time is reduced considerably, but off-site work can be a time-constrained task. The set of measurements can be converted to traditional wire frame representations with difficulty The adequate modeling of entities will depend on the level of operator's expertise. Apparently, the precision of the data will be affected by the reflective properties of the material. Vibration can affect the performance of the equipment Each scanned object will generate a blank shadow

SUMMARY

THIS METHOD IS SUITED FOR ALL APPLICATIONS IN RECORDING AND ESPECIALLY THOSE THAT REQUIRED A 3D MODEL OF BUILT HERITAGE, BUT IT IS VERY EXPENSIVE - THE USE OF IMAGE-BASED TECHNIQUES IS RECOMMENDED TO COLLECT TEXTURE INFORMATION

[a] Addison, A. Gaiani, M.; 'Virtualized Architectural Heritage- New Tools and Techniques for Capturing Built History', Proceedings VSMM98 Conference IOS Press 1998. Vol. I.

Chart 33: 3D long-range scanning or mapping - process

The generation of a model is implemented by identifying and selecting a set of points, which are later either converted to a surface mesh or a else similar pre-defined primitive can be assigned; as well as, the generation of contour lines using triangulate irregular network calculations.

Furthermore, sections through the scanned data can be performed to generate profiles of the subject.

It is important to mention that this software is normally equipped with the most common used CADR facilities, such as powerful navigation (e.g. zooming, panning, viewing, rotating..), construction, and manipulation tools (e.g. trimming, extending, line construction, etc). As well as, rendering and other commands.

Verification: the processes of controlling the measurements can be performing by checking a set of points on-site using an EDM device, an analogue theodolithe or Photogrammetry.

Complementary measurements, modification, and corrections should be executed 'in-situ' by performing complementary scans.

The resulting product is a large amount of 3D points, surface mesh, and/or solid models from primitives that can be used in combination with other non-photographic and photographic techniques, such as photogrammetry; image-based modelling to acquire a full set of geometry and textured information.

The improvement required to the dataset of the survey can be performed by adding more scans ‘in-situ’ or implementing complementary techniques.

Exporting data to other applications: the application is capable of outputting different formats to be further processed and analysed using modelling and visualization packages. The exporting formats include DXF files and other drawing format files.

Variables associated to the use of terrestrial long-range 3D scanning and mapping tools

Speed: the speed of a system is associated to the time it takes to the mapping device to project the laser and calculate its position, which is suggested of 1000 point/second (Addison, A. Gaiani, M., 2000, p. 27)[51].

Precision: it can range between 0.002 m. to 0.01 m. for point acquired (Addison, A. Gaiani, M., 2000, p. 27)[52].

Measuring Range: deals with the physical range of the device, normally from 0 to 130 m.

Field operability (Robustness and Portability): the collecting work is carrying out on-site.

Mapping devices are normally robust against heat, and humidity, however they do not stand rain; they can operative in bright sun light but extreme care should with direct sun light with the laser sensor. The device is relatively heavy (around 12-20 Kg).

Furthermore, although the Mapping device is robust, the portable computer attached to the measuring device can be less robust against environmental conditions and the batteries can have a shorter period of time that Mapping device.

Adjustment and corrections: advanced Knowledge of surveying and CADR application is required for the correct introduction of least square calculations to increase the precisions of the network of points in defining a ‘Site reference’ system and use the processing software included in the package and CADR software used for processing the data.

1 TERRESTRIAL LONG RANGE 3D MAPPING OR SCANNING - INDIRECT SURVEY METHODS (NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE METHOD: TIME-OF-FLIGHT

SYSTEM USED: CYRAX-LEICA GEOSYSTEMS

DATA-COLLECTION

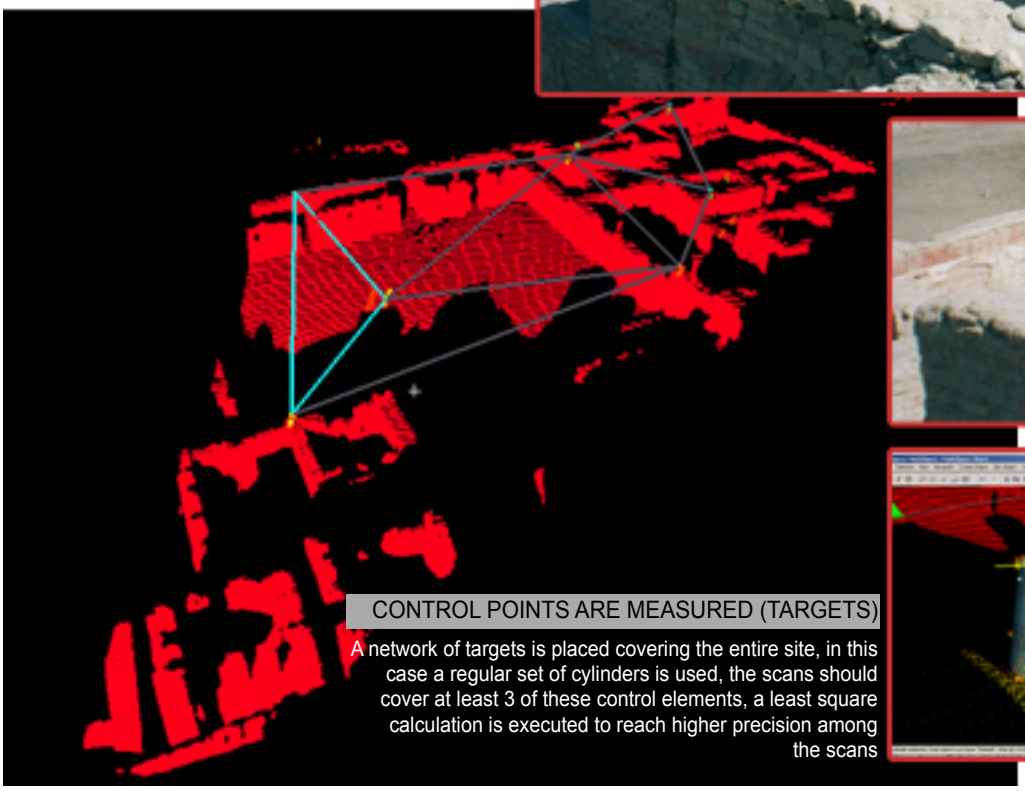
Site: Tambo Colorado, Peru
Material: mud brick
Technique: Cyrax Long-range Scanner



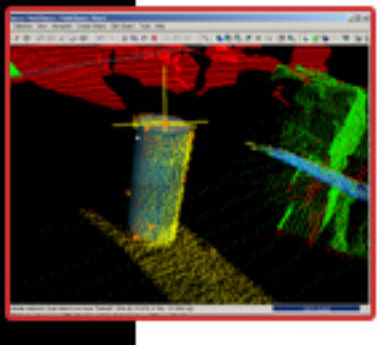
SCANNING - MAPPING

A sequence of scan are executed covering the whole object and with sufficient overlapping, covering at least three-targets and overlooking the interesting features









CONTROL POINTS ARE MEASURED (TARGETS)

A network of targets is placed covering the entire site, in this case a regular set of cylinders is used, the scans should cover at least 3 of these control elements, a least square calculation is executed to reach higher precision among the scans

Courtesy of A. Addison, CDV - UC Berkeley - Tambo Colorado Scanning Project

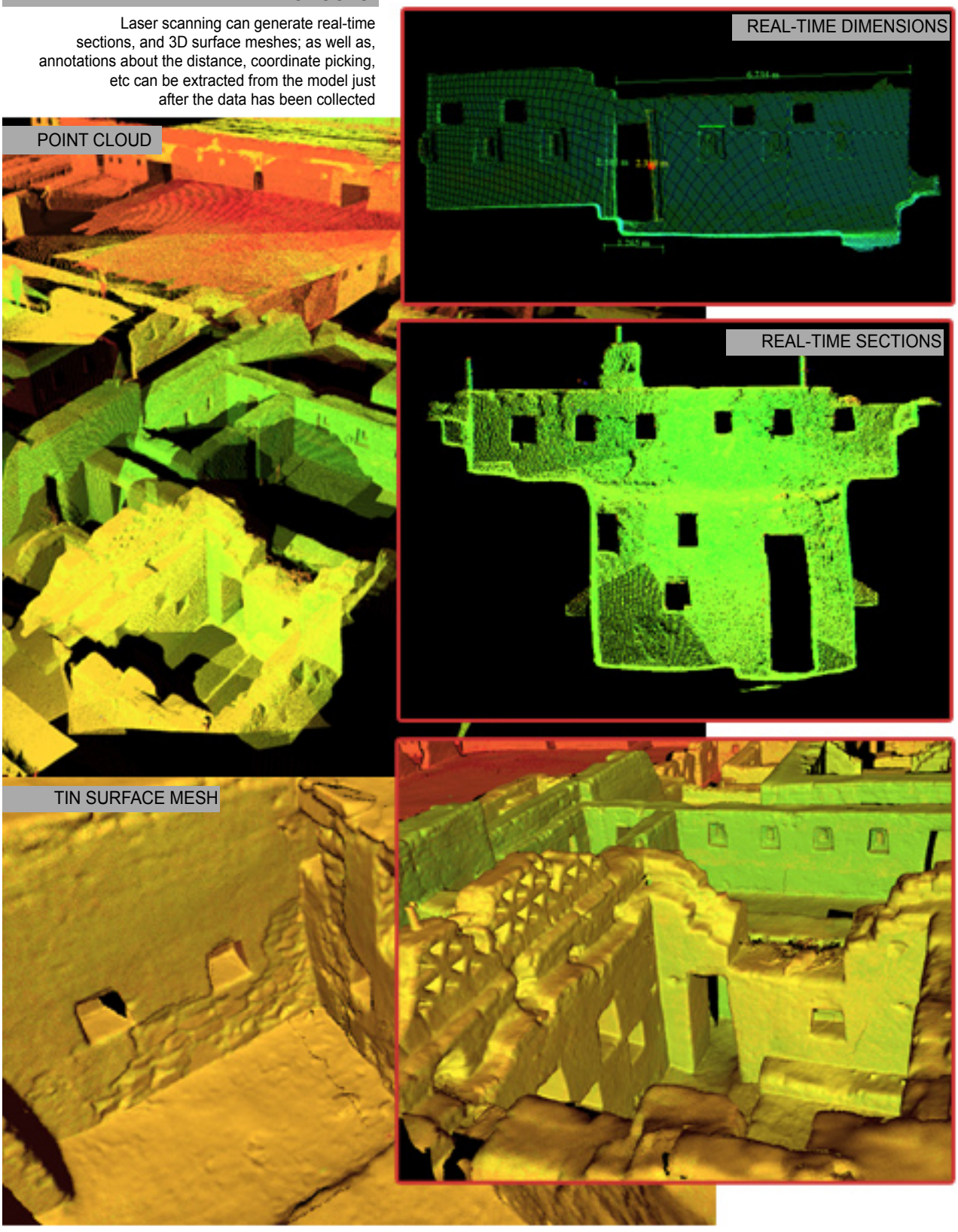
Chart 34: 3D long-range scanning or mapping - examples

2 TERRESTRIAL LONG RANGE 3D MAPPING OR SCANNING - INDIRECT SURVEY METHODS
(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE
METHOD: TIME-OF-FLIGHT

PRODUCTS

Laser scanning can generate real-time sections, and 3D surface meshes; as well as, annotations about the distance, coordinate picking, etc can be extracted from the model just after the data has been collected

SYSTEM USED: CYRAX-LEICA GEOSYSTEMS



Courtesy of A. Addison, CDV - UC Berkeley - Tambo Colorado Scanning Project

Chart 35: 3D long-range scanning or mapping - examples

Cost effectiveness: the most effective in price quality systems of Terrestrial Long-range 3D Mapping system can be around 83000 to 183000 Euros (Including the mapping device, portable computer, scanning software, and CADR application, an Tracing plug-in).

The price depends on the relation between the precision, range, and portability of the system.

Occlusion: multiple scan positions are required to overcome obstacles and to cover the site; although the range is up to 130 m., blank and shadowed areas are difficult to measure and the system will be affected by vibrations if a scaffolding is used for scanning high areas.

Transformation possibilities: the point cloud, surface mesh, and primitives are available in common drawing formats, such as DXF, DGN or DWG. The data can be modified only by the collection of complementary vectors on-site.

Other critical issues dealing with documenting built heritage:

- Although time spend on-site can be considerably reduced, off-site work involving reducing the point of clouds density, merging-matching, and modelling can be a time-consuming.

- The set of measurements can only be converted into traditional wire frame representations with difficulty. The adequate modelling of entities will depend on the operator's level of expertise.

- Apparently, the precision of the data will be affected by the reflective properties of the material.

Vibration can affect the performance of the equipment

Each scanned object will generate a blank shadow, where objects are not visible to the scanner. To solve this problem multiple overlapping positions and views should be chosen to cover the whole site.

It is highly effective in providing instant results while working on-site.

Summary in the use of terrestrial long-range 3D scanning or mapping tools

Certainly the application of laser scanners in historic buildings is one of the most reliable and fastest techniques for recording and understanding the complex geometry of the subject.

However, colour and patterns are also important for analysing the history and actual state of conservation of the object. In this sense, laser scanners are limited, because image-based representations can only be linked or fixed to the scans by mechanic procedures that are not as reliable as the point-cloud data generated from the geometry.

Therefore, this tool is suited for all applications in recording built heritage. It is, however, advisable to be used in combination with photographic tools (photogrammetry, image-based automatic generation of 3D models).

In reality, there have been some discussions about the ability of a mapping device of this kind to effectively detect edges of structures, which is a critical issue in this field. It is the opinion of this research that this matters if the expected output is a line drawing rather than a fully three-dimensional geometric model of the subject's fabric.

Photographic

Plane parallel photographic rectification

Plane parallel photography is a highly effective technique to generate a correct image-based representation of a fully or roughly flat plane; this tool can be use if the following conditions are available:

The surface should be flat, not irregular. Nevertheless, depending on needs the recorder can use a certain degree of assumption about the irregularities of the surface.

The camera should be roughly or absolute parallel to the surface to record.
An external reference system should be implemented to be able to acquire the scale of the object and reduce the distortion of the photograph.

Overlapping of at least 30% is required for recording the surface, if multiple photographs are required

The objective of rectified or plane-parallel photography is to produce a roughly or absolute '*true-to-scale photographic image/ print of an object such as the facade of a building*' (ICOMOS, 1990, p. 54)[53].

Plane parallel photographic rectification has been illustrated in the case studies dealing with:

- Conservation and Broader Audience presentation of Built Heritage: al-Baleed Archaeological Park, Sultanate of Oman (chapter I-part II).
- Experiences in training architectural-conservators in the use of metric survey methods: master students at the R. Lemaire International Centre for Conservation, Almaty Workshop (Republic of Kazakhstan), Sanchi Workshop (India), and Université d'été in Chinon (France) (chapter III-part II).

Data-collecting:

Preparing a reference system using targets for the scale and to reduce distortion thus achieving a parallel position to the wall rectification:

A horizontal reference system: made by hand measuring tools and a levelled rope. Or using external or natural targets for measuring with a theodolithe or total station.
A vertical reference system: made by hand measuring systems, such as plumbs. Or using external or natural targets for measuring with a theodolithe or total station.

A Photograph or multiple overlapping photographs are taken absolute or relative parallel to the plane to be rectified.

Data-processing:

The resulting 'plane parallel photography' are photographs with reduced distortion. However, this product can be further processed using a raster image processing application to manually and mechanically reduce the distortion of the photographs by pulling the edges of the image manually (the horizontal and vertical reference should be extracted and clipped as a background in Photoshop to execute this tool).

Moreover, it is possible to use other more advanced software to reduce this distortion. This type of tools uses a function called 'rubersheet'. It enables the user to pick a point in photographs and find its correlated position in the CADR application, after a minimal number of 4 points located in the same plane identified, the programme is capable of stretching the photograph reducing the distortion within the targets

PLANE PARALLEL RECTIFIED PHOTOGRAPHY - INDIRECT SURVEY METHODS

(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE
METHOD: AUTOMATIC

PROCESS — REDM - AUTOCAD RASTER DESIGN

INSTRUMENTS

1 DATA-COLLECTION

SETTING A REFERENCE SYSTEM

A Horizontal reference system
A Vertical reference system:

PHOTOGRAPHING - MEASURING

A Photograph or multiple overlapping photographs are taken absolute or relative parallel to the plane to be rectified
Measuring the Horizontal and Vertical Reference system

FILM-BASED CAMERA → **FILM PROCESSING AND SCANNING**

Photographs are scanned to the highest possible resolution

DIGITAL CAMERA

CAMERA

FORMAT		PRICE
METRIC	FILM-BASED CAMERA	++++
SEMI-METRIC		++
COMMON		+

RESOLUTION		
HIGH (+5 mp*)	DIGITAL CAMERA	+++
MID (- 3 mp*)		++

RESOLUTION		
HIGH	SCANNER	++++
MID		++
LOW		+

* Million pixels

2 DATA-PROCESSING

(1) The plane parallel photographs are introduced along with the measured reference system to reduced distortion, using either mechanical or automatic corrections
(2a) Mechanical: stretching the photographs to match the reference system (Using a Raster Image-processing and CADR application)
(2b) Automatic: the photographs are automatically stretched to fit the absolute reference system (Using speacilized applications)
(3) The resulting image is vectorized using a CADR application

FEATURES		
PROFESSIONAL	RASTER IMAGE-PROCESSING APPLICATION	+++
MID-RANGE		++
LOW-END		+

FEATURES		
PROFESSIONAL	SPECIALISED RECTIFICATION PACKAGE INCLUDING A CADR APPLICATION	++++
MID-RANGE		++
LOW-END		+

3 VERIFICATION

(1) The correlation of the results by the vectorization of the image should be controlled and if necessary new photographs can be inserted to improve details and add more 'planes'

4 RESULTS

(2) A 2D Vector representation to be exported to a CADR applications
(3) A rectified texture plane that can be exported

PRODUCTS

GEOMETRIC DATA: 2D VECTORED REPRESENTATION

TEXTURE DATA: RECTIFIED PLANE TEXTURE

EXPORT TO OTHER APPLICATIONS

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Average 1 p/s	~0.001 to 0.02 mm. Depends on image resolution, regularity in the plane photograph camera parameters	1 - 30 m.	Robust (Camera) Highly Portable on-site Less portable off-site	Knowledge about photographing planes, and about the software used	Output is produce in compatible formats

COST	OCCLUSION
In Average Suistable	Multiple plane parallel photographs to overcome obstacles, it is affected by lighting and irregularities in the plane photographed

CRITICAL ISSUES DEALING WITH BUILT HERITAGE

Does not work with Irregular planes
Time Consuming
Generally the precision depends in the density and accurate identification points
The raw data generated should be corrected on-site.
A colour chart should be use if the photographs will be base for condition assessments

SUMMARY

THIS METHOD IS SUITED FOR ALL APPLICATIONS IN RECORDING BUILT HERITAGE, BUT IS LIMITED TO ROUGHLY REGULAR PLANES - IT SHOULD BE USED IN COMBINATION WITH REDM DEVICES TO INCREASE PRECISION AND COMBINE DIFFERENT PLANES

Chart 36: plane parallel photography - process

assigned.

Subsequently, the image will be vectorized in a CADR application, depending on the level of detail required the entities are traced using vectors after the distortion has been corrected an the photograph is place in the absolute position (external orientation).

Verification: the processes of controlling the measurements are performed on-site with the output representation. Control measurements can be made using an EDM device, analogue Theodolithe or Photogrammetry.

Complementary measurements, modification, and corrections should be executed taking new photographs with a higher resolution and implementing more advanced distortion correction tools.

The end product is a rectified photograph vectorized with a planar wire frame of vectors which can be used in combination with other non-photographic and photographic techniques to be enhanced, such as measured hand-survey of details, photogrammetry, or REDM device measurement to further digitise the geometry and texture of the object.

The improvement required to the dataset of the survey can be performing by adding a higher density of points by vectorizing more points onto the photograph and implementing complementary techniques.

Exporting: the output consists of a rectified image of a plane and a planar wire frame of vectors in a CADR drawing format.

Variables in the use of rectified photography (manually-mechanically rectification with a raster image processing software or specialized application) tool

Speed: in average 1 p/s the time it takes to identify a point in rectified images after it has been rectified and the referential system has been implemented.

Precision: ~0.01 – to 0.02 m. depends on the correction of the distortion, the flatness of the surface being documented and the precision of the reference system.

Measuring Range: between 0 - 30 m. This range is affected by the resolution of the images.

Field operability (Robustness and Portability): the tool is highly robust (Camera) and portable. A lot of the work is considerably done off-site, where the computer systems are not portable and less robust.

Adjustment and corrections: the possibility of defining the parameters of correcting the distortion of the image (internal calibration) and the level of parallelism to the surface being documented; as well as, the precision of the control network prepared (external orientation).

Cost effectiveness: it is in average sustainable; the price depends on the type of software used in rectification, the camera, and computer system, as well as, the equipment to prepare the control points network for the external orientation.

Occlusion: this technique cannot be used for irregular surfaces; a number of photographs and referential system should be made for each image to be rectified. The photographs can be affected by direct sunlight and shadows.

Transformation possibilities: output is produce in common formats: the vectorized image will be delivered in a drawing format files (e.g. dxf, dwg), image-based representations are provided in common bitmap formats.

Other critical issues dealing with documenting Built heritage:

1 PLANE PARALLEL RECTIFIED PHOTOGRAPHY - INDIRECT SURVEY METHODS

(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: AUTOMATIC

DATA-COLLECTION

Process:

(1) A Photograph is taken, roughly parallel to the plane to rectify, covering the control targets
(2) The Control targets are measured with a EDM device
(3) a. The image is rectified in the specialised software, b. lines are use to trace the entities to create a line drawing elevation of the object



METHOD: REDM TOTAL STATION - DIGITAL CAMERA 3.2 MP. - AUTOCAD RASTER DESIGN

Chart 37: plane parallel rectified photography - examples

It is time Consuming
It cannot be used on irregular surfaces.
Generally the precision depends on the density and accuracy of identified points and generation of vectors defining the entities.
The raw data generated should be corrected on-site.
A colour chart should be used if the photographs are to be use d as base for mapping weathering forms in condition assessments

Furthermore, the time of fieldwork is reduced considerably; rectified photography has limitations, which deal with the quality, the process of camera calibration and element matching to extract measurements from the images. It is highly sustainable using manual-mechanical tools for referencing and correcting the distortion.

Summary in the use of rectified photography (manually-mechanically rectification with a raster image processing software or specialized application) tool

This tool is suitable for flat surfaces, or as referential system for other irregular surfaces, however the use of complementary measuring techniques (EDM or Optical-Analogue devices) and hand-survey for details can complement this technique.

Close-range digital photogrammetry (bundle adjustment and stereo-photogrammetry)

Close-range digital photogrammetry is a technique widely used in studying built heritage. It consists of acquiring 3D measurements from objects by matching points positioned in a pair or multiple numbers of photographs. These images are of course two-dimensional records.

Photogrammetry applications can be divided in stereo-photogrammetry restitution and bundle adjustment techniques for acquiring points from multiple images.

In relation with this technique, the case study dealing with the conservation of built heritage: preparing a proposal for the restoration of the roman theatre of Jebleh, republic of Syria (chapter II-part II) presents an example of the use of this technique to prepare a orthographic projection of the main façade of the monument.

Process review

The process of recording 3D measurements using photogrammetry involves four phases of work: data collection, data processing, verification, and exporting the results to other applications for further work.

Data-collection: three-dimensional data from buildings will be extracted by photogrammetric applications under the conditions that the camera parameters or characteristics are known, that at least three common control points are visible in each photograph and that these controls have been measured previously to determine scale and the orientation of the subject.

This phase of work is executed ‘in situ’, and is divided into three steps of actions: Measurements of control point, photographing (including digitalisation) and calibration of the digital images using the camera characteristics (Camera calibration).

Measurement of control point: consists in the selection of an adequate reference system (control points) by measuring external or natural targets inherent to the fabric of the subject. This process of measurement can be executed using either a traditional hand-survey or more advanced electronic distance measure devices.

Photographing: this phase of work consists of making photographs of the subject using either a digital or a film-based camera with known focal lengths.

DIGITAL PHOTOGRAMMETRY - INDIRECT SURVEY METHODS

(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: BUNDLE RESTITUTION

PROCESS — PHOTOMODELER

INSTRUMENTS

1 DATA-COLLECTION

CONTROL POINTS ARE MEASURED

A set of control points are measured using a REDM Device, Analogues measuring devices or Hand-Survey methods

PHOTOGRAPHING

A sequence of multiple photographs covering the whole object are taken with sufficient overlapping and overlooking the interesting features

FILM-BASED CAMERA → **FILM PROCESSING AND SCANNING**

Photographs are scanned to the highest possible resolution

DIGITAL CAMERA

CALIBRATION

CAMERA

FORMAT		PRICE
METRIC	FILM-BASED CAMERA	++++
SEMI-METRIC		++
COMMON		+

RESOLUTION		
HIGH (+5 mp*)	DIGITAL CAMERA	+++
MID (- 3 mp*)		++

RESOLUTION		
HIGH	SCANNER	++++
MID		++
LOW		+

* Million pixels

FEATURES		
PROFESSIONAL	DIGITAL PHOTOGRAMMETRIC SOFTWARE	++++
MID-RANGE		++
LOW-END		+

2 DATA-PROCESSING: AUTOMATION AND CORRELATION

(1) Inner orientation and calibration of the camera image is performed automatically
(2) Homologous points are identified manually and correlated automatically
(3) Control points are identify in the images for Orientation

3 VERIFICATION

(1) The correlation of the 3D wireframe of points and vectors is controlled and if necessary new correlations and photographs are inserted

4 RESULTS

(2) A set of 3D points and wireframe of Vector to be exported to a CADR applications
(3) Texture can be exported using Ortho-Photographs

PRODUCTS

GEOMETRIC DATA: WIREFRAME: POINTS AND VECTORS

TEXTURE DATA: ORTHOGRAPHIC TEXTURES

EXPORT TO OTHER APPLICATIONS

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Average 1 p/s	~0.01 - mm. Depends on correct correlations of the Homogeneous points	1 - 100[a] m.	Robust (Camera) Highly Portable on-site Less portable off-site	Camera parameters and position should be known	Output is produce in compatible formats

BUDGET	OCCLUSION
In Average Suistable	Multiple view points are aim at overcoming obstacles, affected by lighting

CRITICAL ISSUES DEALING WITH BUILT HERITAGE

Time Consuming
Generally the precision depends in the density and accurate identification and selection of correct homogeneous points
The raw data generated should be corrected on-site, perhaps the generation of Ortho-photographs is convenient to map a higher density of points
A colour chart should be use if the photographs will be base for condition assessments

SUMMARY

THIS METHOD IS SUITED FOR ALL APPLICATIONS IN RECORDING BUILT HERITAGE - THE EXTERNAL ORIENTATION (SCALE - POSITION - DATUM) AND VERIFICATION REQUIRES THE USE OF EDM OR ANALOGUE MEASURING DEVICES

[a] Addison, A. Gaiani, M.; 'Virtualized Architectural Heritage- New Tools and Techniques for Capturing Built History', Proceedings VSMM98 Conference IOS Press 1998. Vol. I.

Chart 38: close-range digital photogrammetry - process

In applications using a bundle-adjustment routine the shots should be made to cover all parts of the fabric, having good right angles (close to 90°), with at least three shots where the features to be covered are visible, a relative level of overlapping is expected in the sequence.

On the other hand, in stereo-photogrammetry a pair of photographs should be made with the relative same distance to the object and from different angles and overlapping. To cover the entire subject overlapping stereo-pairs should be taken from multiple positions.

Furthermore, digitalisation through film processing and scanning will be necessary when film-based cameras are used.

Calibration: this procedure involves 'determining the characteristics of the camera so it can be used as a measurement device' (EOS Systems, 1999, p. 323)[54], which means the reconstruction of the 'bundle of rays' (Alberts, J. & Wiedemann, 1998)[55] by specifying the interior parameters, such as focal length of the lens used, the digitising scale (CCD size of the scanner or Digital camera), and the middle point 'where the optical axis of the lens intersects the photograph' (EOS Systems, 1999, p. 323)[56].

Data-processing (correlation and automation): following the camera and digitalisation parameters have been calculated and implemented, in stereo-photogrammetry the approach involves the '*determination of the relative position of the two images of a stereo pair (relative orientation)*' (Alberts, J. & Wiedemann, 1998) [57].

Furthermore, the result of this procedure is a three-dimensional model that can be vectorized with the use of glasses for stereovision and an input device(s) (mouse). Subsequently, the model is scaled and oriented by marking the Control points (absolute orientation) measured previously.

On the other hand, in bundle adjustment, where multiple images are used 'The strategy of taking photos is that each point to be determined should be intersect by at least two rays of satisfactory intersection angle' (Grussenmeyer, P. Hanke, K. Streilein A., 2001, p. 305)[58].

Once the parameters of the photographs are calibrated, the process of extraction of 3D measurements can be implemented. Each homologous point should be manually identified in at least two photographs (but for better precision use three or more) covering the targeted features. Further, the result of the automatic correlation process in bundle restitution will be a 3D wire frame of points and vectors; as well as orthographic textures from the photographs.

Verification: most photogrammetric applications provide tools for verifying the projection of the points being matched and correlated in the different images used. This feature can be of use to add more homologues points matched to measurements where the projection is wrongly calculated by the application, caused by errors in the intersection of rays.

This verification process should be conducted previously to export the model to other applications. The implementation of parallel controls measured using EDM devices. A comparison of the results with the resulting wire frame of measurements is advisable.

Exporting: the wire frame of points and vectors measured can be exported to CAD applications for further development of models or to combine other sources of information.

Furthermore, the production of digital ortho-photographs is of great use. They can be used for a more detailed digitalisation of elements in the fabric of the object lying in

1 DIGITAL PHOTOGRAMMETRY - INDIRECT SURVEY METHODS
(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE
METHOD: BUNDLE RESTITUTION

Process:

DATA-COLLECTION

Taking photographs from various points of view with known camera parameters



Chart 39: close-range digital photogrammetry - process (example)

2 DIGITAL PHOTOGRAMMETRY - INDIRECT SURVEY METHODS

(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: BUNDLE RESTITUTION

DATA-PROCEESING
AUTOMATION AND CORRELATION

Process:

Identification and correlating homologous points in at least two or more images

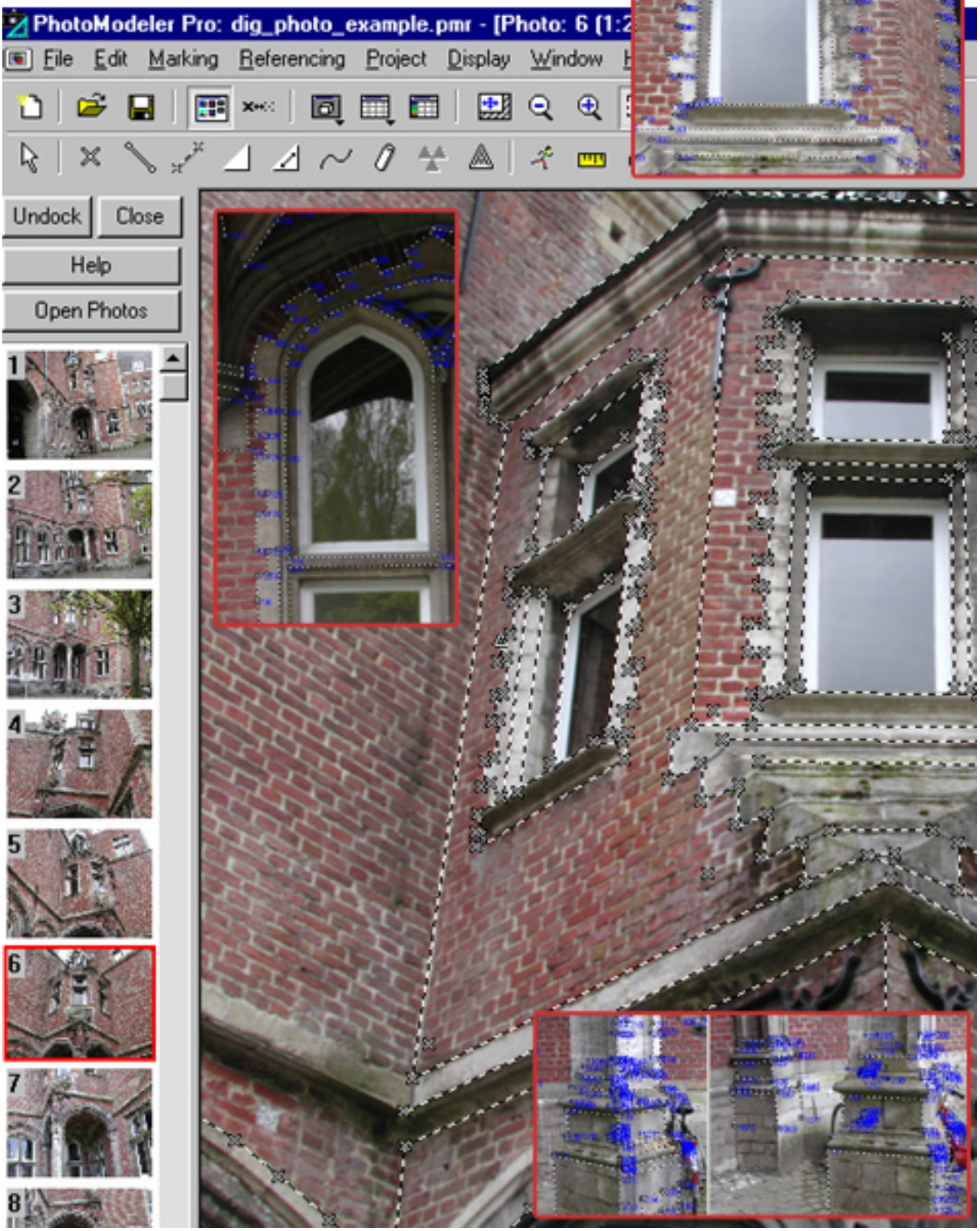


Chart 40: close-range digital photogrammetry - process (example)

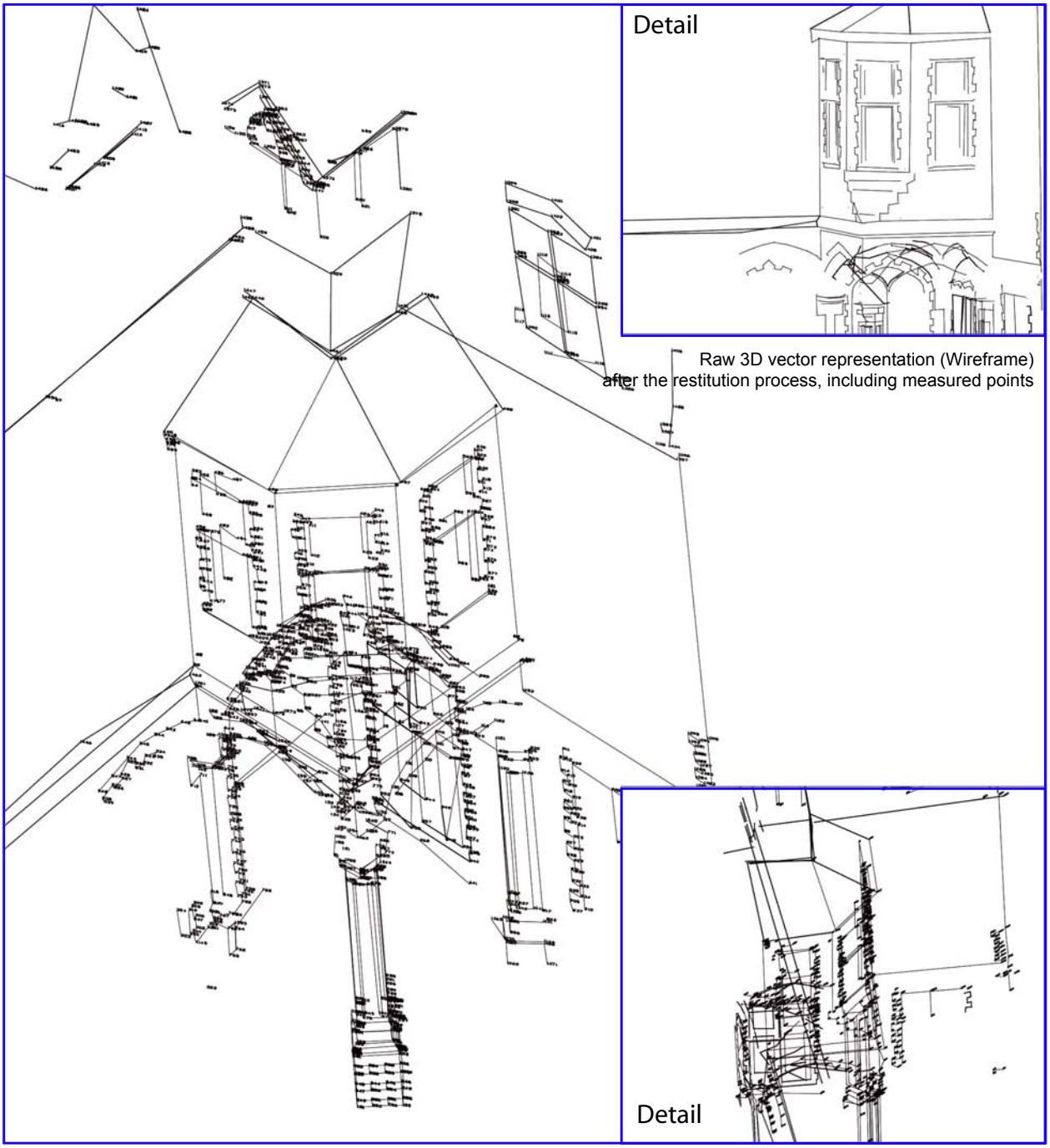
3 DIGITAL PHOTOGRAMMETRY - INDIRECT SURVEY METHODS

(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: BUNDLE RESTITUTION

VERIFICATION AND EXPORT

Process:
3D visualisation of the manual correlation and automatic restitution to control the measurements and if necessary add more correlation in different photographs or add more photographs



The raw wireframe can be export to a CADR application for further Modelling

Chart 41: close-range digital photogrammetry - process (example)

4 DIGITAL PHOTOGRAMMETRY - INDIRECT SURVEY METHODS

(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

METHOD: BUNDLE RESTITUTION

VERIFICATION AND EXPORT | **ORTHO-PHOTOGRAPHS**

Process:

An orthographic projections can be generated by the definition of a Plane with the measurements extracted and the images used.



Chart 42: close-range digital photogrammetry - products (example)

5 DIGITAL PHOTOGRAMMETRY - INDIRECT SURVEY METHODS
(PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE
METHOD: BUNDLE RESTITUTION

EXPORT - PRODUCTS | ORTHO-PHOTOGRAPHS

The Ortho-photographs can be use for vectorizing different planes using a single photograph.

Using CAD applications

(1) Raw measurements from the Ortho-Photograph Rectified

(2) Vectorized Ortho-Photograph Rectified

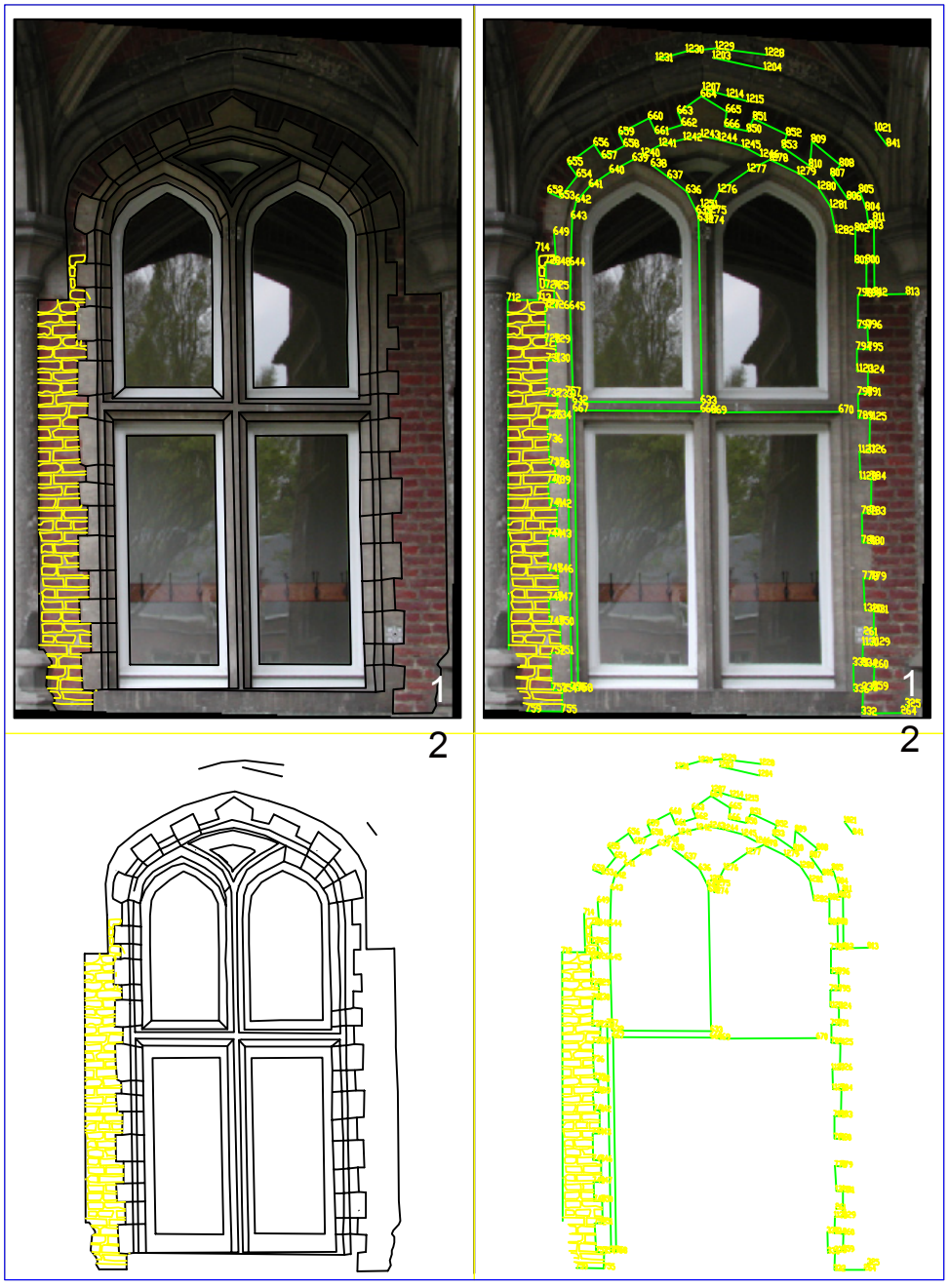


Chart 43: close-range digital photogrammetry - products (example)

different planes.

However, it is very common that after selecting and matching all the lines and points this information is exported to other CAD applications for further processing or to visualization tools, such as virtual reality or image-based rendering.

Variables in the use close-range digital photogrammetry (bundle adjustment and stereo-photogrammetry) tools

Speed: in average 1 p/s, based on the speed it takes to identify homologous points in two or more images and the process of correlation (bundle-adjustment) and in stereo-vision photogrammetry on average 0.5 p/s the time it takes to identify a point in the stereo pair of images.

Precision: ~0.01 - mm. depends on the correct correlation of the homogeneous points in the images.

Measuring Range: between 1 - 100 m[59]. This range is affected by the resolution of the images.

Field operability (Robustness and Portability): the tool is highly robust (Camera) and portable. The work is considerably off-site on a computer.

Adjustment and corrections: camera parameters (internal calibration) and position should be known; as well as, the control points should be integrated to orientate and scale the set of measurements (external orientation).

Cost effectiveness: it is on average sustainable; the price depends on the type of software used in photogrammetry, the camera, and computer system, as well as, the equipment to prepare the control points network for the external orientation.

Occlusion: multiple viewpoints are required for overcoming obstacles. The photographs can be affected by direct sunlight and shadows.

Transformation possibilities: Output is produce in compatible formats: ASCII list of coordinates, drawing format files (e.g. dxf, dwg), image-based representations are provided in common bitmap formats).

Other critical issues dealing with documenting built heritage:

It is Time Consuming.
Generally speaking the precision depends on the density and accurate identification and selection of correct homogenous points.
The raw data generated should be corrected on-site, perhaps the generation of ortho-photographs is convenient to map a higher density of points.
A colour chart should be used if the photographs will be use for weathering forms mapping in preparing condition assessments

Furthermore, the time of fieldwork is reduced considerably; photogrammetry has limitations, which deal with the quality, the process of camera calibration and element matching to extract measurements from the images.

Summary in the use of close-range digital photogrammetry (bundle adjustment and stereo-photogrammetry) tools

This tool is suited for all applications in recording built heritage, however the use of complementary measuring techniques (EDM or Optical-Analogue devices) are required for the external orientation (scale, position, and datum) of the system of control points.

Furthermore, it is recommended to combine the use of REDM devices to verify the data collected from the images.

Image-based 3D layering Recording tool and information system for studying built heritage

Recent image-based acquisition and modelling technology, such as VIRTERF[60] currently in a prototype state introduces an '*acquisition tools largely automated*' for the generation of three-dimensional depth

maps, textures, and a cloud of points. The procedure is performed by *'a limited amount of interaction'*, including the indication of *'reference points in the images to allow their localization*' (Schouteden, J. Pollefeys, M. et al, 2001)[61].

Furthermore, this set of identified points is be used for the matching process along with the pre-calibration information of the camera. From this point, the process becomes automatically, it '*finds additional matches and refines the calibration*' (Schouteden, J. Pollefeys, M. et al, 2001)[62].

This tool allows extracting a 3D texture model that corresponds to the irregular shape of the object. The model can be sliced producing a point cloud section.

Although the results can be apparently used '*both for measurements and for visualization purposes*' (Schouteden, J. Pollefeys, M. et al, 2001)[63], it is proven that at this stage of development is difficult to verified the resulted precision of the 3D textured, cloud of points, and depth map generated.

Phases of work: data-collection, calibration (Intrinsic and extrinsic), data-processing (Construction, database, and querying), verification, and exporting.

Data-collection (ESAT module): three-dimensional data from buildings will be extracted by the application through the phase of work: measurements of control point, photographing (including digitalisation) and calibration of the digital images using the camera characteristics.

Measurement of control point: consists of the selection of an adequate reference system (control points) by measuring external or natural targets inherent to the fabric of the subject. This process of measurement can be executed using either traditional hand-survey or more advanced electronic distance measure devices.

Photographing: this phase of work consists in making a pair of photographs of the object using either a digital or a film-based camera with known focal lengths.

The photographs are taken from the object to cover all parts of the fabric, having good right angles (close to 90°); a relative level of overlapping is expected in the sequence.

Furthermore, to cover the entire subject overlapping stereo-pairs should be taken from multiple positions.

Furthermore, digitalisation through film processing and scanning will be necessary when film-based cameras are used.

Calibration: consists of intrinsic and extrinsic calibration, the intrinsic consists of an estimation algorithm applied to internally in the software; the camera parameters should be fixed when taking the photographs. The external calibration is executed by surveying a set of natural or external network of control points.

Data-processing (ESAT - PMA module):

'Once the calibration has been obtained, dense stereo matching can be used to recover the detailed surface geometry from the images. This is done using dense stereo matching' (Schouteden, J. Pollefeys, M. et al, 2001)[64].

The output is either a '*depth map or a textured point cloud*', which is exported to the data-processing module.

On the other hand, the software allows to be defined '*regions of interes*t', in order to 'eliminate unwanted sections or sections that are matched badly (such as trees in front of the scene) (Schouteden, J. Pollefeys, M. et al, 2001)[65].

The textured point cloud, depth map, and 3D point file generated in the previous module

IMAGE-BASED 3D LAYERING RECORDING TOOL & INFORMATION SYSTEM - INDIRECT SURVEY METHODS

(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

PROCESS

VIRTEF (PROTOTYPE)

1 DATA-COLLECTION

CONTROL POINTS ARE MEASURED

A set of control points are measured using a REDM Device, Analogues measuring devices or Hand-Survey methods

PHOTOGRAPHING

A stereo-pair of photographs of the object are taken (multiple pairs can be made, they will be process separately)

FILM-BASED CAMERA

FILM PROCESSING AND SCANNING

Photographs are scanned to the highest possible resolution

DIGITAL CAMERA

CALIBRATION

2 DATA-PROCESSING: POINT CONVERSION, DENSE MATCHING, & MULTIPLE MODELS MERGING

(1) Each pair of oblique photographs is processed through a dense stereo matching method to recover the detailed surface geometry from the images
(2) 3D point conversion: the output of the textured point cloud is converted into a 3D point file - filtered, meshed and textured
(3) The resulting data from the pair of photograph model are merge and a TIN textured surface mesh is generated of the subject.

3 MODEL CONSTRUCTION

(1) Construction of the Model: a series of tools involving, attribute definition, vector graphic, and links are used to assign thematic content to the 3D textured surface, drawing of vectors, sections, point picking, and linking the geometric data to other type of digital sources

4 RESULTS

(1) A 3D Information system is built with Geometric, textured and other sources of information (Model Querying)
(2) A wireframe of vectors, Cloud of Points, and Textures (Ortho-images) can be exported

EXPORT TO OTHER APPLICATIONS

INSTRUMENTS

CAMERA

FORMAT		PRICE
METRIC	FILM-BASED CAMERA	++++
SEMI-METRIC		++
COMMON		+

RESOLUTION		
HIGH (+5 mp*)	DIGITAL CAMERA	+++
MID (- 3 mp*)		++

RESOLUTION		
HIGH	SCANNER	++++
MID		++
LOW		+

* Million pixels

PROTOTYPE APPLICATION

PRODUCTS

GEOMETRIC DATA: CLOUD OF POINTS - WIREFRAMES OF VECTORS - CONTOUR LINES
3D SURFACE MESH
TEXTURED DATA: ORTHO-IMAGES & 3D TIN SURFACE

VARIABLES

SPEED	PRECISION	RANGE	FIELD OPERABILITY	ADJUSTMENTS CORRECTIONS	TRANSFORMATION POSSIBILITIES
Not available - see text	Not available yet	1 - 30 m.	Robust on-site (involving a camera) - Involves Extended off-site work	Advanced knowledge in Surveying and Photographing Built Heritage	Output is produce in compatible formats

COST	OCCLUSION
Not available yet	Multiple pairs of photographs should be made to cover the object.

CRITICAL ISSUES DEALING WITH BUILT HERITAGE

Still under development - a considerable level of uncertainties in the precision and uniformity of the 3D data collected
Time Consuming in identifying TIN meshes for the layering and attribute database.
A colour chart should be use if the photographs will be base for condition assessments

SUMMARY

THIS METHOD IS SUITED FOR ALL APPLICATIONS IN RECORDING AND ESPECIALLY THOSE THAT REQUIRED A 3D MODEL OF BUILT HERITAGE, BUT IT IS STILL UNDER DEVELOPMENT - it is recommended to combine the use of REDM devices to verify the data collected from the images

Chart 44: image-based 3D layering recording tool & information system - process

that calculates the camera calibration and dense depth maps 'yield all the necessary information to build 3D models'.

3D point conversion: the output of the textured point cloud is converted into a 3D point file, which are then filtered, meshed and textured. Subsequently, these points are stored in a database.

Merging of models from multiple processed pairs of images: the points generated from the different pairs of images processed are merged and combined with the texture generating a 'Triangulated Irregular Network' mesh textured with the images.

Model construction (ASRO module) integrated 3D model Information system:

The 3D model resulting from this application is an integrated information system that allows the navigation, visualization and exploration of all kind of thematic information through a 3D geometric-texture model of the object.

Construction of the model

Attribute definition: this definition tool is used for thematic studies aimed at organizing the information collected from various sources and evidenced in the subject's fabric for further analysis and diagnosis in studying Built Heritage for conservation.

'Attribute themes may group information on materials, pathology or construction phases' (Smars, P. Nuyts, K. & Van Balen, K., 2001)[66]. The 'Virterf' tool allows the user to specify an unlimited number of attributes (e.g. construction materials, weathering forms, historical stratigraphy, etc) evidenced by the geometric-textured model of the subject's fabric.

Subsequently, these attributes can be divided into themes. The later are combined with the use of layering systems of organization in CADR applications.

The definition procedure is executed by selecting the geometric representation of the object's fabric expressed in a TIN (triangulated irregular network) by single triangle picking or by defining a polygon for unlimited selection of triangles. Later, when the selection for user feedback is enlightened, the selected shapes are qualified by assigning a specific theme from the database.

The open-source of this application enables the user to define scripts for command in the selection and features of the attribute – theme definition and in the selection of triangles.

Vector graphics: this application also allows the user to use conventional features present in other surveying tools for preparing line-drawings from the fabric of the object, composed of vectored wire frames and points.

This feature allows directly producing points that can be defined by picking the TIN representation of the subject's geometry.

Furthermore, the subject's fabric profiles can be defined by a 3-point vector, which is then projected to the 3D geometric model producing a section. This feature can be enhanced to produce a set of contour lines with a user specified interval.

Links: this tool also allows the user to generate textual annotations and link other types of sources into the model going beyond the use or production of only geometrical and textured information.

A specific selection of triangles from the model can be linked to documents, images, databases, or other digital file formats.

'Links are materialised by small spheres coloured according to the type of file linked. With the mouse, the user can query their name and a description or visualise their content via an external application' (Smars, P. Nuyts, K. & Van Balen, K., 2001)[67]

Model querying

The main idea behind this application is that the user should be capable, at any stage, to evaluate the contents of the information system. This can be executed by visualization, geometry, or database querying.

Visualization querying: deals with displaying the attributes be associated with the model and the vectors drawn with the drafting tools.

Furthermore, the application offers conventional tools for visualizing the model, such as zooming, panning, orbiting or setting a camera position.

On the other hand, complementary tool allows defining orthogonal projection by defining plane parallel views.

Geometrical querying: conventional features allows subtracting geometric information about distance between two or more points in the fabric, coordinate picking, and defining a surface yielding the area calculation.

Database querying: it is possible to visualize the results of a criterion (theme) by querying directly into the database.

Verification: one of the critical issues about this ongoing investigation is to achieve verification about the integrity and precision of the geometric model generated by this application. However, a recent study roughly comparing the output of a 3D mapping device has yielded that the point of clouds generated is accurate.

In future, this feature should be adapted to the application, where the user can control the output by comparing the results with other surveying tools.

Exporting: the resulting wireframe of vectors and points; as well as, a single theme layers can be exported in DXF files and VRML models.

Furthermore, common raster file formats, such as TIFF or PPM can be exported.

Variables in the use the image-based 3D Layering Recording tool and Information System for studying built heritage tool

Speed: in average the speed deals with the engineering time it takes the hardware and software to calculate the cloud of points and the balance with the on-site work for collecting the control points and making the multiple pairs of photographs.

Precision: still under development.

Measuring Range: between 0 - 30 m. This range is affected by the resolution of the images.

Field operability (Robustness and Portability): the tool is highly robust (camera) and portable. Work is mostly done off-site on a computer.

Adjustment and corrections: the software is equipped with algorithms to automatically find the camera's parameters (internal calibration). The external calibration is performed by identifying the measured site reference system of targets in the pair of images. This control system is measured with an EDM device, hand-survey techniques or optical analogue theodolithe.

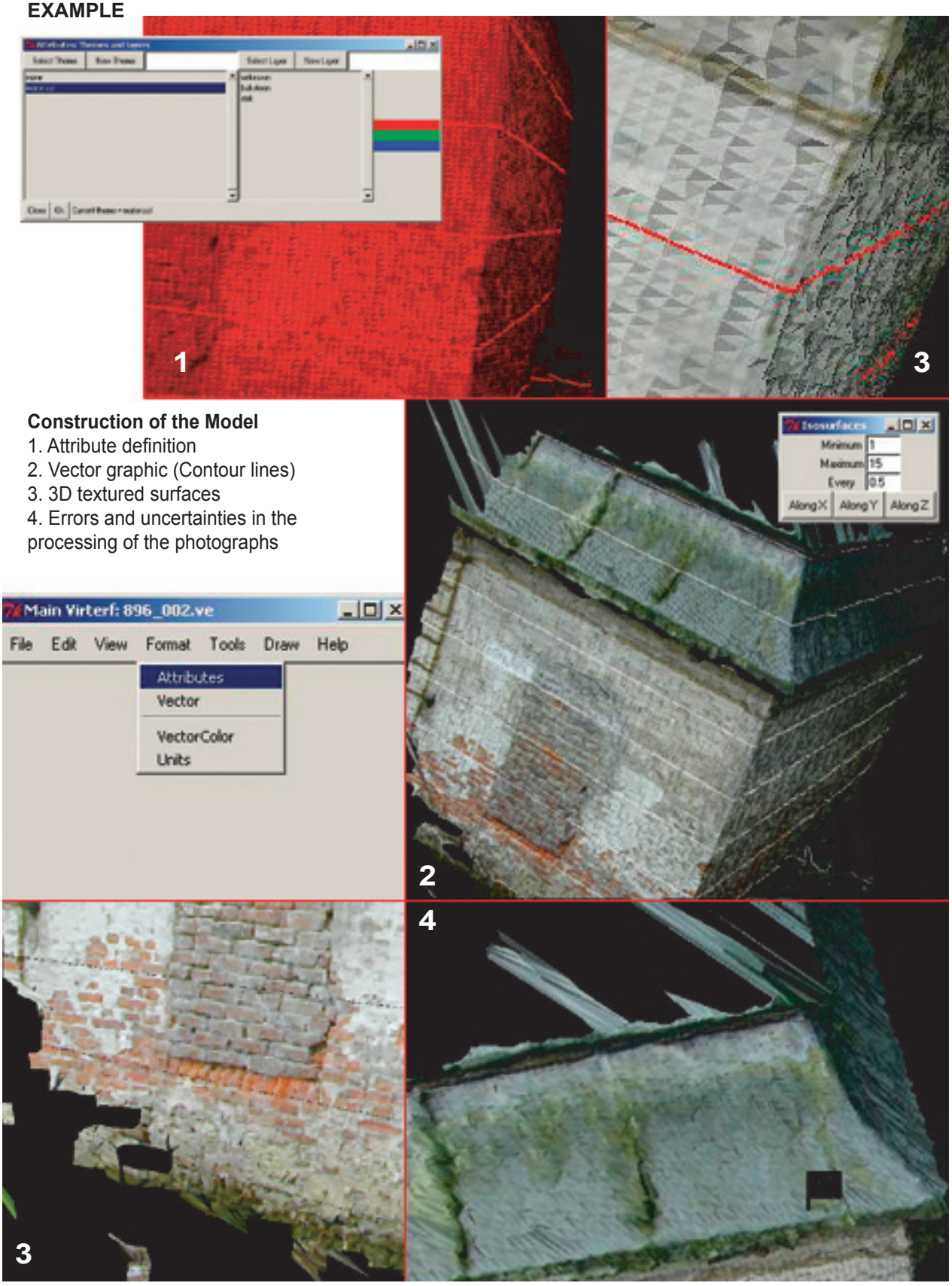
Cost effectiveness: it is not yet applicable, under development, however the price will depend on the software used, the resolution of the camera, and computer system, as well as, the equipment to prepare the control points network for the external orientation.

Occlusion: Multiple pair of photos

IMAGE-BASED 3D LAYERING RECORDING TOOL & INFORMATION SYSTEM - INDIRECT SURVEY METHODS

(NON-PHOTOGRAPHIC) - METHODS FOR DOCUMENTATION IN STUDYING BUILT HERITAGE

EXAMPLE



Courtesy of K. Van Balen, VIRTERF research project - KU Leuven(60)

Chart 45: image-based 3D layering recording tool & information system - example[60]

in different viewpoints is required for overcoming obstacles. The photographs can be affected by direct sunlight and shadows.

Transformation possibilities: output is produced in compatible formats: ASCII list of coordinates, drawing format files (e.g. dxf, dwg), the image-based texture representations are provided in common bitmap formats.

Other critical issues dealing with documenting built heritage:

Time consuming in identifying TIN meshes for the layering and attributed database.

Still under development – a considerable level of uncertainty in the precision and uniformity of the 3D data collected. Preliminary reports say that its precision is in the range of centimetres, depending on the resolution of the photographs.
A colour chart should be used if the photographs are used to map weathering forms in condition assessments.

Areas which appear in shadow or hiding in the pair of photographs that can not be covered, will be processed by the calculations, producing inexistent textured cloud points, this effect can be diminish if the areas are mark as not desired, but it is a important restriction.

Furthermore, the time of fieldwork is reduced considerably. This tool has limitations, which deal with the quality, the process of camera calibration and element matching to extract measurements from the images, the automatic generation of textures is still under development.

Summary in the use of the image-based 3D Layering recording tool and information system for studying built heritage tool

This tool is still under development, but it has been developed for the recording of built heritage. However the use of complementary measuring techniques (EDM or Optical-Analogue devices) are required for the external orientation (scale, position, and datum) of the system of control points.

Furthermore, it is recommended to combine the use of REDM devices to verify the data collected from the images.

5.5.4 METRIC SURVEY STUDY DATASET: MEASURED BASE DATA PRODUCTS: POSSIBILITIES OF TECHNIQUES

The chart presents a basic comparison instrument, reviewing the type of '**building geometry**' representations of the fabric's subject that can be produced using acquisition, processing, and dissemination tools and that are required in the metric survey dataset.

The building geometry representations produced in the Metric Survey study are divided into two groups: Geometry (3D solid Models, vector wireframes, cloud of points, etc) and texture fabric representations (ortho-photographs, 3D textures, rectified photographs, etc) that can be obtained from the process.

In addition, two groups of targeted activities can be identified: recording of '**standing structures**' **and buried 'structures**'.

Standing structures relates to buildings and archaeological remains over the topography.

Buried structures relate to structures underground that are uncovered in archaeological excavations.

This chart uses two choices: Possible or not possible. Each of these classifications are embedded in a number of limitations.

Possible: the tool can produce the specific representation under a number of

METRIC SURVEY DATASET: BUILDING MORPHOLOGY
BUILDING AND CONTEXT GEOMETRY - TEXTURE REPRESENTATIONS

TOOLS	ACTIVITIES	Building and Context Geometry and Texture: Standing Structures							
	3D Metric Reference System	Fabric Geometry GEOMETRIC REPRESENTATIONS: WIREFRAME: POINTS AND VECTORS - SOLID MODELLING 2D ORTHOGONAL PROJECTIONS:			3D:		Fabric Texture TEXTURE REPRESENTATIONS: ORTHOGRAPHIC TEXTURES - 3D TEXTURED MAPS 2D		3D MAPS:
		Elevations	Vertical or Cross Sections	Plan Elevations Plan Section (Including context & topography)	3D Wire - frames	3D Surface - Solid Modelling	Orthographic Corrected Photographs: Elevations Vertical Sections Plan Section	Rectified Photographs: Elevations Vertical Sections Plan Section	3D Textured Maps
Direct Survey Techniques									
Non-Photographic									
EDM POINT COLLECTION EDM Instrument (EDM Total Station) Referential Hand-Sketching CADR Application DTM Application	**Possible (1)**	**Possible (2)**	**Possible (2)**	**Possible** well suited for topography TIME CONSTRAINT	**Possible (2)**	**Possible (2)**	**Not Possible**	**Not Possible**	**Not Possible**
REDM POINT COLLECTION REDM Instrument (REDM Total Station) Referential Hand-Sketching CADR Application DTM Application	**Possible (1)**	**Possible (4)**	**Possible (4)**	**Possible** well suited for topography TIME CONSTRAINT	**Possible (4)**	**Possible (4)**	**Not Possible**	**Not Possible**	**Not Possible**
REDM TRACING REDM Instrument (REDM Total Station) Portable computer equipped with a Tracing plugin and a CADR Application	**Possible (1)**	**Possible (4)**	**Possible (4)**	**Possible (4)**	**Possible (4)**	**Possible (4)**	**Not Possible**	**Not Possible**	**Not Possible**
Indirect Survey Techniques									
Non-Photographic									
TERRESTRIAL LONG-RANGE 3D MAPPING OR SCANNING Time-of-flight device(Cyrax, Callidus, ...) including a Portable PC equipped with 3D manipulating and processing application for the data collected CADR Application DTM Application Consider emerging technology	**Possible (6)**	**Possible** (7)	**Possible** (7)	**Possible** (7)	**Possible** (7)	**Possible** (7)	**Not Possible**	**Not Possible**	**Not Possible**
Photographic									
PLANE PARALLEL PHOTOGRAPHIC RECTIFICATION Digital Camera or Analogue Camera + Scanner Reference system per plane (Horizontal or- Vertical Measured Control Points Measured with the help of EDM (REDM) - Traditional Methods MECHANICAL RECTIFICATION: A Raster Image Processing application (E.G. Adobe PhotoShop) CADR Application AUTOMATIC RECTIFICATION: CADR Application Rectification Software (E.G. MSR Rollei, AutoCAD Raster Design)	Possible (11)	**Possible** (8)	**Possible** (8)	**Possible** But preferably use (R)EDM methods for indoors work **TIME**	**Possible** (9)	**Possible** (9)	**Possible (10)**	**Possible (10)**	**Not Possible**
CLOSE-RANGE DIGITAL PHOTOGRAMMETRY ORTHO-PHOTOGRAPHY GENERATION Digital Camera or Analogue Camera + Scanner Reference system: control points Measured with the help of EDM (REDM) - Traditional Methods STEREO PLOTTING (Photo-Pairs) Photogrammetric Application CADR Application	Possible (11)	**Possible (8)**	**Possible (8)**	**Possible (12)**	**Possible (8)**	**Possible (8)**	**Possible (8)**	**Not Needed Ortho-Photographs are generated by Digital Photogrammetry**	**Possible (8)**
BUNDLE ADJUSTMENT (Multiple Photos) Photogrammetric Application CADR Application		**Possible (13)**	**Possible (13)**	**Possible (12)**	**Possible (13)**	**Possible (13)**	**Possible (13)**		**Possible (13)**
IMAGE-BASED 3D LAYERING RECORDING TOOL & INFORMATION SYSTEM VIRTERF Digital Camera or Analogue Camera + Scanner Reference system: control points Measured with the help of EDM (REDM) - Traditional Methods APPLICATION Extra: CADR Application	Possible (11)	**STILL UNDER DEVELOPMENT**							

(1) Requires for Absolute Referencing: 2 Known points or the use of a GPS device For Relative Referencing: a compass
(2) Limited to the reach of surveyor holding the reflector - Time Constraint
(3) Limited to the reach of surveyor holding the reflector - affected by occlusion - Time Constraint
(4) Limited to the range of the reflectorless mode - affected by occlusion - Time Constraint
(5) Limited to the range of the reflectorless mode - affected by occlusion - Time Constraint
(6) Preferably use in combination with a (R)EDM Total Station Requires for Absolute Referencing: 2 Known points or the use of a GPS device For Relative Referencing: a compass
(7) Limited to the range of the acquiring device Suffers of Occlusion and vibration in unstable grounds
(8) Limited to image resolution for detailing - Possible Occlusion
(9) Limited to image resolution for detailing - Possible Occlusion Wireframe corresponds to plane by plane basis - Time Constraint

Chart 46: comparison chart - metric survey dataset: output representations

MEASURED DATASET

Building and Context Geometry and Texture: Buried Structures

Fabric Geometry GEOMETRIC REPRESENTATIONS: WIREFRAME: POINTS AND VECTORS - SOLID MODELLING					**Fabric Texture** TEXTURE REPRESENTATIONS: ORTHOGRAPHIC TEXTURES - 3D TEXTURED MAPS			COMMON PRODUCTS	REMARKS
2D ORTHOGONAL PROJECTIONS:			3D:		2D		3D MAPS:		
Profiles	Vertical or Cross Sections	Plan Elevations Plan Section (Including context & topography)	3D Wire - frames	3D Surface - Solid Modelling	Orthographic Corrected Photographs: Profiles Vertical Sections Plan Section	Rectified Photographs: Elevations Vertical Sections Plan Section	3D Textured Maps	**GD: GEOMETRIC DATA** **TD: TEXTURE DATA**	
Possible (3)	**Possible (3)**	**Possible** well suited for buried surfaces **TIME CONSTRAINT**	**Possible (3)**	**Possible (3)**	**Not Possible**	**Not Possible**	**Not Possible**	GD: Wireframe: Points and vectors DGM (Contour lines &/or 3D mesh)	Time Consuming - Density points collected on-site limited - The range in High points is limited to reach holding the prism rot Suitable for topographic and buried structures
Possible (4)	**Possible** (5)	**Possible** well suited for buried surfaces **TIME CONSTRAINT**	**Possible** (5)	**Possible** (5)	**Not Possible**	**Not Possible**	**Not Possible**	GD: Wireframe: Points and vectors DGM (Contour lines &/or 3D mesh)	Time Consuming Density points collected on-site is limited The range is limited to the reflectorless mode and it is sensitive to the material brightness - Suitable for any application
Possible (5)	**Possible** (5)	**Possible** (5)	**Possible** (5)	**Possible** (5)	**Not Possible**	**Not Possible**	**Not Possible**	GD: Wireframe: Points and vectors DGM (Contour lines &/or 3D mesh)	Time Consuming - Density points collected on-site is limited - The range is limited to the reflectorless mode and it is sensitive to the material - brightness - **Suitable for any application, results are produce on-site**
Possible (7)	**Possible** (7)	**Possible** (7)	**Possible** (7)	**Possible** (7)	**Not Possible**	**Not Possible**	**Not Possible**	GD: Point Clouds, Contour lines, 3D Surface mesh	On-site time is reduced, but off-site work can be a time-constrained - The set of measurements can be converted to wire frame representations with difficulty The adequate modelling of entities will depend on the level of operator's expertise - The precision of the data might be affected by the reflective properties of the material. Vibration affect the equipment - Each scanned object will generate a blank shadow It is highly effective in providing real-time results while working on-site.
Possible (9)	**Possible (9)**	**Possible** but a horizontal reference system should be prepared, preferably with a (R)EDM method **TIME**	**Possible (9)**	**Possible (9)**	**Possible (10)**	**Possible (10)**	**Not Possible**	GD: 2D vectored representation corresponding to a plane TD: Rectified plane texture	Does not work with Irregular planes Time Consuming Generally the precision depends in the density and accurate identification points The raw data generated should be corrected on-site. A colour chart should be use if the photographs will be base for condition assessments
Possible (8)	**Possible (8)**	**Possible TIME CONSTRAINT**	**Possible (8)**	**Possible (8)**	**Possible (8)**	**Not Needed Ortho-Photographs are generated by Digital Photogrammetry**	**Possible (8)**	**GD: 3D Wireframe: Points and Vectors TD: Orthographic textures**	Time Consuming Generally the precision depends in the density and accurate identification and selection of correct homogeneous points The raw data generated should be corrected on-site, perhaps the generation of Ortho-photographs is convenient to map a higher density of points A colour chart should be use if the photographs will be base for condition assessments
Possible (13)	**Possible (13)**		**Possible (13)**	**Possible (13)**	**Possible (13)**		**Possible (13)**		
STILL UNDER DEVELOPMENT								**GD: Point cloud - 3D Wireframe: Points and Vectors, Contour lines - 3D Surface Mesh TD: Orthographic textures & 3D Triangulated Surface meshes**	Still under development - a considerable level of uncertainties in the precision and uniformity of the 3D data collected Time Consuming in identifying TIN meshes for the layering and attribute database. A colour chart should be use if the photographs will be base for condition assessment

(10) **Only** if the Plane is roughly flat, But each plane has to be processed separately - Time Constraint
(11) Preferably use a (R)EDM Total Station or other conventional to measure the control points the system should be according an Absolute Referencing 2 Known points or the use of a GPS device For Relative Referencing: a compass
(12) But preferably use (R)EDM methods for indoors work - Time Constraint
(13) Limited to image resolution and correct correlation of homologues points in multiple photographs - affected by occlusion

limitations.

Not possible: the tool is not capable of producing a certain representation, but can be used in combination with another group of tools (Non- or image-based instruments) to produce the desired product.

5.6 CLOSING REMARKS

The objective of this chapter has been to explain the selection of metric survey tools according to a number of applications in studying built heritage, which are structured using a framework of variables.

These variables provide the parameters and restrictions that the tools should overcome to be efficient in providing representations about the geometry and texture of the subject and its context.

In addition, metric survey involves the study of the 'intrinsic meaning' dealing with the 'spatial and visible forms' (Conway, H. Roenisch, R., 1994, p. 23)[68] through the mapping of the subject's geometry.

This process involves an intensive degree of surveying to obtain a dense number of measurements that can yield geometric characteristics of the fabric of the subject, and specifically in the case of conservation of built heritage the mapping of all the elements composing the masonry.

The set, which is a result of the dissemination tools, is subsequently used as the 'base data' to carry out thematic assessments (historical, condition, etc) aimed at analyzing the authenticity or relevance of the monument, and its actual state of conservation.

In summary, it is possible to conclude that the metric survey is the essential part of this process of seeking answers about the past and present of the monument, which can later serve for taking immediate measures to ensure is continued existence.

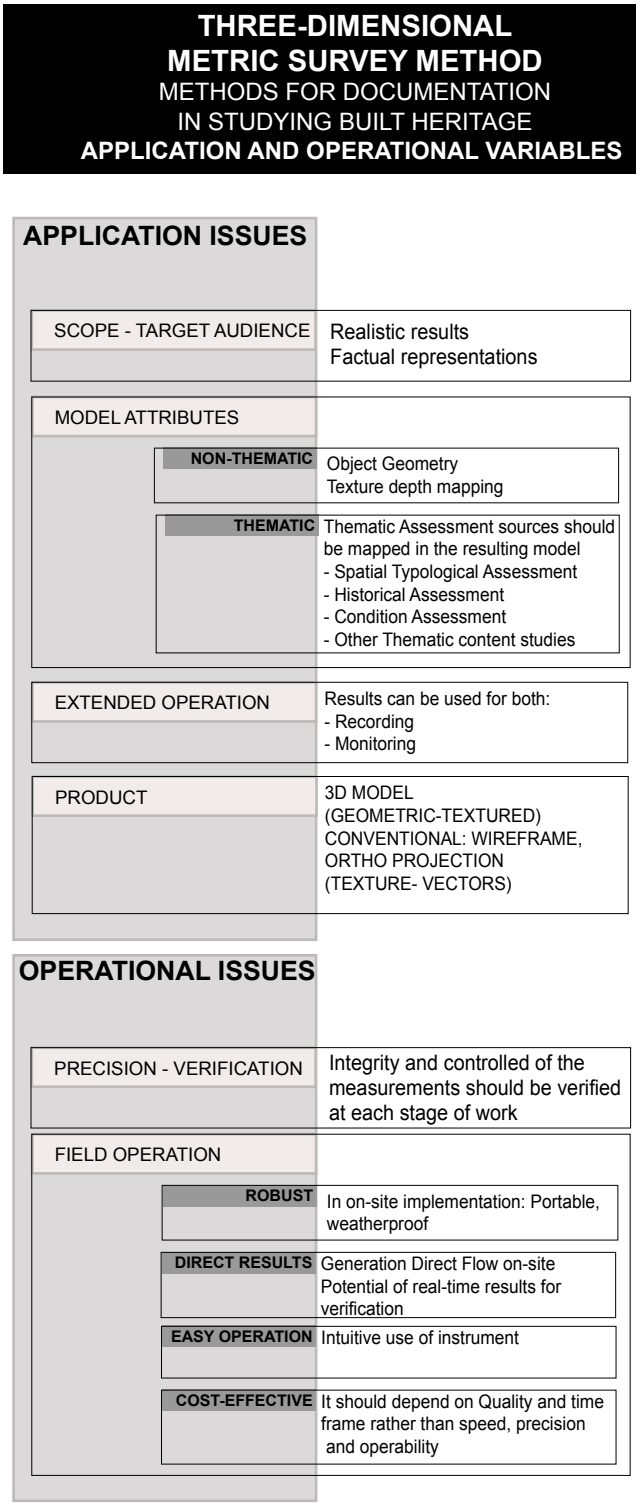


Chart 47: a 3D metric survey tool

The vital role of metric survey is evident by the attention attributed to it and the quantity of existing instruments.

On the other hand, the conventional use

of recording tools to yield line drawings seems restricted and it should be enhanced. Today's approach into documentation techniques allows for the development of real three-dimensional approaches that not only seek to collect 3D but to display and manipulate the data using three-dimensional frameworks.

This initiative is especially evidenced in the use of Virterf and Laser Scanning, where the output is difficult to transform into line drawings representations and therefore heavily criticized by conventional practitioners of the field.

5.6.1 METRIC SURVEY: CREATING A TOOL TO COLLECT AND PROCESS REAL-TIME 3D GEOMETRIC AND TEXTURE MODELS

The use of three-dimensional representations in other fields, such as medicine and manufacturing has proven to be very effective. A vectored representation or photo-realistic model created by CADR tools should not be the final product. New opportunities should embrace the development of actual three-dimensional mapping techniques, expert systems that can use actively the three-dimensional output and serve as a base data to collect more, in which the practitioner studying built heritage could be able to directly map the information three-dimensionally.

Furthermore, in this summary it is possible to distinguish two sets of variables to consider new integrated metric survey tools:

Application issues: dealing with the scope and target audience to use tool
Operational issues: associated with issues about the interaction between the tool and inherent characteristics of built heritage.

5.6.1.1 Application issues

The tool should be adapted to different scopes and target audiences, it should be capable of yielding results, which can be both realistic and that can yield factual knowledge about the geometry and texture of the object in study.

The tool should provide tools to link and map other thematic assessments about the monument, including historical facts, weathering forms and processes, etc.
The tool should be polyvalent, in that it can be used to extend the 'time frame' for recording and the monitoring of the various 'Activities' in the process of understanding built heritage, especially when applied for conservation.

The output should yield 3D measurements and textured depth maps as well as conventional formats, such as wireframe vector models containing important points, and orthographic projections of the texture and vectored set of measurements.

5.6.1.2 Operational issues

The tool should provide a level of precision and integrity of the dataset that can be directly controlled and verified at all stages of work.

It should be robust allowing on-site implementation, in other words it should be portable (with a battery for remote areas), and it should be resistant to dust and rain.

The generation of direct data flow for on-site processing and the ability to offer immediate feedback is desirable.

Easy operation: intuitive adjustment procedures and the use of the instrument
It should be cost-effective: low cost operability is desired. The cost of the system should not only depend on speed, operability, and precision, but also on the quality of the

results, and time frame available.

Finally, in this respect, this research not only encourages the development of image-based techniques that can be factually verified and linked to other metric survey tools to ensure the integrity of the measured dataset, but tools that embrace the use of other thematic assessments to understand the condition and history of the subject.

Notes:

[1] Böhler, W. Heinz, G. ,Documentation, Surveying, Photogrammetry' http://www.i3mainz.fh-mainz.de/publicat/cipa99/cipa99.pdf (Last visited 19/05/2002).

[2] Clark, K. ' Informed Conservation: Understanding historic buildings and their landscape for conservation' English Heritage, London 2001. p. 73.

[3] Ibid 3.

[4] ICOMOS; Guide to Record Historic Buildings; Butterworth Architecture, London 1990. P. 43.

[5] Conway, H. Roenisch, R. 'Understanding Architecture: An introduction to architecture and architectural history' Routledge, London, 1994. p. 69.

[6] Ibid 1.

[7] 'True or Grid meridian: the first deals with the longitude calculated by the 'astronomical observation', and the last by 'drawing a plane parallel lines to form the north-south lines of the national grid'. Hewitt, R.; Guide to Site Surveying; Architectural Press, London 1976. p. 132.

[8] 'Magnetic north is often sufficient orientation for architectural surveying'. Hewitt, R.; Guide to Site Surveying; Architectural Press, London 1976. p. 20.

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CHAPTER VI

EPILOGUE :
RESEARCH TENDENCIES AND FUTURE PERSPECTIVES

CHAPTER VI:
RESEARCH TENDENCIES AND FUTURE PERSPECTIVES

Alors que faut-il conclure? Eh bien, c'est que la conservation du patrimoine n'est ni une mode ni un jeu. C'est une réponse à un besoin humain fondamental. Si l'homme est devenu homo-sapiens après avoir été homo-erectus et l'homo-habilis c'est précisément parcequ'il a une mémoire consciente, une mémoire a laquelle il peut faire appel, qui est pour lui une source d'imagination, et de créativité grâce à cette correspondance et ces actions réactions constantes entre la mémoire et l'intelligence.

Alors si nous voulons que l'homme poursuive sa route sur la voie de l'homo-sapiens, nous avons l'obligation de préserver les témoignages du passe[1] (Lemaire, R., 1997, pp. 24).

This part of Raymond Lemaire's lecture to the '*Ordre des Ingénieurs et Architectes de Beyrout*h' in Beirut presented above underpins the essence of this work. It is a natural human impetus to want to understand built heritage, the testimonies of the past and the need of veracity, criteria, and tools to understand their message for the progress of the human race.

The message that architecture provides is imprinted into words and graphic representations, which are then used for communicating to other the actions needed in the conservation of the physical integrity of the subject and/or the preparation of legal instruments for its protection to ensure the existence of built heritage for future generations.

Subsequently, this research specifically tackles the understanding of the procedure to find explanations about the past imbedded in the 'intrinsic meaning' of buildings, which are related to their 'spatial and visible forms' (Conway, H. Roenisch, R., 1994, p. 23)[2], and that are recorded by the use of metric survey techniques in representations.

The product of these techniques is the diagram, prototype, or facsimile of the building geometry and texture of the subject that forms part of the 'core data', consisting of thematic assessments required for the analysis aimed at conserving built heritage.

6.1 RESEARCH TENDENCIES

> *'Conservation: all efforts designed to understand cultural heritage, know its history and meaning, ensure its material safeguard and, as required, its presentation, restoration and enhancement' (Nara, 1994, p. xxv)[3].*

This aim of this research is to present a number of statements and ideas to prepare '*operational guidelines*' for the use of three-dimensional metric survey studies in documentation and dissemination 'designed to understand' built heritage. In which, the intervention of multidisciplinary teams, the need of adequate preparation of such studies,

'presentation' of them, and 'enhancement' of this type of study in the conservation framework is promoted.

The structure of this study is based on the retrospective look for background arguments and fundamentals in the study of built heritage; as well as, assumptions and definitions in the use of surveying of buildings and landscapes.

Subsequently, the combination of these concepts helps create a broader context to tackle the use of metric survey methods in studying monuments.

The achievement here presented, are not measured by a technological accomplishment that in a relative short time will become obsolete and part of history, but the development of principals in the use and implementation of Metric Survey methods.

These methods, their selection and use is discussed in this research, the variables of discussion are flexible and the aim is that in the future they will serve to improve and help in updating their potential use in documenting and communicating built heritage.

6.1.1 FUNDAMENTALS IN STUDYING BUILT HERITAGE: THE ROLE OF DOCUMENTATION

6.1.1.1 The role of the metric survey in documentation of built heritage

Studying built heritage involves the documentation of different sources of information and the participation of experts from different fields. The documentation process is based on understanding values attributed to the subject in its present state of conservation. The knowledge of the building is enhanced by the interpretation of these values through the use of important fundamentals, which have been developed and explained in several charters, guidelines, and publications dealing with heritage.

6.1.1.2 Built heritage: a unique and irreplaceable source of information

The information acquired from historic buildings is unique and irreplaceable; it serves for the identification and classification of object for the development of adequate policies for its conservation and maintenance, as well as to promote identity and cultural tourism.

6.1.1.3 Phase of study

The documentation phase is one of the most important stages in the process when studying built heritage for the protection of a monument; it plays an important role as 'core-data' for deciding the types of intervention to increment the life and promotion of a monument.

Specifically in this issue, the role of the 'metric survey techniques' is essential in providing tools for speeding and making more effective the preparation of a 'base data' to be used in the documentation and dissemination of information sources of all kinds associated to the subject and its context. However, the use of conventional methods should be used wisely, maximizing their level of adaptations to the process needs and the characteristics of the field of studying built heritage.

6.1.2 DOCUMENTATION OF BUILT HERITAGE: AUTHENTICITY AS THE CONCEPT DEFINING THE 'MEASURED DATASET'

The digital 'measured dataset', product of the implementation of the Metric Survey Study in documentation and Dissemination of built heritage is defined as the result of

a 'mapping process' of the geometry and texture of the fabric of the subject and its context that are transferred to a 'computer-readable format' (Domik, G., 2000, p. 17)[4] for further Thematic assessment, such as historical, condition, and other studies aimed at the analysis of the Authenticity embed in the object of study;

6.1.2.1 Authenticity: a layered concept to studying built heritage

Subsequently, the analysis of the subject's authenticity will be based on the 'core data' dataset, combining thematic assessments, and which is carried out using the metric survey study output as a basis.

This process of stewarding the information to future generation is a very complex task that requires the production of a document in form of an information system for enhancing the knowledge of the subject and its context, as well as, producing a legal instrument to guarantee its protection.

In addition, this document or information system should be prepared with the mapping of factual evidence to avoid falsifications. These instruments are crucial to the positive or negative impact on the public in relation to the trueness and credibility of a monument.

Part I - chapter II dealt with the review and preparation of 'Authenticity' for studying built heritage.

The use of adequate digital three-dimensional modeling and representation systems will enable to simulate the complexity of the structure and its relationship with other architectural elements of the building. All the architectural elements should be included in the model although they might seem trivial or difficult to be simulated by the computer.

6.1.3 PREPARING THE MEASURED DATASET: BAUFORSCHUNG AND THE 'STATE OF THE ART' IN METRIC SURVEY TECHNIQUES

Setting grounds on the meaning of Bauforschung, the study of which that '*involves the first investigative phase of architectural historical research, combining the analysis of archaeological, historical and iconographical source material with the complete recording of a building's appearance and pathology*' (RLCC, 1996)[5].

Part I - chapter III approached the fundamentals of Bauforschung in relation to the evaluation of a series of existing and emerging documentation and dissemination techniques, specifically the use of metric survey tools.

These instruments are associated to the last sentence from the statement presented previously 'complete recording of a building's appearance and pathology' enhanced by the study of its context, in dealing with the use of Bauforschung in the study of built heritage.

Furthermore, a careful selection of techniques is presented, looking into account the following:

- Techniques, which can be use for recording the geometry and texture of the subject and its context, excluding alternative referential use of digital or analogue photography supporting a written report.
- Techniques, those are both cost-effective and sustainable in recording Built Heritage.
- The Techniques, which have been previously, tested first-hand.
- Techniques that have proven successful in their application to study heritage from an analytical point of view, based on scientific and commercial literature available.
- Techniques using electronic measuring instruments that are able to exceed

the 50 m. range in surveying standing structures and archaeological sites.

In addition, the most common problems of the large gamma of tools available for 'gathering 3D data of architectural-scale real-world objects' are based on:

- The development of specialized tools adapted to the different applications aimed at studying and disseminating built heritage.
- The combination of different recording instruments, processing tools, and dissemination application using defined standards and systems of verification.
- The objectives to prepare a measured set of representations in documentation are not clearly stated.
- The selection of the sources of information in the process of documentation is not clear, relevant or stated in the measured dataset resulting from the process.

These techniques are embraced in methods and are further enhanced in part I - chapter V, with the contribution of first-hand experiences, as well as, in numerous recent scientific, conventional, and commercial publications.

In addition, this chapter embraces fundamentals used in hand-survey techniques for understanding the fabric of the building and its history, assuming that the documentation of built heritage is a slow and 'time consuming' task.

6.1.4 METHODOLOGY: DOCUMENTATION AND DISSEMINATION OF BUILT HERITAGE: THE NON-THEMATIC MEASURED DATASET: METRIC SURVEY

According to the principals outlined in previous chapters, dealing with the significance of heritage and techniques in preparing a dataset for the analysis, this part introduces a methodology that was developed merging techniques, variables, and issues illustrated in recent literature and first-hand examples.

Furthermore, this part acknowledges the existence of specific needs for specific groups of people and therefore discusses the need to define the purpose of documenting built heritage, which deals with the relationship between the scope and the people that will use it (target audience).

Subsequently, each phase of implementation, and specially the dissemination dealing with information systems should incorporate variables for making the process transparent and consistent in every step, making the verification of the precision, observational accuracy, and relevance of the information shared, selected, and interpreted.

At the same time, the careless use of capturing, processing, and dissemination tools can mislead the operator and the user. The later can be encouraged to believe and therefore assume values of the monument that are not correct or never existed.

This problem is relevant to the nature of this field, where a substantial amount of knowledge is available and correct storage, management and retrieval tools can make the difference to the perception of the monument.

Moreover, the need, without any prejudice the attribution of a variable called 'not defined' should also be included, to identify

those areas or entities, where there is no evidence, the gap and/or missing information is too large.

In the implementation phase, it is important to review the problems dealing with 'obsolesce', when ever it deals with scientific guidelines for dealing with the methodology and the computer formats used for storing, managing, and retrieval.

Public awareness is also very important in promoting the conservation of built heritage, the use of information systems is implemented in many cases for the decision making process of protecting an object. In this application the correct use of visualizations is of relevance to obtain positive reactions.

Globally, heritage is under threat and the industry and academic communities should react. Swiftly to protect this heritage

The merging of concepts, such as 'sustainable' and 'optimised techniques' should be adopted. It is of the utmost importance thus that adequate methodologies for documenting built heritage are used.

For, it not only contributes to the creation of a permanent record of our heritage, past and present. It also helps us to understand its importance in order to encourage its future conservation.

6.1.5 APPLICATIONS: FRAMEWORK FOR THE SELECTION OF METRIC SURVEY TOOLS FOR THREE-DIMENSIONAL DOCUMENTATION AND DISSEMINATION OF BUILT HERITAGE

The methodology presented in part I - chapter IV is enhanced in this part by presenting a number of applications in studying built heritage that provides guidelines for the metric survey study in the selection of three-dimensional documentation and dissemination methods.

6.1.5.1 Metric Survey trends and summary remarks

Metric survey studies are the 'measured dataset' of digital and/or printed representations, forming the 'core data' to implement other assessments to understand the monument.

A great difference in the extent and quality of the metric survey study needed is provided on the one hand by the objective of the study (application) and on the other hand, on the extent of the works of surveying.

This is evidenced in comparing the needs of the metric survey study when preparing a 'measured dataset' for historical research applications, where the metric survey is used only to record the actual condition of the fabric and context of the building, while in conservation of built heritage, metric survey techniques are used along a dynamic and extended process. In which, several interventions in the fabric of the monument should be recorded, including the current condition prior to, during and after the works to monitor, document and evaluate the process.

6.1.5.2 The need of combining metric survey tools

This chapter deals with a proposal that was developed by merging techniques, variables, and issues illustrated in recent literature and first-hand examples. This implementation methodology may not be economically viable, however it should be used as a guideline.

Furthermore, this part discussed several elements being conjugated in the determination of the purpose of documenting, such as the relation between the scope and the people that will use it (target audience). This research acknowledges the existence of specific needs for specific groups of people.

The correct definition of the 'target audience' can have a great impact on the understanding of the end product towards protecting

heritage.

6.2 PERSPECTIVES – WHERE TO GO WITH THE DEVELOPMENT OF METRIC SURVEY METHODS FOR STUDYING BUILT HERITAGE

Electronic and image-based methods of documentation for preparing the Metric Survey Dataset provided a number of advantages over conventional recording methods. These are:

- A higher number of measurements, which can be acquired in a limited amount of time.
- Occlusion caused by height areas, legal and/or environmental restrictions can be overcome with the use of close range remote sensing methods.
- Tools can be combined for surveying and verifications of the integrity and precision of the 'measured dataset' acquired.
- The photographs used in image-based recording methods can be exploited to acquire more measurements if desired at a later stage or they can be used for comparing the state of conservation and conservation therapy interventions executed over a period of time.

Subsequently, these advantages can be combined with the use of three-dimensional information systems that merges the conventional geometric and texture acquiring, processing, and dissemination tools and the digitalisation of thematic sources of information embedded in the subject and context to create a broader instrument of storage and management aimed at the 'critical analysis' for conserving built heritage.

6.2.1 WHERE TO GO: 'A NEW GENERATION OF TOOLS FOR SELECTION AND DEVELOPMENT OF THREE-DIMENSIONAL METRIC SURVEY METHODS'

Developing a 3D tool for manipulation of geometric and texture informations from historic buildings, mapping all their elements.

The power of visualization to exploit human perception offers both a challenge and an opportunity. The challenge is that incorrect patterns can be perceived in visualizations, leading to incorrect decisions and actions (Mackinlay 2000).

6.2.2 A THREE-DIMENSIONAL INFORMATION SYSTEM FOR THEMATIC ASSESSMENTS IN STUDYING BUILT HERITAGE

An information system should be developed by using a single or multiple 3D 'Geometry-based representation(s)' (Heylighen, A., 2000, p. 67)[6] as Graphic User Interfaces as a tool of mapping, storage, management and retrieval of information sources from the subject of study in built heritage.

The representation will be depicted in its basic components, consisting of entities in 3D models and/or polygons in 2D representations.

These units are grouped in components, which are stored and organized in different user-defined hierarchical orders (Horizontal and Vertical).

The users can customize the entire systems for evaluation, navigation, collaboration, and maintenance of the dataset.

However, it is not intended as a modeling tool, the geometric-based interface remains non changeable. Only the users

defined as administrators can import a new entity replacing an old one in cases where more evidence is found, or metric survey techniques which allow better 'measured representations'.

Furthermore, the interface involves the comprehensive utilization of '*relation databases*' (Mitchell, W.J. & Mc Cullogh, M., 1995, p.479)[7] that can be created by assigning thematic attributes to the entities displayed in the user-interface.

The system should provide the possibility of customizing different views and level of details (location or clustering: displaying clusters-bounding boxes, geometric primitives, full detail with or without texture mapping) according to the needs.

On the other hand, the system should be used for different applications in studying built heritage. The following studies have been defined:

6.2.3 ALTERNATIVE HORIZONS IN THE USE THREE-DIMENSIONAL METRIC SURVEY STUDIES OF BUILT HERITAGE

6.2.3.1 Architectural design

Architects in the process of conception of design can use the 'precedent knowledge' donated by studies of historic buildings, either for the renovation of a historic building, for the analogical thinking to conceive new buildings.

This opportunity of research can search for those answers which an architect is looking for during the process of design or during the adaptation of the past to the new concepts.

6.2.3.2 3D manipulation of built environments: development of computer applications manipulating three-dimensional objects

This research presents a set of concepts to be used for the development of new technologies to enhance the use of metric survey techniques in the study of built heritage.

However, the use of three-dimensional metric survey methods can also offer tools for creating new input and output devices better integrated to the manipulation of three-dimensional representation of objects in other related fields, such as industrial design, and arts.

6.2.3.3 Case-based reasoning in architectural design

Using a three-dimensional graphic platform to access historic buildings can be used in cased-based reasoning framework in the design phase to conceive new structures.

The use of the 'precedent knowledge' fundamentals provided by this research can help create a case-based platform to enhanced the design process in conception of new buildings

6.2.3.4 Applications and strategies for educating 'architectural conservation' (Anglin, L., 1995, p.56)[8] dealing with the study of built heritage

The development of the proposed system can help to prepare applications and strategies in the training of conservation specialist in the process of recording the fabric of the subject and the thematic mapping of the historical and condition assessments in order to understand the valorization of monuments using a real-time and 3D information system.

Notes:

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[2] Conway, H. Roenisch, R. 'Understanding Architecture: An introduction to architecture and architectural history' Routledge, London, 1994. p. 34.

[3] Larsen, K.E. Ed. 'Nara Conference on Authenticity' Proceedings, UNESCO-ICCROM-ICOMOS, Japan 1994. p. xxv.

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[5] Introduction, Preparatory architectural investigation in the restoration of historical buildings. R. Lemaire Centre for Conservation, K.U. Leuven, Leuven 1996.

[6] Heylighen, A. 'In Case of Architectural Design: Critique and Praise of Case-Based Design in architecture' PhD dissertation submitted to obtain the degree of Doctor in Engineering, KU Leuven, Leuven, 2000. P. 67.

[7] Relational database: Representational structure based on a collection of tables composed of entities sharing particular attributes, each of which is expressed in a single value. Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 80.

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APPENDIX

GLOSSARY

TERMS AND CONCEPTS: METRIC SURVEY TOOLS FOR STUDYING BUILT HERITAGE

GLOSSARY

FUNDAMENTALS IN STUDYING BUILT HERITAGE

Conservation: all efforts designed to understand cultural heritage, know its history and meaning, ensure its material safeguard and, as required, its presentation, restoration and enhancement. (Cultural heritage is understood to include monuments; groups of buildings and sites of cultural value as defined in article one of the World Heritage Convention) (Nara Conference on Authenticity, 1994)[1].

Dataset: the result of the metric survey study of the subject, consisting of a set of analogue (plotted) and digital measured representations, including orthogonal projections (sections, plan sections, etc) and three-dimensional models.

Core data: the result of the thematic assessments prepared of the subject using the Metric survey study as a mapping instrument to acquired and record the actual state of conservation (weathering forms, structural analysis, etc), and historical chronology (historical documentary research, stratification, etc); as well as, other assessments adapted to the specific needs and situation of the subject. This 'core data' is used to prepare the Analytical and critical report.

Analytical and critical report: term used in the Chapter of Venice, in this research it is described as the resulting product of the Non-thematic (Metric Survey) and thematic studies (Condition assessment, historical assessment and other assessments required) aimed at accessing and analysing the information embedded in the subject and context and relevant for its conservation.

BAUFORSCHUNG: METRIC SURVEY STUDY

Analytical Recording: consists largely in the interpretation and subsequent record of the significant evidence for a building's original form and subsequent history that is contained within its fabric (ICOMOS, 1990)[2].

Attribute: Column of a table in a relational data model. Represents a property shared by one or more entities (Mitchell, W.J. & Mc Cullogh, M., 1995, p.468)[3].

A property or characteristic of a graphical object, e.g. its colour. Attributes can also be non-graphical, e.g. cost (Szalapaj, P., 2001, p. 220)[4]

Bauforschung: "*is a fundamental part of every methodology specifically designed to evaluate and maintain historical buildings" (RLICC, 1995)*[5]. The first stage towards conservation and restoration requires consulting all sources related to the history of the building in order to be well informed.

Therefore, it is important to survey it in all its different aspects and at every possible level of significance. "*Bauforschung involves the first investigative phase of architectural historical research, combining the analysis of archaeological, historical and iconographical source of material with the complete recording of a building's appearance and pathology"(RLICC, 1995)*[6].

Data (digital format): is the result of a mapping process from the world (reality—the problem domain) to a computer-readable format (Domik, G., 2000, p. 17)[7].

Documentation: 1. Any evidence that

supplies factual information about a subject. 2. The data that record the existing and prior condition of an existing building, structure, or site; typically includes measured drawings, earlier as-built and original working drawings, historic and contemporary photographs, historic references to the appearance and materials, and, sometimes, archaeological research. 3. The process of tracing the history and establishing the authenticity of a cultural artifact. 4.The national Register information that describes, locates, and explains the significance of a historic property (Bucher, W., 1996, p.70)[8].

Entity: Basic unit of storage in a geometric database. Usually corresponds to a graphic primitive, transformed, with assigned non-geometric properties (Mitchell, W.J. & Mc Cullogh, M., 1995, p.471)[9].

Geometry: this concept is widely used in the use of computer Aided drafting, it describes 'the properties of CAD objects that determine their shape, such as their construction in terms of point, lines and angle values' (Szalapaj, P., 2001, p. 221)[10].

Metric or measured survey: any form of survey conducted using a repeatable and verifiable method such that the design, execution, sequence of construction, occupation and function of a structure is clearly shown on plans, sections and elevations (Clark, K., 2001, p.113)[11].

SURVEYING CONCEPTS

Azimuth (Surveying): the horizontal direction of a line measured clockwise from a reference plane, usually the meridian. Often called forward azimuth to differentiate from back azimuth (R.E.A. 1983)[12].

Bearing: the direction of a line within a quadrant, with respect to the meridian. Bearings are measured clockwise or counterclockwise from north or south, depending on the quadrant (R.E.A. 1983)[13].

Bench mark: a relatively permanent object, natural or artificial, bearing a marked point whose elevation above or below an adopted datum is known. Usually designated as a BM, such a mark is sometimes further qualified as a PBM (permanent bench mark), or as a TBM (temporary bench mark). (R.E.A. 1983)[14].

Error: 1. The difference between an observed or true value of that quantity. 2. A class of small inaccuracies due to imperfections in equipment or techniques, surrounding conditions, or human limitations; not to be confused with blunders or mistakes (R.E.A. 1983)[15].

Occlusion: Hiding an object or a portion of an object from sight by interposition of other objects (Forte, M. 2000, p. 260)[16].

Universal Tranverse Mercator (UTM) projection: '*is a world-wide system of transverse Mercator projections based on the International Earth Ellipsoid 1924. It comprises about 60 zones, each 6o in longitude wide, with central meridian at 3o, 9o, etc. from zero meridian. The zones are numbered from 1 to 60. In latitude, the UTM system extends from 80o N to 80o S, with the polar caps covered by a polar stereographic projection*' (Scofield, W., 2002, p. 240)[17]

CADR GENERAL CONCEPTS

Computer Aided Drafting (CADR): this research replaces the 'D' for Design with Drafting, dealing with the use of these type of applications to in recording and representing the actual state of the subject instead of a conceptual tool to prepare a measured representation of an architectural design.

Layers: Logical groupings of geometric entities, usually for visibility purposes, in which the member entities remain individually addressable (Mitchell, W.J. & Mc

Cullogh, M., 1995, p.475)[18].

Operation: a basic CADR system function (Szalapaj, P., 2001, p. 223)[19].

Polyline: an entity formed by line segments and curves joined end-to-end (Mitchell, W.J. & Mc Cullogh, M., 1995, p.478)[20].

Wire-frame: the presentation of a 3-D CAD model in terms of lines in 3-D space (Szalapaj, P., 2001, p. 225)[21].

DATA-COLLECTION: ACQUISITION OF THE RAW DATASET

Data-acquisition: the process of retrieving measurements from the existing building directly to construct a digital drawing (Stenvert, R., 1991, p.120)[22].

Digital Data: information captured, stored and managed electronically through the use of electronic tools, such as computers[23].

CLOSE-RANGE DIGITAL PHOTOGRAMMETRY

Fiducial: is a physical point in a camera that is positioned such that when photograph is taken, it is imaged on the film at the same time as the image coming through the lens. Fiducials are attached to the body of the camera so the images of the marks leave a frame of reference on the film image that ties the image to the camera. So no matter how the image is cropped, enlarged, shifted or scanned (PhotoModeler, 1998, p..395)[24].

Orthophotographs: two dimensional photographs which have been corrected for scale errors, that is, the scale is consistent across the photograph, irrespective of the relief or change in plane of the subject. They are product of digital photogrammetry (Clark, K., 2001, p.113)[25].

Photogrammetry: "*it can be defined as a field of competence devoted to methods collecting geometrical data from material objects through photographs, and has been developed since the middle of the 19th century"* (Haller, B., 1967) [26].

PLANE PARALLEL PHOTOGRAPHIC RECTIFICATION

Optical rectification of photographs: is performed by aero sketch-masters where photographs and the plan are brought to a perspective. It is commonly applied only to complete some details in already existing plans (Badekas, J. 1975, p.23)[27].

Picture plane: Local two-dimensional coordinate system, defined relative to absolute three-dimensional coordinate system, onto which three-dimensional objects are projected for viewing (Mitchell, W.J. & Mc Cullogh, M., 1995, p.477)[28].

DATA-ANALYSIS: PROCESSING AND MODELING

Interface: Any device, software, or technique that allows people to perform task with a computer (Forte, M. 2000, p. 260)[29].

Solid model: Three-dimensional representation including vertices, edges, faces, and the occupation of enclosed space (Mitchell, W.J. & Mc Cullogh, M., 1995, p.480)[30].

Texture mapping: The projection of values from a texture bitmap onto model geometry at time of viewing. Texture map may be sampled (scanned) or synthesized (Mitchell, W.J. & Mc Cullogh, M., 1995, p.482)[31].

TIN: Triangulated Irregular Network. Irregular mesh of planar triangular facets usually used to represent terrain surface. Facet density may be varied in correspondence with fineness of detail (Mitchell, W.J. & Mc Cullogh, M., 1995, p.482)[32].

Vectorization: in the process of vectorization, every geometrical primitive -often somewhat confusingly called object- is provided with several parameters. For example a line segment is defined by coordinates of begin- and endpoint and their relationship (here: line). At the same time for every object information about color, line width, line style, Layer etc. is additionally stored (Stenvert, R., 1991, p.97)[33].

DATA-SYNTESIS: DISSEMINATION AND INFORMATION SYSTEMS

Augmented reality: the use of transparent glasses on which a computer displays data so that the viewer can simultaneously view virtual and physical objects. As general definition, the variety of techniques that combine computer-generated images and other objects with real scenes, creating augmented reality (Forte, M. 2000, p. 260)[34].

Level of detail (LOD): A model of a particular resolution among a series of models of the same object. Greater graphic performance can be obtained by using a lower LOD when the object occupies fewer pixels on the screen or is not in a region of significant interest (Forte, M. 2000, p. 261)[35].

Modeling: a valid and reliable mapping process of the world (Domik, G. 2000, p. 17)[36].

Presence: a feeling of being immersed in an environment, able to interact with objects there. A defining characteristic of a VR system (Forte, M. 2000, p. 261)[37].

Realtime: the condition in which results are calculated at least as quickly as they are anticipated, i.e., without perceptible delay (Mitchell, W.J. & Mc Cullogh, M., 1995, p.479)[38].

Relational database: representational structure based on a collection of tables composed of entities sharing particular attributes, each of which is expressed in a single value (Mitchell, W.J. & Mc Cullogh, M., 1995, p.479)[39].

Virtual reality (VR): is a computer-mediated illusion of the real world that looks, sounds, smells, tastes, feels, and behaves real (Kerlow, I.V. & Rosebuch, J., 1994, p. 242)[40]. The way to get there involves perfecting and integrating several kinds of realism. It demands smoothly rendered three-dimensional graphics. Furthermore, the sound might be produced binaurally, but it must be environmentally positioned. On the other hand smell and taste are sources that have not been mastered yet.

CONSERVATION OF BUILT HERITAGE

ARCHAEOLOGICAL EXCAVATIONS

Occupational level: describes a stratum covered with the remains of one period of history on the site (Detweiler, A.H., 1948, p.10)[41].

Stratification: this a concept used in archaeology related to the material culture contained in the structure's fabric, a addition of all the cultural occupation levels, at individual or collective levels (Feiffer, C., 2000, p. 46)[42].

CONSERVATION: THEMATIC STUDIES

Information sources: all material, written, oral and figurative sources which make it

possible to know the nature, specifications, meaning and history of the cultural heritage (Nara Conference on Authenticity, 1994)[43].

CONDITION ASSESSMENT

Finite Element Analysis (FEA): an application based upon 3D boundary or solid representation is called Finite Element Analysis, a technique in which the 3D structure of the model is divided into a large number of finite elements usually rectangular or triangular shapes) forming an interconnecting network of concentrated. By using a computer with significant compu tational capabilities, the entire object can be analysed in this way for stress-strain, heat transfer, and characteristics by calculating the behaviour of each node. By determining the interrelating behaviours of all the nodes in the system, the behaviour of the entire object can be assessed. A useful application of FEA in the humaniora is for example the determination of casting technologies for historic casting in which simulations of the casting process are used to simulate and understand the historical weaknesses found in the cast metal tools, which were caused by cracks during solidification (Stenvert, R., 1991, p.105-106)[44].

HISTORICAL ASSESSMENT

Historical research: this stage consists of the acquisition, analysis and interpretation of the available documentation concerning the construction (drawings, designs, surveys, etc), and a chronology of events such as work affecting the structure and the foundations, failures, alterations, earthquakes, etc.

Special care should be given to events that might have influenced structural behavior, while the reliability of the sources should also be considered. (Croci, G., 1998, p. 66)[45].

Iconographical sources: this term is related to the definition of Iconography in the Britannica Online encyclopedia *"it is the science of identification, description, classification, and interpretation of symbols, themes, and subject matter in the visual arts*" (Britannica online, 1997)[46]. In this research, Iconographical sources are defined as the identification, classification and manipulation of visual item to be found among historic documents.

OTHER CLARIFICATIONS (HABS, 2000)[47]

Façade vs. elevation: A Façade is the wall of a building, usually the front; an elevation is a drawing of a wall.

Interior vs. inside; exterior vs. Outside: Interior and exterior connoted defined boundaries, while the others are nonspecific

Historic vs. historical: historic is the adjective used to denote something that is old and presumably important, i.e., historic building fabric; historical is the adjective used when the subject relates to history, i.e., historical society

Notes:

[1] Larsen, K.E. Ed. 'Nara Document on Authenticity', Proceedings of the Nara Conference on Authenticity, UNESCO-ICCROM-ICOMOS, Japan 1994.
[2] ICOMOS; Guide to Record Historic Buildings; Butterworth Architecture, London 1990.
[3] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 468.
[4] Szalapaj, P. 'CAD Principles for Architectural Design: analytical approaches to computational representation of architectural form' Architectural Press, Oxford 2001, p.220.
[5] Introduction; International updating course on the role of Preparatory architectural investigation of historical buildings (1996).
[6] Ibid 4
[7] Domik, G. 'Do We Need Formal Education in

Visualization' IEEE Computer Graphics and Applications; IEEE Computer Society, Vol 20/4, Jul.-Aug. 2000, p. 17.

[8] Bucher, W. 'Dictionary of Building Preservation', Preservation Press, New York 1996, p. 70.

[9] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 471.

[10] Szalapaj, P. 'CAD Principles for Architectural Design: analytical approaches to computational representation of architectural form' Architectural Press, Oxford 2001, p.221.

[11] Clark, K. ' Informed Conservation: Understanding historic buildings and their landscape for conservation' English Heritage, London 2001. p. 113.

[12] Staff of Research and Education Association; Handbook of Field Surveying; Research and Education Association, New York, 1983.

[13,14,15] Ibid 10.

[16] Forte, M. 'VR Terminology', Virtual Reality in Archaeology, Barcelo, J.A., Forte, M. & Sanders, D. Ed. BAR International Series 843, Oxford 2000. p. 260.

[17] Scofield, W., 'Engineering Surveying, 5th edition, Butterworth and Heinemann, Oxford 2002, p. 240.

[18] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 475.

[19] Szalapaj, P. 'CAD Principles for Architectural Design: analytical approaches to computational representation of architectural form' Architectural Press, Oxford 2001, p.223.

[20] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 478.

[21] Ibid 18, p.225.

[22] Stenvert, R. 'Constructing the past: computer-assisted architectural-historical research: the application of image-processing using the computer and Computer-Aided Design for the study of the urban environment, illustrated by the use of treatises in seventeenth-century architecture' Proefschrift Rijks Universiteit Utrecht, Utrecht 1991. P. 120.

[23] Handouts from the Introductory Course: Digital Heritage Recording Principles and Practices; low-cost Computers tools for Heritage Conservation Practices; (1995), P.11.

[24] PhotoModeler, EOS Sytems, 1998, p. 395.

[25] Clark, K. ' Informed Conservation: Understanding historic buildings and their landscape for conservation' English Heritage, London 2001. pp. 81-82.

[26] Hallert, B. (1967)

[27] Badekas, J. 'Photogrammetric Surveys of Monuments and Sites' North Holland/American Elsevier, 1975, p. 23.

[28] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 477.

[29] Forte, M. 'VR Terminology', Virtual Reality in Archaeology, Barcelo, J.A., Forte, M. & Sanders, D. Ed. BAR International Series 843, Oxford 2000. p. 260.

[30] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 480.

[31] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 482.

[32] Ibid 26.

[33] Stenvert, R. 'Constructing the past: computer-assisted architectural-historical research: the application of image-processing using the computer and Computer-Aided Design for the study of the urban environment, illustrated by the use of treatises in seventeenth-century architecture' Proefschrift Rijks Universiteit Utrecht, Utrecht 1991. P. 97.

[34] Forte, M. 'VR Terminology', Virtual Reality in Archaeology, Barcelo, J.A., Forte, M. & Sanders, D. Ed. BAR International Series 843, Oxford 2000. p. 260.

[35] Ibid 29. p. 261.

[36] Domik, G. 'Do We Need Formal Education in Visualization' IEEE Computer Graphics and Applications; IEEE Computer Society, Vol 20/4, Jul.-Aug. 2000. p. 17.

[37] Ibid 29. p. 261.

[38] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 479.

[39] Mitchell, W.J. & McCullogh, M 'Digital Design Media; A handbook for Arch. & Design Professionals' 2nd edition, John Wiley & Sons, INC., NY 1995. P. 479.

[40] Kerlow, I.V. & Rosebuch, J.; Computers Graphics for Designers & Artists; Van Nostrand Reinhold, N.Y. 1994. p. 242.

[41] Detweiler, A.H. 'Manual of Archaeological Surveying', American Schools of Oriental Research, Publications of the Jerusalem School, New Haven 1948, p. 10.

[42] Feiffer, C. 'La Conservazione delle superfici intonacate: il metodo e le tecniche', Skira, Milano 2000, p. 117. Original Italian paragraph: Stratificazione sta a indicare un concetto di tipo archaeologico, una attenzione alla fabbrica in quanto contenitore di culture materiali, una sommatoria di livelli culturally, di istanze individuali e collective

[43] Larsen, K.E. Ed. 'Nara Document on Authenticity', Proceedings of the Nara Conference on Authenticity, UNESCO-ICCROM-ICOMOS, Japan 1994.

[44] Stenvert, R. 'Constructing the past: computer-assisted architectural-historical research: the application of image-processing using the computer and Computer-Aided Design for the study of the

urban environment, illustrated by the use of treatises in seventeenth-century architecture' Proefschrift Rijks Universiteit Utrecht, Utrecht 1991. P. 105-106.

[45]Crocci, G. 'The Conservation and Structural Restoration of Architectural Heritage', Advances in Architecture Series, Sevilla 1998, p.66.

[46] *Britannica Online service* in the Internet; http: //www.eb.com/ (1997)

[47] Historic American Building Survey 'HABS/HAER Guidelines HABS: Historical Reports' http://www.cr.nps.gov/habshaer/habs/guidelines/HABS-historian-guidelines.PDF (Last visited: 16/07/2001)

PART TWO

THE PRACTICE: CASE STUDIES

CHAPTER I

CASE STUDY

Conservation and Broader Audience presentation of Built Heritage:

al-Baleed Archaeological Park, Sultanate of Oman

CHAPTER I

CASE STUDY: CONSERVATION AND BROADER AUDIENCE PRESENTATION OF BUILT HERITAGE:
AL-BALEED ARCHAEOLOGICAL PARK, SULTANATE OF OMAN

This part presents the efforts of an interdisciplinary and international team of experts lead by Professor Michael Jansen, which has been working for the conservation of the archaeological site of 'al-Baleed', for the development of an archaeological park and the preparation of guidelines for sustainable and adapted approaches in the documentation of the site, making emphasis in the training of local experts and develop legislation for protecting monuments.

The appropriate application of Metric Survey techniques in archaeological sites not only contributes to create a permanent record of its past and present, but also to understanding its importance and thereby ensuring its conservation.

1.1 AIM

The role of documentation in the conservation of archaeological sites involves the use of recording techniques capable of producing a measured assessment or dataset that includes the geometry and texture of the fabric and context of the subject.

This dataset of measured plans is a very important and reliable source of information remaining of a monument that is either destroyed by natural phenomenon or by human action.

This case study is based in a number of field examples, where the recording instruments and methods of documentation and dissemination of monuments has been used for preparing a measured 'dataset' of representations of all stages of work, which are aimed at serving as tools for preparing thematic assessments, dealing with mapping the condition of the fabric (materials used in the fabric, weathering forms, structural problems), understanding its history (documentary research, stratigraphy, map regression, etc).
and other studies.

Subsequently, this resulting 'core data' of different assessments will be use for preparing a '*analytical and critical report*' (Charter of Venice, 1964, pp.13)[1] to understand the relevance and actual state of conservation of a subject and its context to be used in an appropriate conservation strategy. These examples were developed using recording tools widely used in geodesy and adapted to the needs of the specific area and the available resources, making emphasis in the use of optimal and sustainable methods for developing countries.

1.2 AL-BALEED ARCHAEOLOGICAL PARK, SULTANATE OF OMAN

Al-Baleed, the old Dhofar, in the vicinity of the modern town of Salalah in South Oman was one of the important seaports (see figure 47), which had trade connections by ship to South-East Asia at least from the 8th to the 16th century AD. Its fast decline has to be seen in the direct connection with the colonial



Figure 47: General view from the west of al-Baleed. The location of the site in Oman and different views of the site.

ACTIVITY PLAN

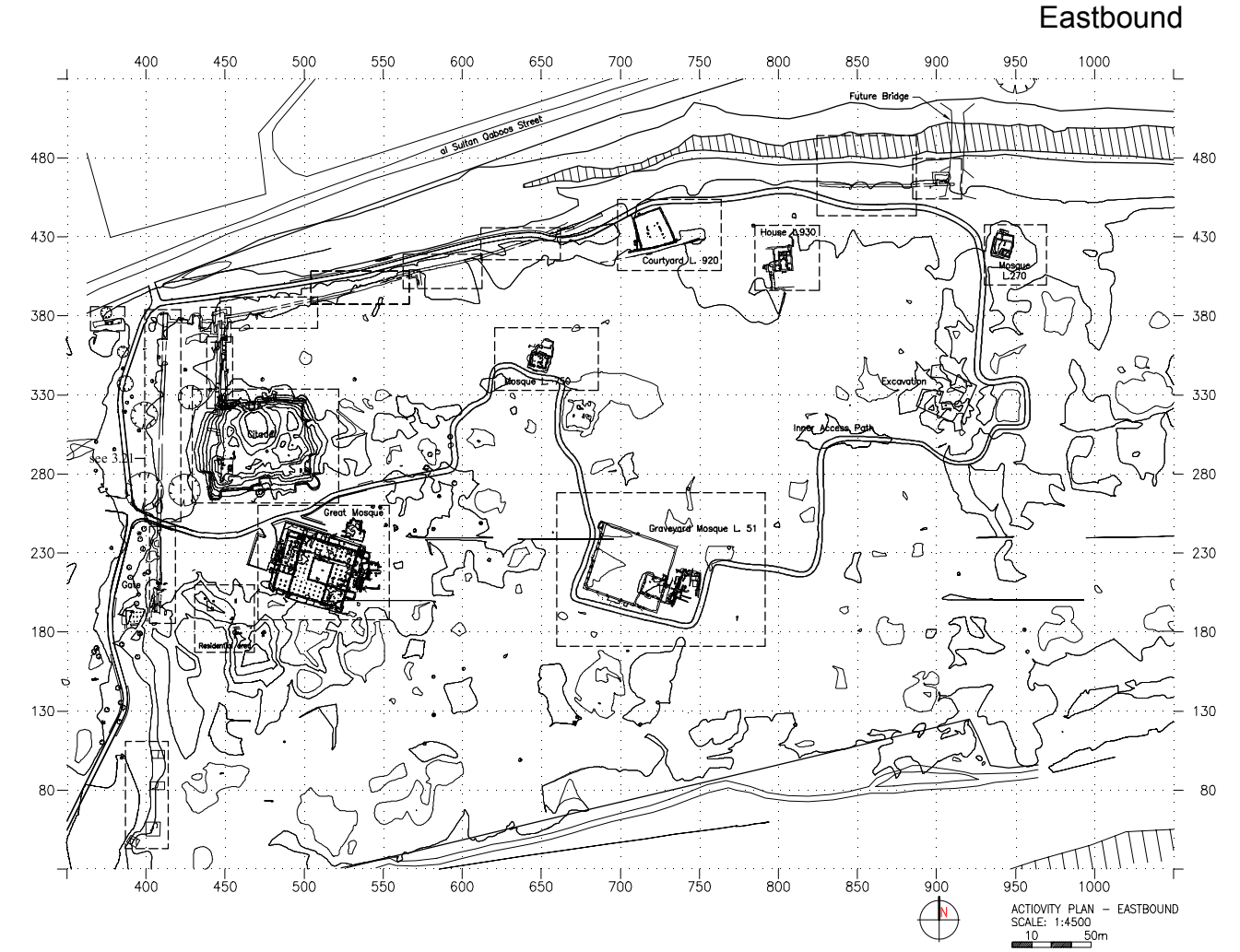

Figure 48: general activity plan of the eastbound of the site

expansion of the Portuguese under Vasco da Gama after 1498 AD.

As archaeological park, al-Baleed, will support cultural tourism in Oman. Jointly with three other sites representing the traditional frankincense trade of the Roman ´Arabia Felix´, in 2000 al-Baleed was accepted by UNESCO as a World Heritage Site.

1.3 METRIC SURVEY IN DOCUMENTATION OF ARCHAEOLOGY

The role of metric survey studies in documentation of archaeology plays an essential role as in many cases it may become a primary source for research after the removal of earth and structures. The traditional recording is mainly done by conventional or traditional hand-survey methods through (vertical) profile and (horizontal) planum in orthogonal measuring methods.

Recording in archaeology means in the ideal sense three-dimensional recording and thereafter simulation of excavated (and mostly removed) setting. Technically speaking we are still far away from any such recording. At least and partially with the introduction of a 3D recording method by the use of electronic distance measurement total station and its software an appropriate approximation can

be obtained.

Furthermore, documentation in archaeology also means recording of structure surface textures like material patterns of walls (brick, stone etc.). Here the texture as a pattern is of primary importance, not its precision in measurement. Instead of time consuming traditional hand measurements, simple approximate photographic recordings with their electronic interpretation may under specific conditions lead to better, faster and more economic documentaries.
Subsequently, documentation in this field also means administration and management of huge information databases. Here a newly developed administration Information system has been developed jointly with the private sector and may help in supporting, storing, and quick access to complex data structures.

As a consequence of modern time and finance constraints new ways of rationalization also in archaeology have to be looked for. While hardly any improvement can be envisaged in excavation techniques, definitely rationalization can be obtained in the sector of documentation. This presentation may offer one way of doing so.

1.3.1 DEFINITION FRAMEWORK IN THE SELECTION OF METRIC SURVEY TOOLS TO ACQUIRE THE GEOMETRY AND TEXTURE OF THE SITE

Applications

In this case study, and according to the needs of the project, the use of metric survey tools have been concentrated in preparing a ‘measured dataset’ that can be use for conservation works and for the presentation of the site to a broader audience.

The target audience of this application is both professional as visitors and decision makers. Making emphasis in the use of metric survey representations for protection and education purposes.

Subsequently, the combination of these two applications generated a higher emphasis in the collection and dissemination of the measured dataset using different representation tools.

On the one hand, sets of representations are prepared for experts studying and monitoring the excavation works in the site and interventions required to protect the integrity of the fabric of the site.

On the other hand, a set of digital three-dimensional animations and three-dimensional models printed on paper have been prepared to explain the actual state of conservation of the site and present several hypothetical reconstructions of different parts of the site showing how it might have been looking like. This last has been always presented using transparent models to explain the public that they are fictitious (See chart 48).
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Expected Quality and task definition

The ‘metric survey study’ is composed of measured representations with a reliable completeness of information and that are of the highest possible quality. The tasks of the ‘metric study’ are of a higher extend, including measurements prior, during and after excavation works (See chart 48).

Variables in the identification of restrictions in the use and selection of metric survey tools

The variables are ordered according to their relevance in the application (See Chart 48).

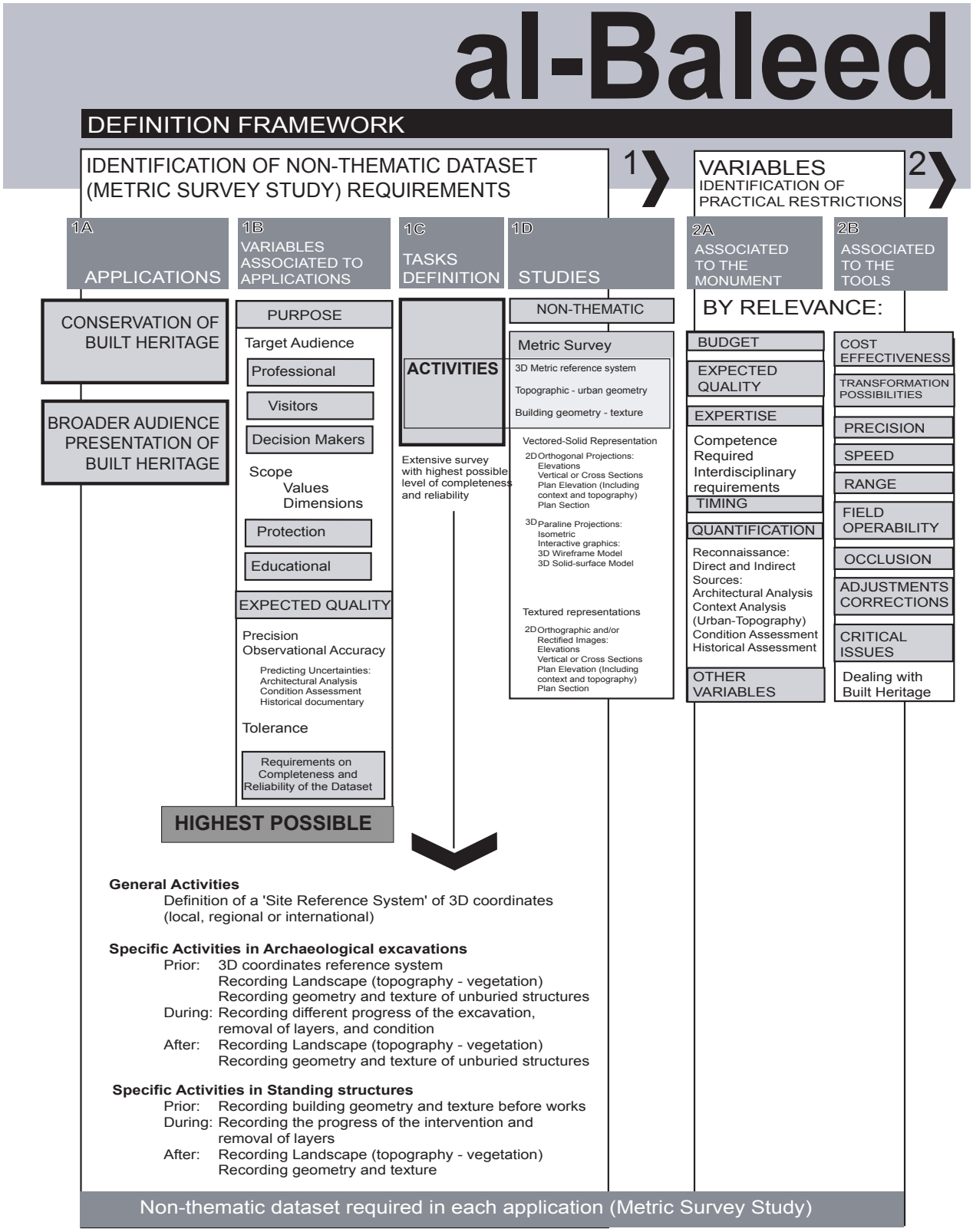


Chart 48: application framework applied to this case study.

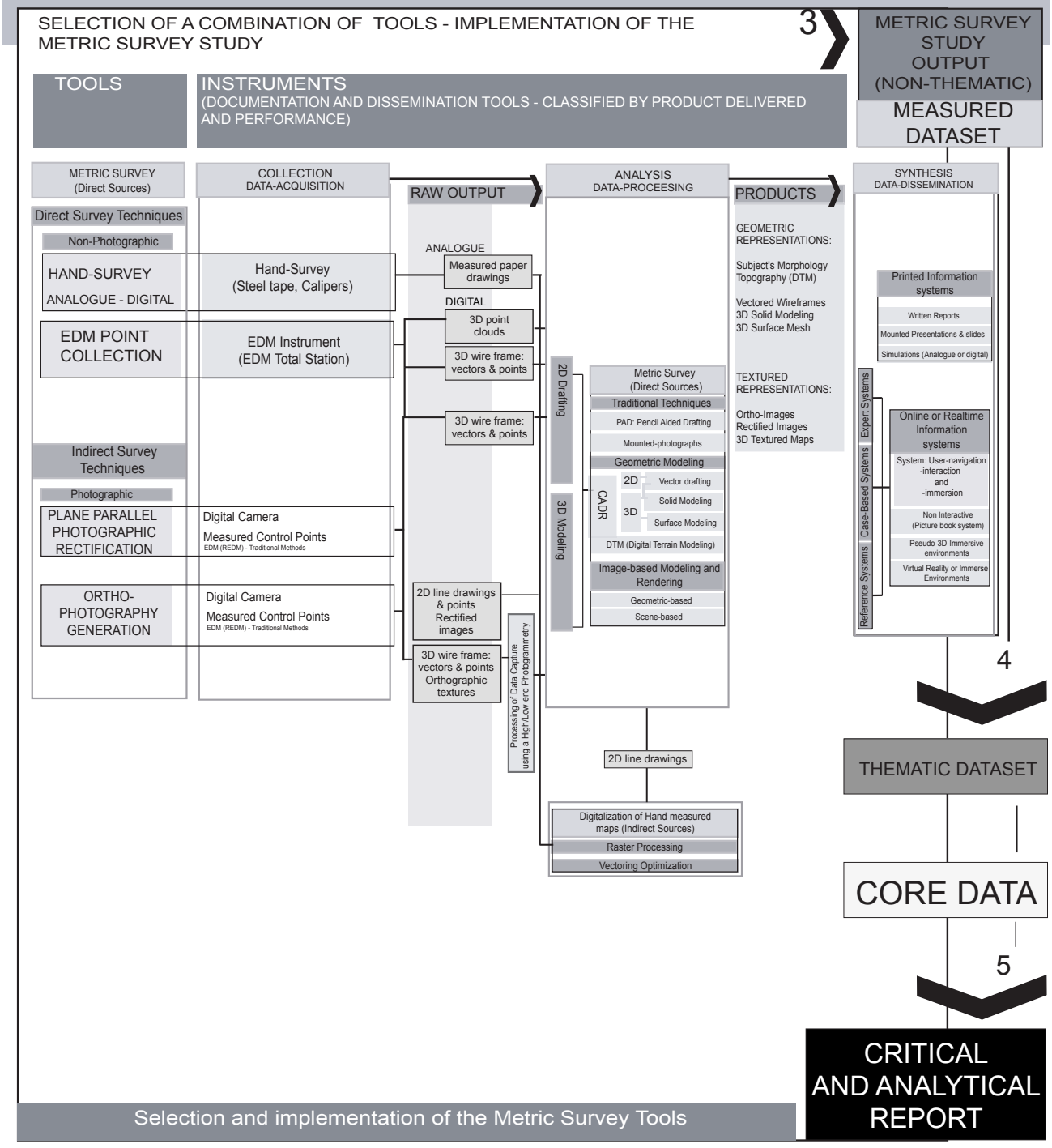
Budget

The metric survey tools used in the works of documentation al-Baleed are cost-effective according to the amount of money available for documentation, which also includes the preparation of a photographic database of the site, pottery database and measurements of the excavation works.

This variable associated to the monument affects the selection of tools that can

FRAMEWORK: SELECTION OF TECHNIQUES IN PREPARING THE METRIC SURVEY MEASURED DATASET

SELECTION FRAMEWORK



effectively deal with: cost-effective, level of precision, transformation possibilities of the dataset collected to be use in different representations, speed-range, field operability and their capacity to deal with critical issues in recording built heritage.

Expected quality

See expected quality and task definition.

This variable associated to the monument affects the selection of tools that can effectively deal with: cost-effective, transformation

possibilities of the dataset collected to be use in different representations, level of precision, speed-range, field operability and their capacity to deal with critical issues in recording built heritage.

Expertise

The use of digital tools were appropriate to the need of having an interdisciplinary team of professional that could help building up a 'measured dataset' adapted to the needs. The property of digital technology to be modified and upgraded during the whole process was very successful to produce a good set of representations.

This variable associated to the monument affects the selection of tools that can effectively deal with: cost-effective, transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, field operability and their capacity to deal with critical issues in recording built heritage. But especially attention should be concentrated in their requirements in adjustments-corrections.

Timing

The interdisciplinary team of international experts has been working in the site for a period of one to two months, two times a year. This restriction affected the selection of metric tools that could deliver sufficient data in a relative short time.

This variable associated to the monument affects the selection of tools that can effectively deal with: cost-effective, transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

Quantification

The metric survey study has been adapted each campaign to fulfill the needs of the specific tasks. During the first year an extensive topographic and surface mapping of standing structures was carried out to have an adequate idea of the extend of the site and work required.

During the following campaigns the works was concentrated in measuring the activities being excavated and therefore update the first general plan made of the site.

This variable associated to the monument affects the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

Other variables

Since the project was made in cooperation with local authorities, accessibility was not restricted.

Training of local experts can be included as a variable to consider, since a lot of effort was made to make accessible the procedures and tools used in preparing the measured dataset, this certainly limits a bit the action of the recorder but ensures the successful transmission of the methods to local staff to carry out them during a longer period of time.

These variables associated to the monument affect the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

1.3.2 METRIC SURVEY TOOLS

The use of metric survey tools in the different sites is associated with the collection of a vast amount of information from different sources. These sources are related to the implementation of different activities for gathering information and thereby developing guidelines for the conservation of the site. These activities are classified in:

- Excavation
- Conservation
- Landscaping
- Didactics

Documenting Excavation works

Excavation deals, structurally speaking, with the documentation of surfaces prior, during excavations and after excavation works; as well with the detail documentation of the fabric masonry (e.g. stone by stone), horizontally as well as vertically.

The loci of objects can be easily identified by the 3D co-ordinates obtaining with the total station output thus allowing immediate 3D identification. Of course this recording does not substitute the traditional planum- profile recording.

While methods for 3D surface recording by a Electronic Distance Measurement total-station (Topcon, Leica etc.) have been proved to be extremely effective and precise, plan parallel recordings with simple photography transferred into electronic recording programs has been proved sufficient in relation to approximate survey tolerance for the identification and study of surface structures such as stone by stone documentations. The same method can be applied for the recording of planum and profile with the critical re-working in the photo/ record itself.

The information gathered is recorded and produced simultaneously to the works through the use conventional and sustainable off-shelf application and instruments widely available in the market, such as a Total Station, Computer-Aided Drafting applications, digital and analogue cameras, scanner, and raster image processing applications used for plan parallel roughly rectified photography.

<u>Establishing a local reference (coordinate) system: using an EDM Total Station point collection tool</u>

Two different local coordinates systems were prepared in previous excavations at al-Baleed, the first one Frank Albright from the USA in the 1950s and the second one by P.M. Costa in the 1970s.

The Local reference system of was prepared by a surveying team composed by D. Lehner, D. Langer, R. Niehörster and M. Poths were based on P.M. Costa's system.

The new local system was prepared by creating a standpoint called ST-1 which had the coordinates 700/300 in P.M. Costa's local system and coordinate 730/300 as east horizontal reference. The selected height was set to be 100 meters to avoid negative numbers. Furthermore, two TPs (trigonometric points) provided by the Ministry of Housing of Oman were measured into system in order to adapt the system to the international standards if required in the future, these points concur with the '*larger World Geodetic System of 1984* (WGS 84)' (Lehner, C, 1999) [2].

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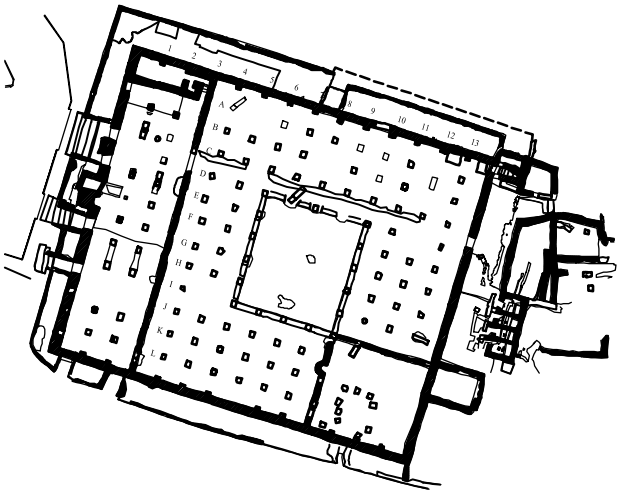
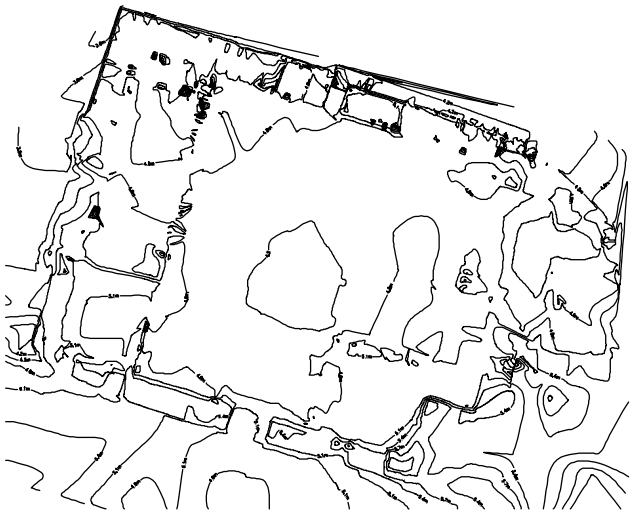
The measurements were made using an Electronic Distance Measurement Total Station Topcon GTS 6B, other new standpoints were prepared and record in the memory card of the instrument. These points were fixed in different areas covering the entire site and visible from each other. The total station records by sending an infrared beam to a reflector (set at the same height as the instrument) placed at the specific point

Measuring excavation works

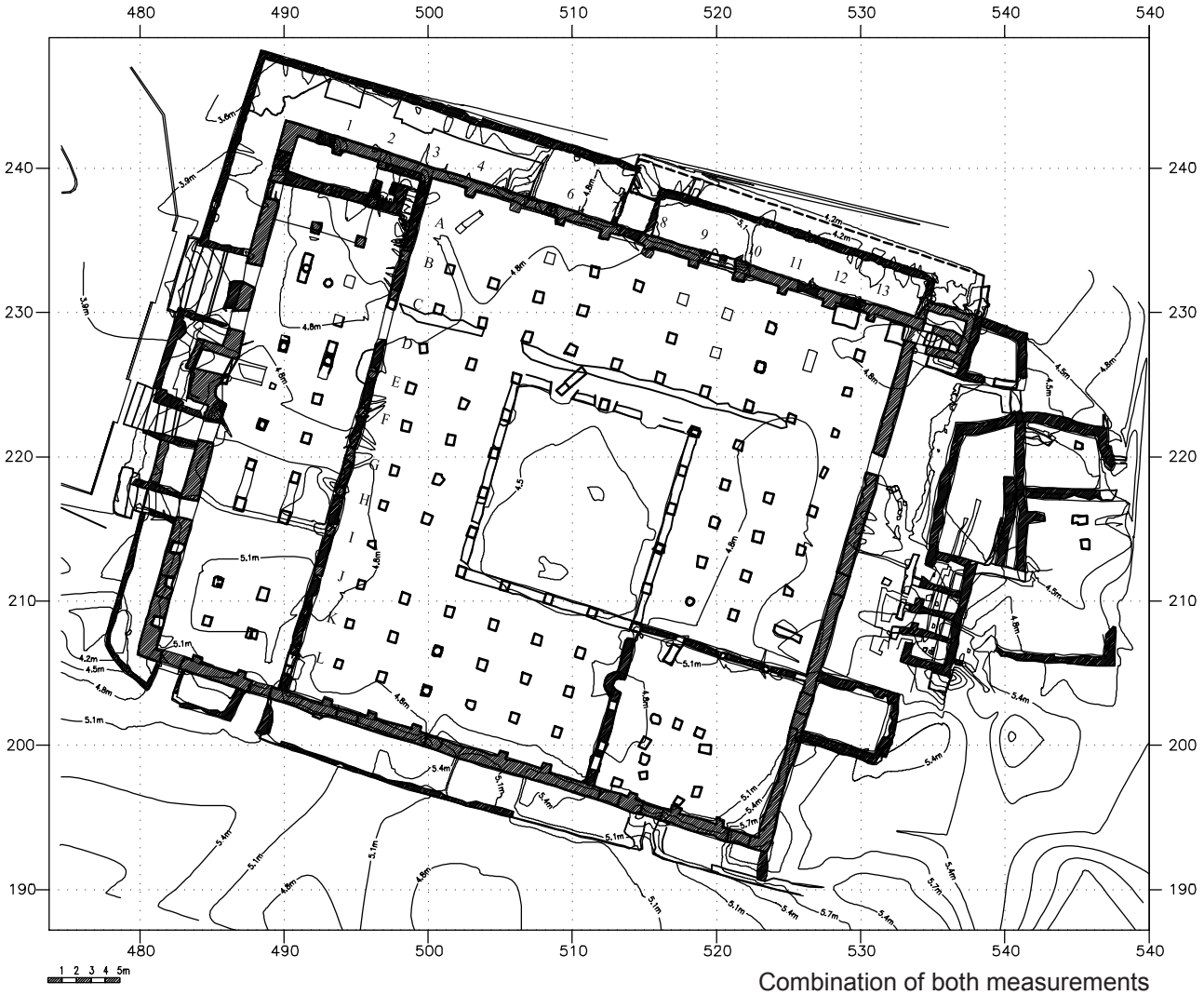
Great Mosque



Measurements of architectural features



Measurements of topographic features



Combination of both measurements

Figure 49: measuring excavation works, example: recording architectural and topographic features of the Great Mosque. Author.

to be measure alloying the instrument to calculate the three-dimensional co-ordinate of the point and if required the horizontal or vertical angle from the standpoint.

Furthermore, the records were stored in a memory card located in the total station, after surveying the points collected in this card was transferred to a notebook computer using the CR-1 unit and a software that transform the surveying data into a format readable by a CADR application.

The survey and storage of the collected points were divided into two sets. One part was devoted to the geometry of topographic features and the other to the architectural features or remains (see figure 49).

Moreover, the architectural features are surveyed by placing the reflector in the top and bottom of the object thus providing two known points for it. The measured points will be use to create the elements using the solid or surface modelling extension in the CADR application. On the other hand, the topography is surveyed by making a systematic measurement with a specific distance depending on the complexity of the slope. As for instance every 5m in a triangular schema.

Each day the information was transferred to the computer and process to create the first plans of the area. The collected points were introduced into the CADR environment using an alternative Digital Terrain Modeller (DTM) application called AutoTerrain that enables the calculation of the topography of the site using three-dimensional contour lines and surfaces.

Subsequently, the architecture features are constructed using the commands included in the Computer-Aided Drafting tool (CADR). On conclusion of the survey, the working up and editing of the data required five weeks. The resulting plans showed the topography and archaeological remains in a single three-dimensional representation. The CADR application enabled the drawings to appear in different formats for study or publication.

Simple Digitalisation of Plan Parallel Photography: Excavation and Conservation of the Great Mosque

The wall elevations of the Great Mosque were measured during the excavation and conservation works, using plan parallel photographs were taken from each structure to minimized distortion.

These photographs were scanned and an transfer to a raster image processing application to reduce the distortion and prepare photographic mosaics showing the whole elevation.

Subsequently, the resulting image clipped in a CADR application was vectorized stone-by-stone and measured plans were prepared.

The resulting metric survey dataset limited in precision, but with an adequate level of detail of the masonry of the fabric is used in the monitoring of the site.

Mechanical rectification of plan parallel photography: Courtyard L.920 and House L.910

The aim of applying this tool is to produce a measured representation that combines the photographic texture of the subject and the topographical survey prepared with an EDM total Station and CADR (see figure 50).

Targets: grid system for photographic reference points

A grid of control points was prepared along the structures using the EDM Total Station. Each point was set at an interval of approximately three meters in the Courtyard and 5 meters in the house. Some of the

intervals were smaller or bigger in some cases to avoid damaging the remains, however only odd multiples were used, such as 0,5, 1 or 2 meters from each other.

This system ensures a regular reference system to be able to perform an easier and correct rectification of the photographs. This measured representation will be used as frame to mechanically rectified the photographs.

Plan parallel aerial photography and mechanic rectification

With the help of a lift, photographs are taken covering the whole structure, with an overlapping of at least 30% and covering four targets (control points).

Subsequently, the photographs are scanned and transfer to the Raster Image Processing Application. In this tool the photographs are position, scale, and distort (using transformation tools, such as distort, skew, rotate and scale) to fit the previous framework of the measured plan generated by the CADR application with the control points is place on top of each of the

The final output can be clipped again to the CADR drawing and plotted to scale.

Combination of automatic rectification of plan parallel photography and photogrammetry: the Citadel

The acquisition of actual state of conservation of this site, included the preparation of a set of measured plans with the geometry (vectored representation) and texture (rectified images) of the standing and uncovered walls surrounding the Citadel, which consists of several structures laying in different levels, in both roughly regular picture planes and rounded picture planes.

The documentation was carried out using rectified and ortho-photography. Each of these techniques provides enough tools to create a good overview of the fabric of the ruins, as well as to determine the levels, and other features.

However, the process also has encountered a series of uncertainties that affect the geometric precision and consistency of the representations prepared.

These uncertainties are related to the selection of a single picture plane to project and rectified all the images acquired and the assumption that all the roughly straight walls are of regular shape.

Furthermore, using a Simple photogrammetric application called PhotoModeler was used for the generation of ortho-photographs, due to the difficulty of generating correct photographic projections of rounded shapes. They were mainly used for documenting the towers (see figure 52).

Targets

Roughly regular picture planes or walls: a set of at least four targets were placed and measured using the Total Station, the photograph is taken in a way that each target occupies a corner of the image. Moreover, to ensure precision in large areas the photographs were made with at least 20% overlap.

Rounded walls (towers): a specific number of targets were adapted to the rounded walls, with an interval of more less 1, 5 m. (a target in the top and one in the bottom). For the photogrammetric survey, the oblique photographs were made using a sequence with a great number of overlapping targets. Other common elements were added, such as, aluminum rots and other references that can be easily be identified in the photographs.

Along with levels, each target has been identified with an unique ID number, these measurements (coordinates: North, East, and Height) of each of the targets is stored in a database of measurements prepared for the site work.

Simple digitalisation of plan parallel photography: excavation works

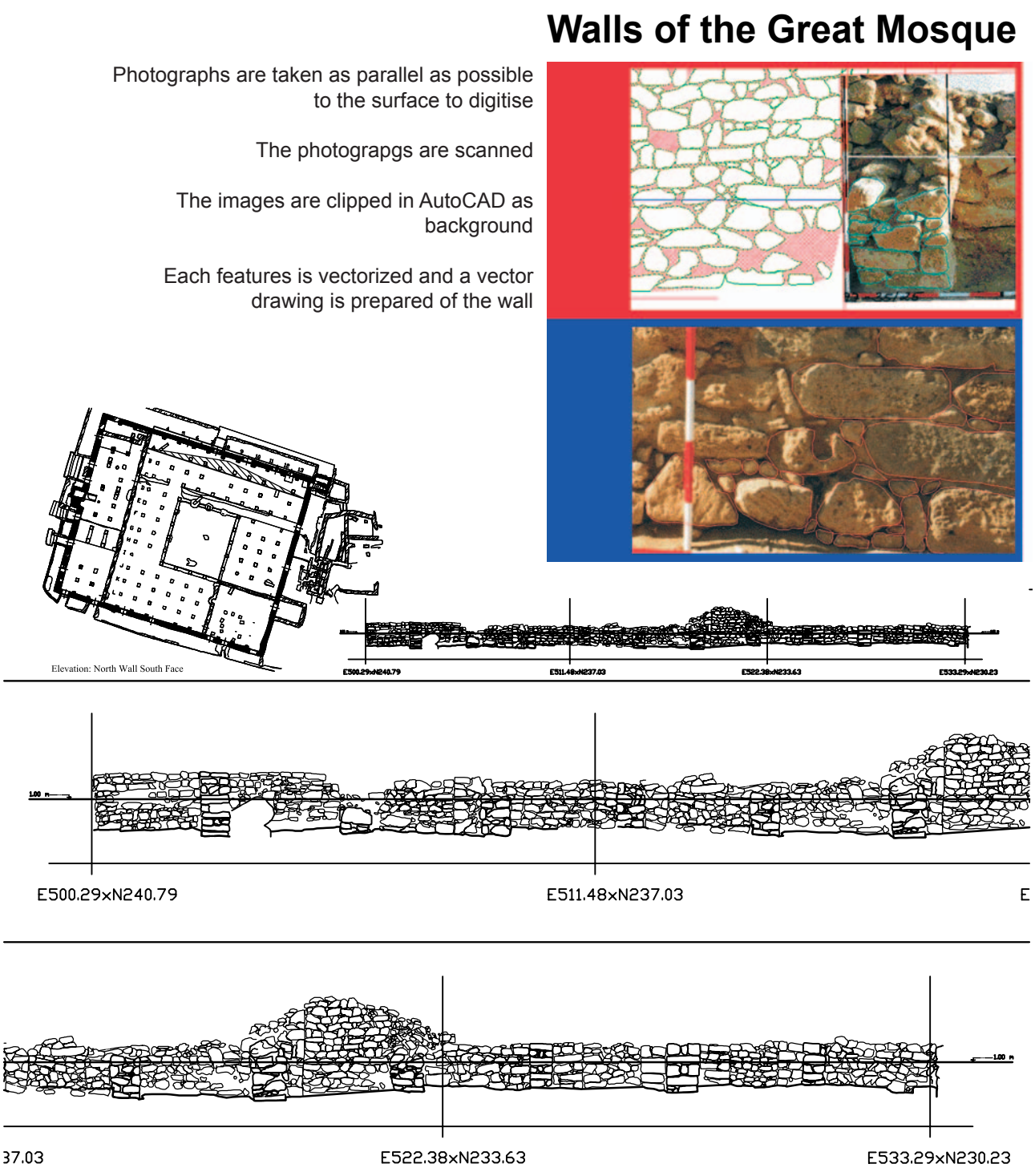


Figure 50: recording the standing walls in the Great Mosque using plan parallel photography. Author.

Digital photographs

It was decided to use the largest possible resolution (3.32 million pixels) for the photographs using a low-compression file type (*.tif) to ensure good results. The set of pictures in included in the image database, as well as attached to the CADR drawings prepared.

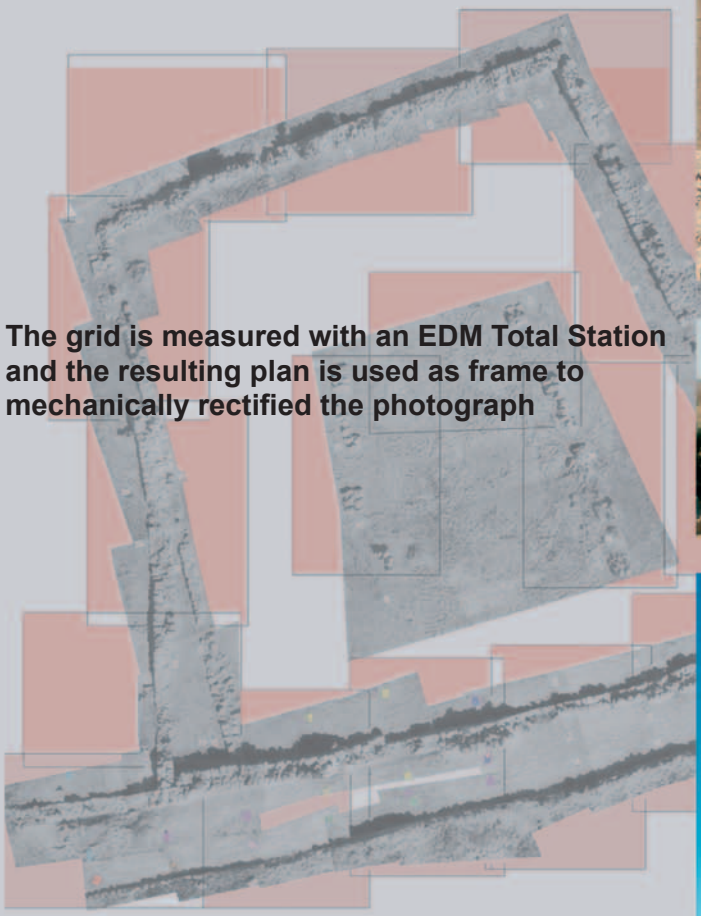
Processing

The plan-parallel photographs were rectified by defining a parallel projection picture plane using the targets measured with the

Mechanical Rectification of Plan Parallel Photography: Courtyard L.920

1 **A regular grid of fixpoints is prepared covering the entire site to be photographed and rectified**





2 **The grid is measured with an EDM Total Station and the resulting plan is used as frame to mechanically rectified the photograph**

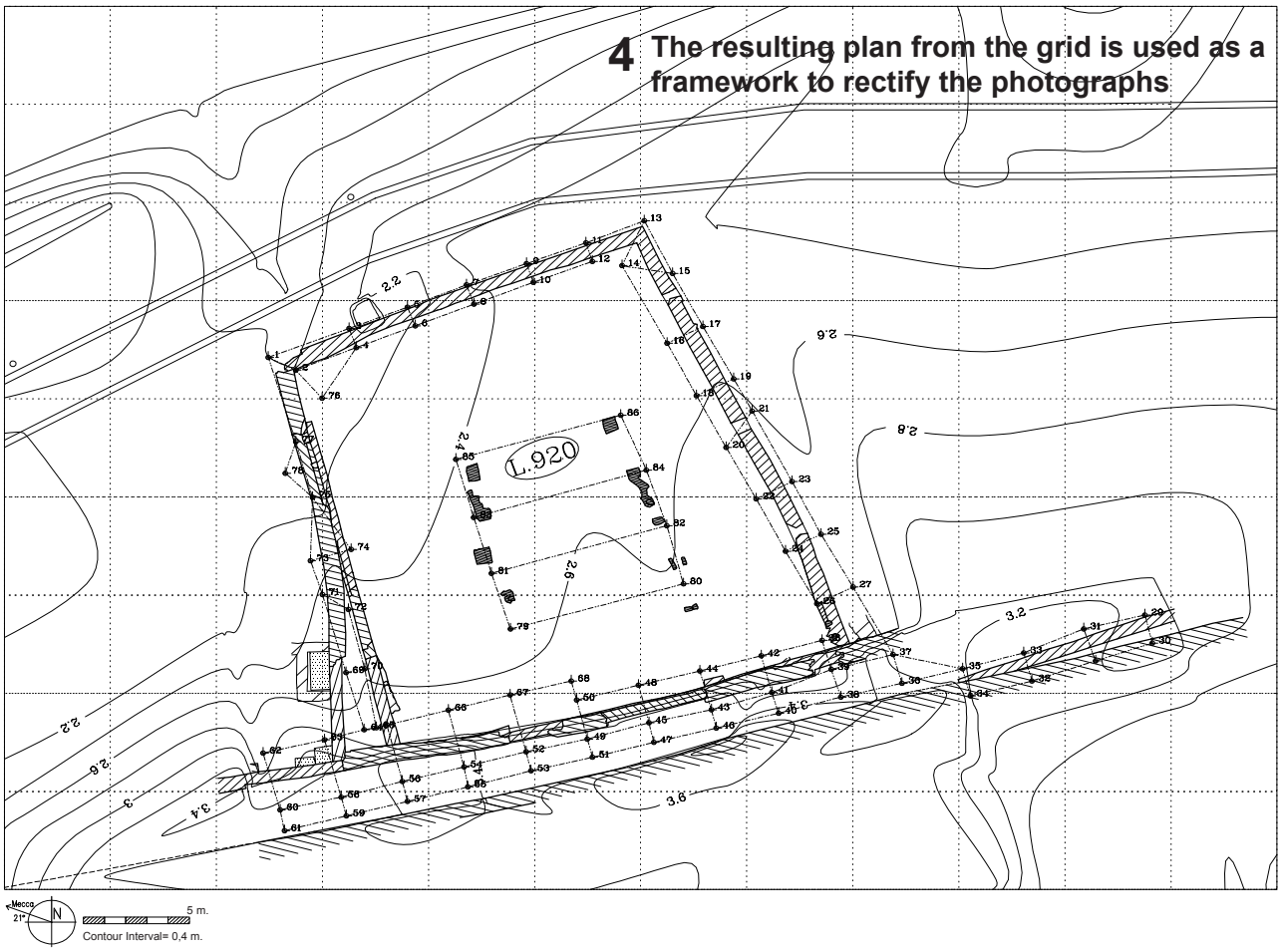


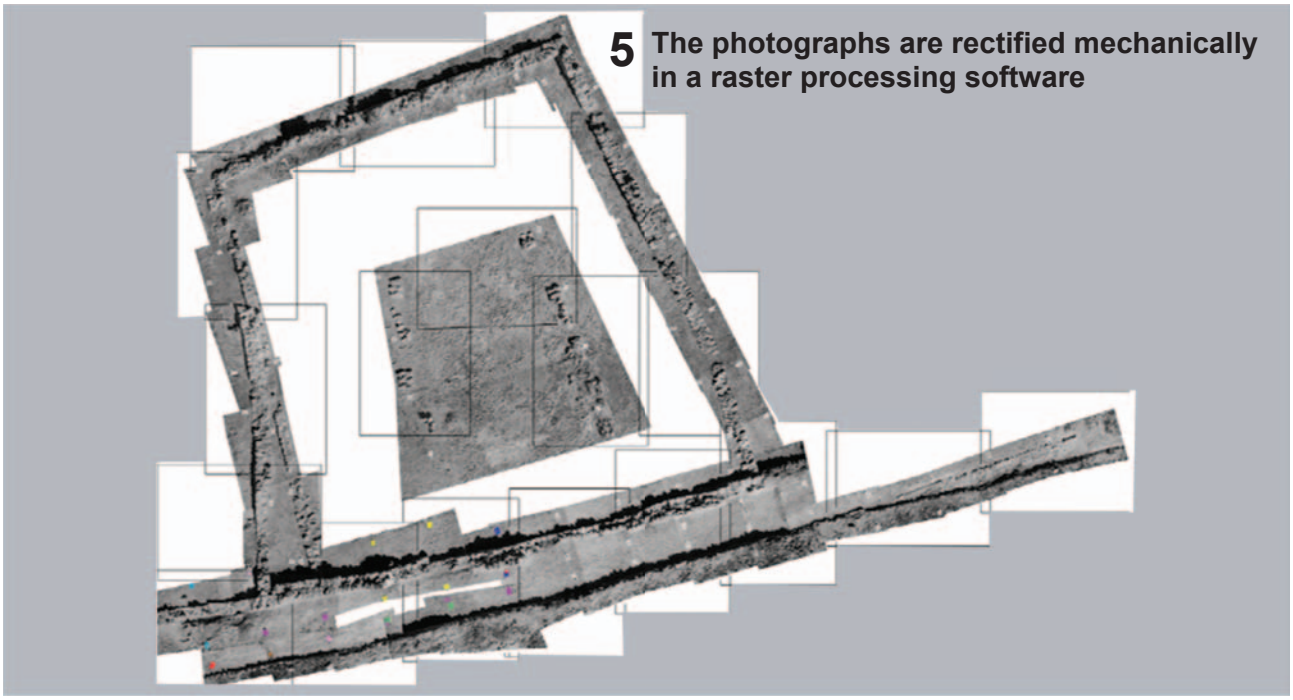


3 **The grid is photographed, each photograph should be parallel to the surface to be documented and sufficient overlap should be done.**

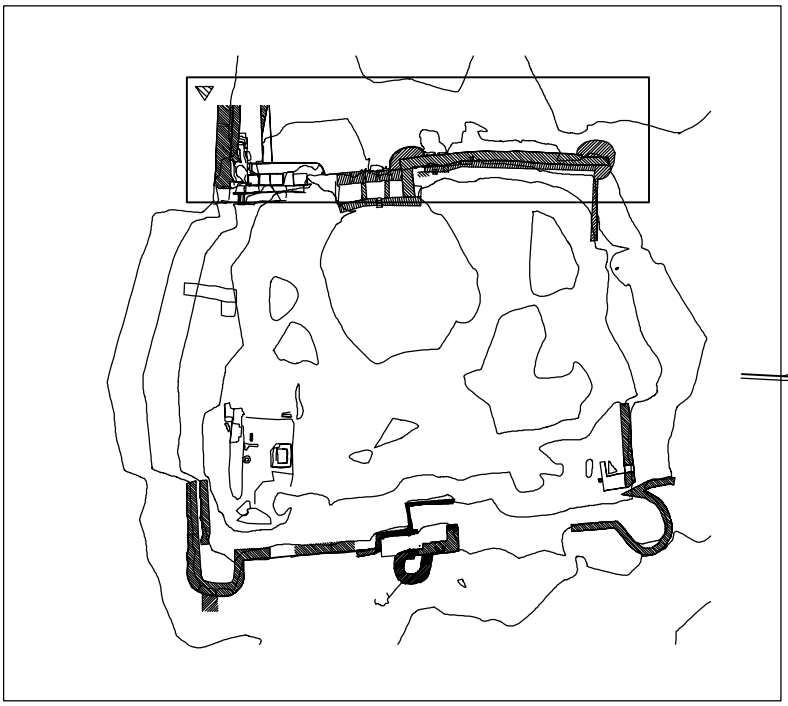
Figure 51: mechanical rectification of plan parallel photography, using the courtyard locus 920 as example of this technique of documentation. Author.

Above: the resulting grid of fixpoints (targets) to rectify the photographs measured with the EDM Total Station , below: rectified photographs after processing work

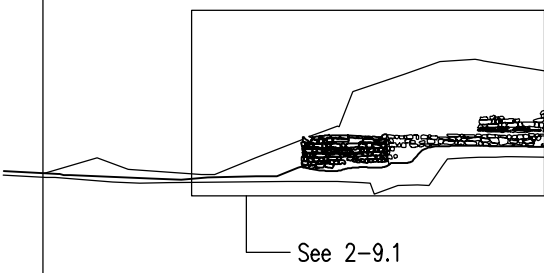




Combination of Automatic Rectification of Plan Parallel Photography and Photogrammetry



1 **A number of targets are prepared covering the entire wall to be photographed and rectified**

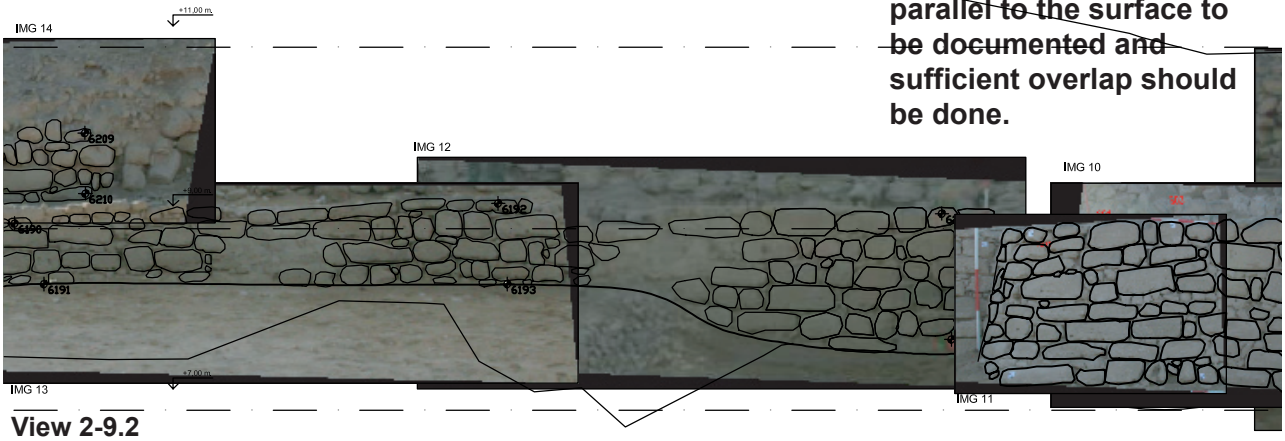


2 **The targets are measured with an EDM Total Station and the resulting plan is used as frame to automatically rectified the photograph and generate orthophotographs from rounded surfaces**



Measuring the targets

3 **The targets are photographed, each photograph should be parallel to the surface to be documented and sufficient overlap should be done.**

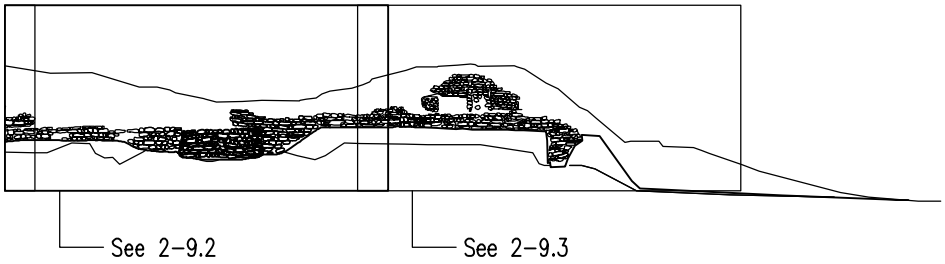


View 2-9.2

Figure 52: combination of automatic rectification of plan parallel photography and photogrammetry to document both regular and rounded picture planes, using the Citadel as example of this technique of documentation. Author.

CITADEL - ELEVATIONS

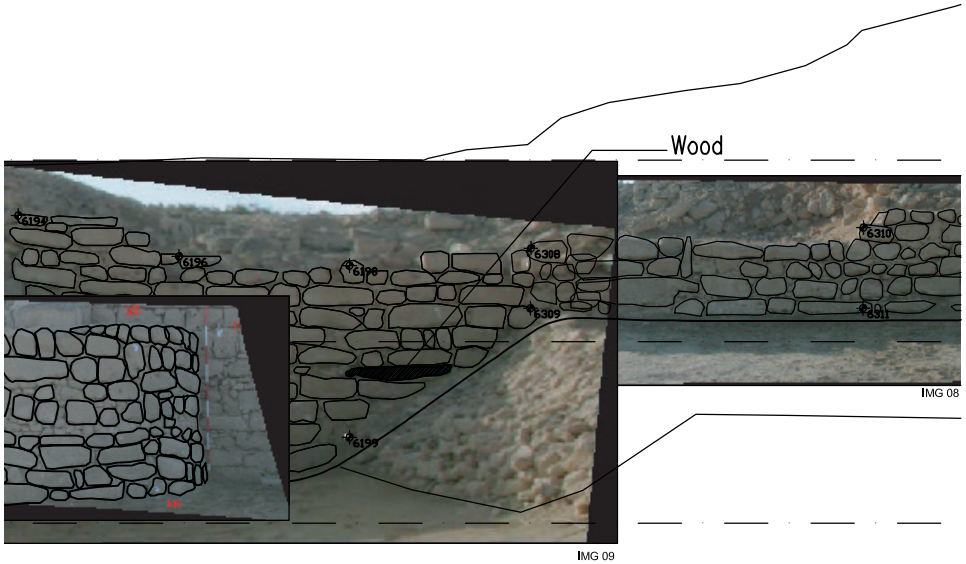
4 **The resulting plans of the targets are used as a framework to rectify the photographs**



5 **The photographs are rectified automatically with specialized software, the rounded surfaces are orthographically projected using a low-end photogrammetric application**



Taking the Photographs



IMG 08

IMG 09

IMG 11 - 12: Ortho-photo
IMG 08 to 10, 13 - 14: Plan Parallel

0 1 2 m.

Total Station.

The targets were used to define a new coordinate system (UCS) and the view in AutoCAD was adapted to be parallel to this new UCS.

The resulted view and targets were transferred to a separate file and the photographs were clipped and transform using AutoCAD Overlay.

Furthermore, the topography was inserted by making sections through the elevation model (based on TIN) previously prepared using a Digital Terrain Modeler application.

On the other hand, the ortho-photographs were inserted and adapted to the current view by applying AutoCAD Overlay to the visible targets, both in the photograph and in the vectored drawing.

Conservation Forms

The completed structure documentation of the site, prior, during and after the excavation works has permitted the preparation of a "Conservation Manual", which is used for monitoring the state of conservation of the different sectors or identified structures in the site and provides strategies for adequate immediate conservation work and historic recording.

These measured plans presented in the forms are complemented by a '*damage index*' [Fitzer et al, 2002] and a therapy action index.

The damage index consists of a number of shapes and colors charts to map the different weathering forms of the fabric and the Therapy action index consists of common interventions to be executed in the fabric of the subject for its conservation.

Subsequently, these forms can be stored in the administration information system to monitor the different interventions implemented (see figure 53).

Landscaping

An adequate number of topographic measurements are obtained from the surface recording by Electronic Distance Measurement device, which are added to the detailed floral survey of the natural setting providing the basis for further action according to proper planning. This, of course also accounts for all further planning.

Didactics

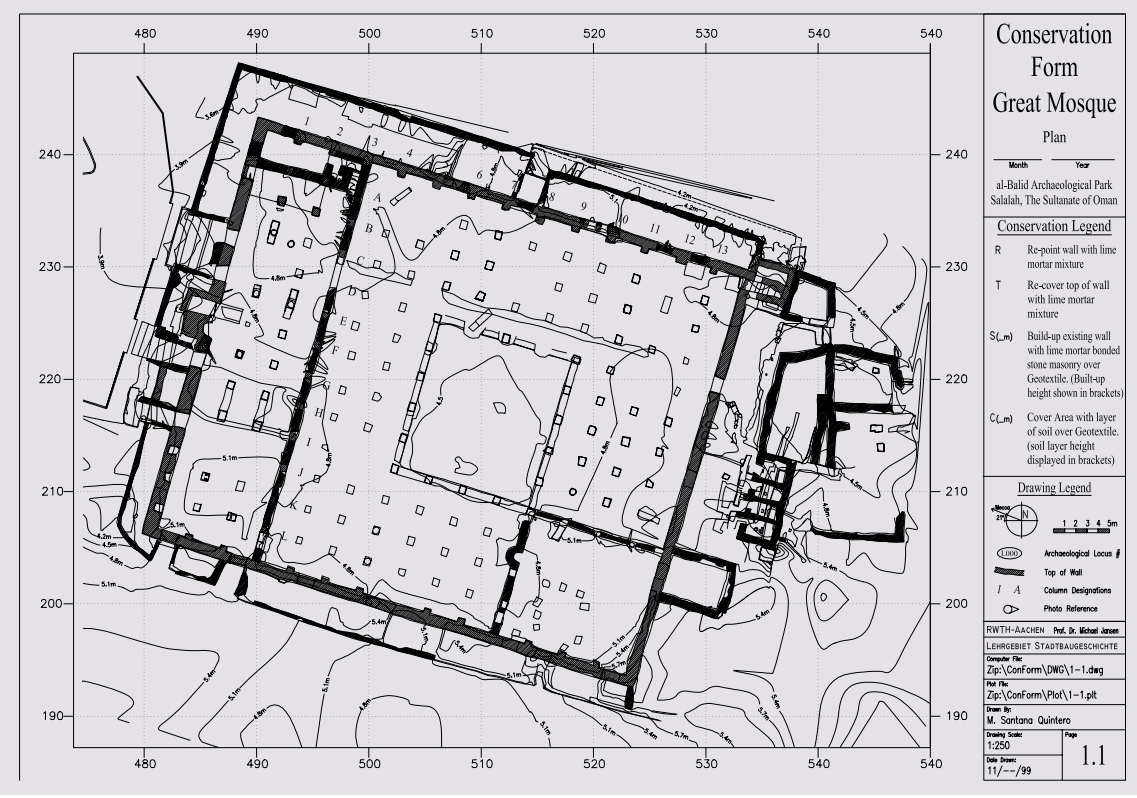
The extensive direct survey of the geometry and texture at all stages of excavation and conservation works of the subject and setting is complemented by the historical documentary research carried out in the site has provided evidence to establish the phases of constructions and modifications through the history of the site.

These records have been used to prepare tools for understanding the components of the site and its history. This didactic material can be placed across the site to provide accurate and reliable information to the visitor. Finally, instead of reconstructing architecture, digital simulations based on scientific research may stimulate the imagination of the visitors (see figure 54).

Management of complex archaeological data

As a recording devise photography still is a very important component of the documentation of the site. Traditionally photographic records are kept in manual documentaries with time consuming access. To improve the accessibility, Aachen University in collaboration with a the private sector has developed a software

CONSERVATION FORMS
3D Metric Survey tools (EDM Total Station - CADR-DTM application



Conservation forms of the Great Mosque consists of plan elevations, and a ground mapwith predefined therapies to ensure adequate interventions and monitoring the effects in the fabric of the remainings.

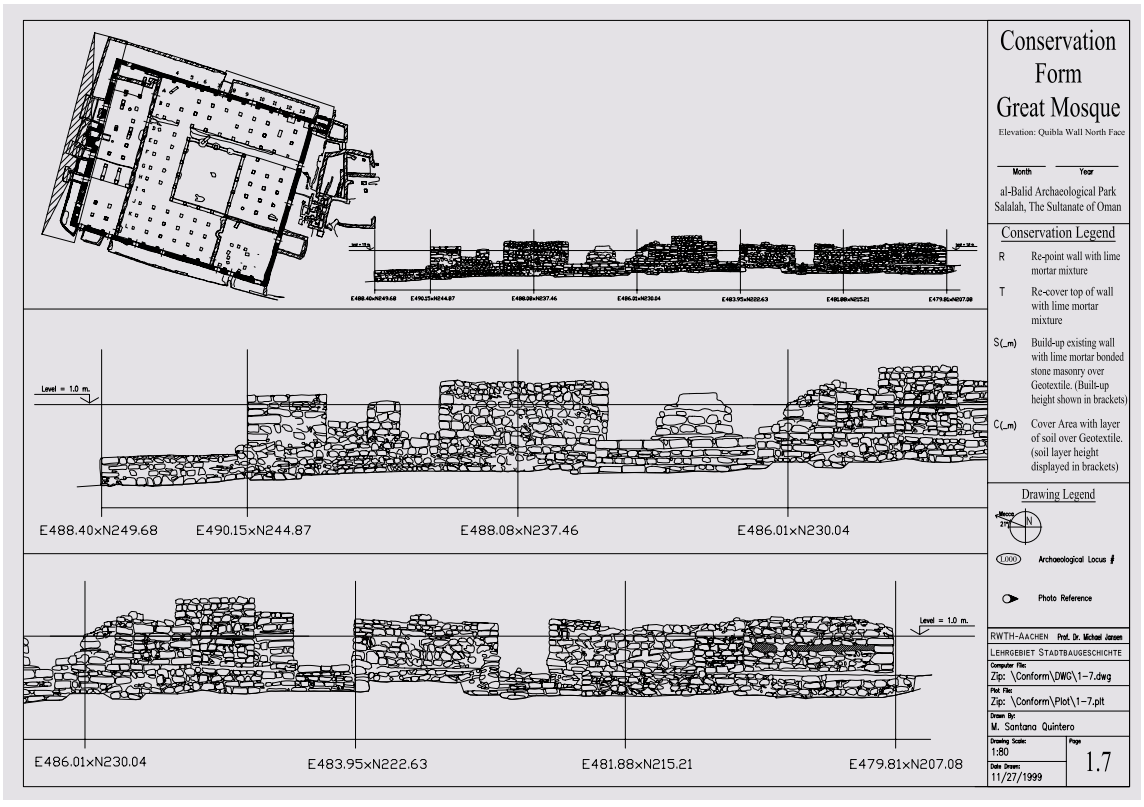
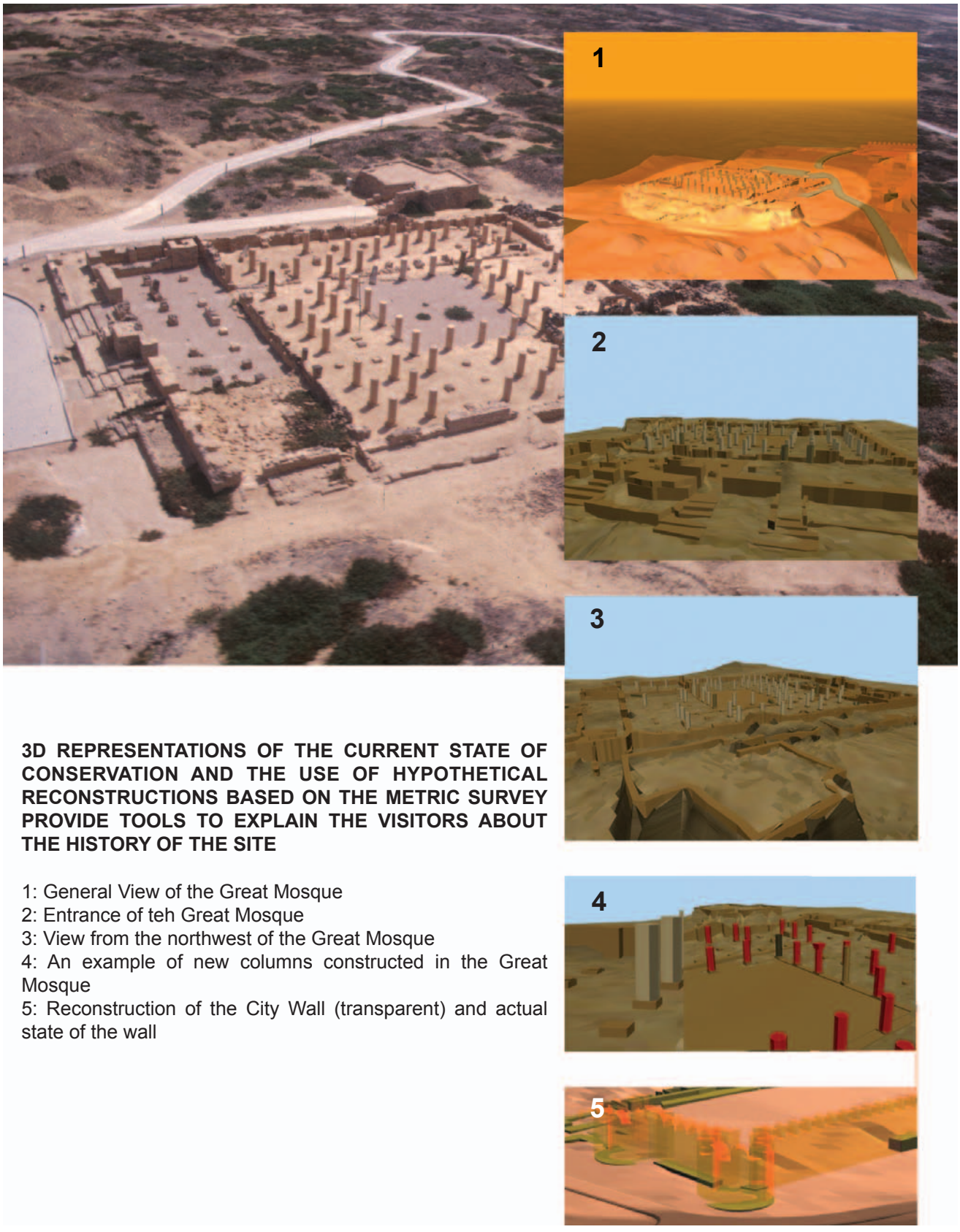


Figure 53: an example of the conservation forms usied for monitoring the site, the forms above corresponding to the Great Mosque consist of a Ground and elevation plans of the actual state of conservation. Author.

DIDACTICS
3D REPRESENTATIONS: ACTUAL CONDITION - HYPOTHETICAL RECONSTRUCTIONS



3D REPRESENTATIONS OF THE CURRENT STATE OF CONSERVATION AND THE USE OF HYPOTHETICAL RECONSTRUCTIONS BASED ON THE METRIC SURVEY PROVIDE TOOLS TO EXPLAIN THE VISITORS ABOUT THE HISTORY OF THE SITE

1: General View of the Great Mosque
2: Entrance of teh Great Mosque
3: View from the northwest of the Great Mosque
4: An example of new columns constructed in the Great Mosque
5: Reconstruction of the City Wall (transparent) and actual state of the wall

Figure 54: an example of the digital didactics tools produced with the measured plans prepared of the Great Mosque, displaying the actual state of conservation of the Great Mosque. Author.

application to store, retrieve and manage all the photographic records and other data necessary as a simple navigation platform to retrieve information about the work carried out a site. This software is presently under testing and will be soon available.

1.3.3 TRAINING OF LOCAL EXPERTS IN DOCUMENTATION TECHNIQUES

In addition to the documentation of all stages of work in the archaeological sites, the University of Technology Aachen RWTH has promoted the organization of complementary training workshop for the local experts.

These courses are prepared using specialized expertise in the use of recording tools for studying built heritage. It focus on immersing the trainee in the use of sustainable electronic and image-based instruments and software.

The main aim of this activity is not only promote the understanding of recording every stage of work during the excavation and conservation, but also to monitor the decay of the site during the years to come.

Main areas of training in recording tools consists:

- A broader perceptive of the techniques and instruments available in the market.
- Concepts and principals in recording built heritage.
- An appropriate balance among the quality of the records to be prepared, budget available for the survey, and variables of the recording techniques available
- Guidelines for preparing an adequate set of measured plans of the site, including three-dimensional topographic models and orthographic representations, rectified photography of standing and buried structures, and other relevant measured representations required.

1.4 CLOSING REMARKS

This case study demonstrates that the adapted used of sustainable tools of documentation with specific precision and quality requirements of the measured representations adjusted to the specific needs of a problem and the desired dissemination product are appropriate for the developed of tools for the management and conservation of an archaeological sites.

Comparative studies using the different metric survey studies carried out during the excavation work permits the scientists to evaluate (see figures 55 and 56):

- The amount of material removed from the site.
- Evaluating initial hypothesis about the distribution of the site
- Prepare a permanent document showing the different phases of work
- Evaluate the development of the works, speed and constraints

Furthermore, it proposes a model of training local experts for the promotion and development of local administrations in the documentation and care of built heritage.

Notes:

[1] 'The Charter of Venice' 1964, 'International Charters for Conservation and Restoration', Petzet, M. Ziesemer, J. Ed., Monuments and Sites I ICOMOS, Munich 2001.

[2] Lehner, C. 'First Topographic Surveying of the Site, 1995-6'; 'Interim report of the campaigns carried out on the archaeological site al-Balid, Salalah, Sultanate of Oman 1995 - 2001' , Jansen, M. ed. , Wissenschaftliche Schriften an der Fakultät für Architektur der RWTH Aachen, expected for November 2002.

DOCUMENTING EXCAVATION WORKS
3D Metric Survey tools (EDM Total Station - CADR-DTM application)

CITADEL

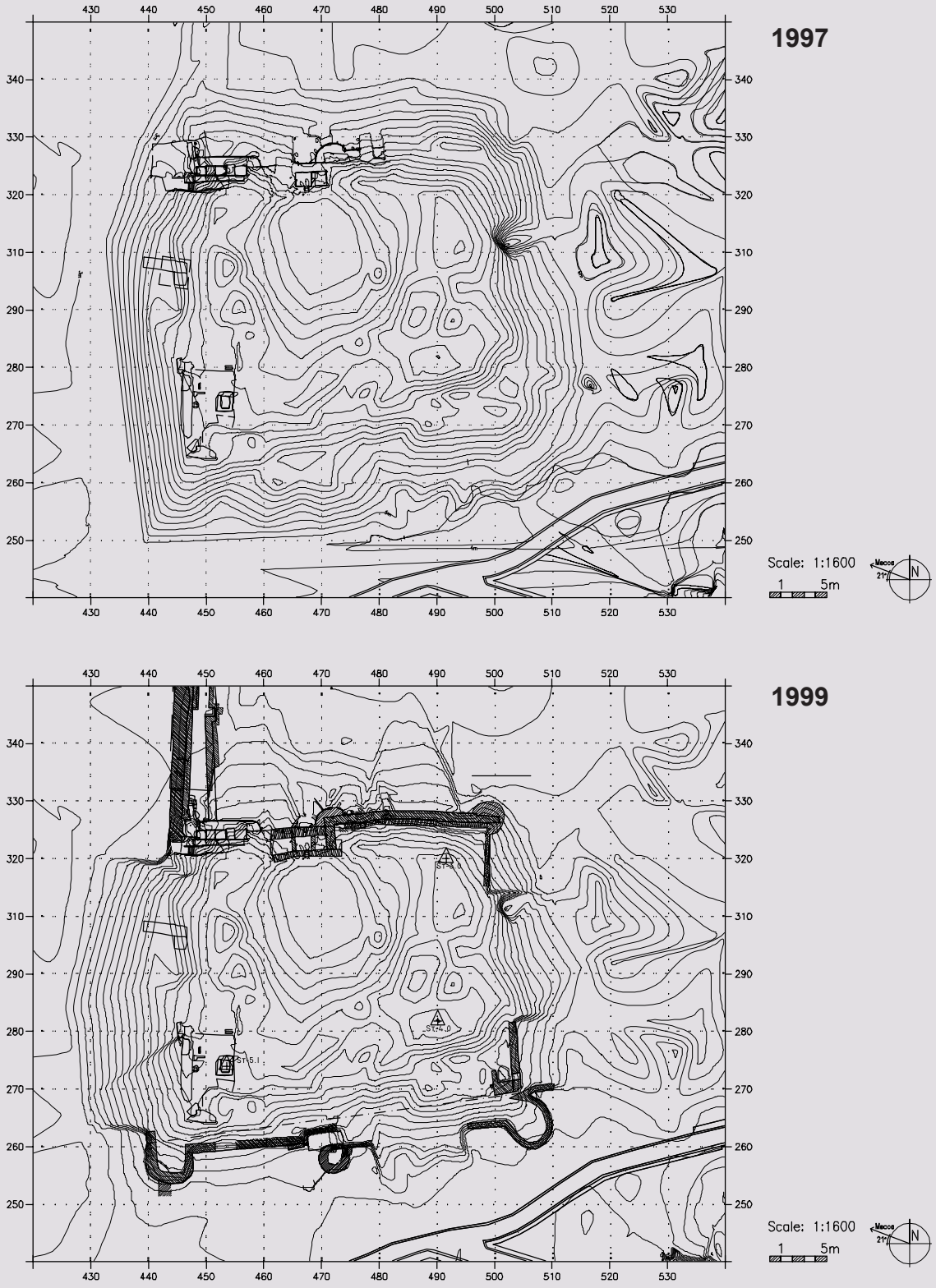
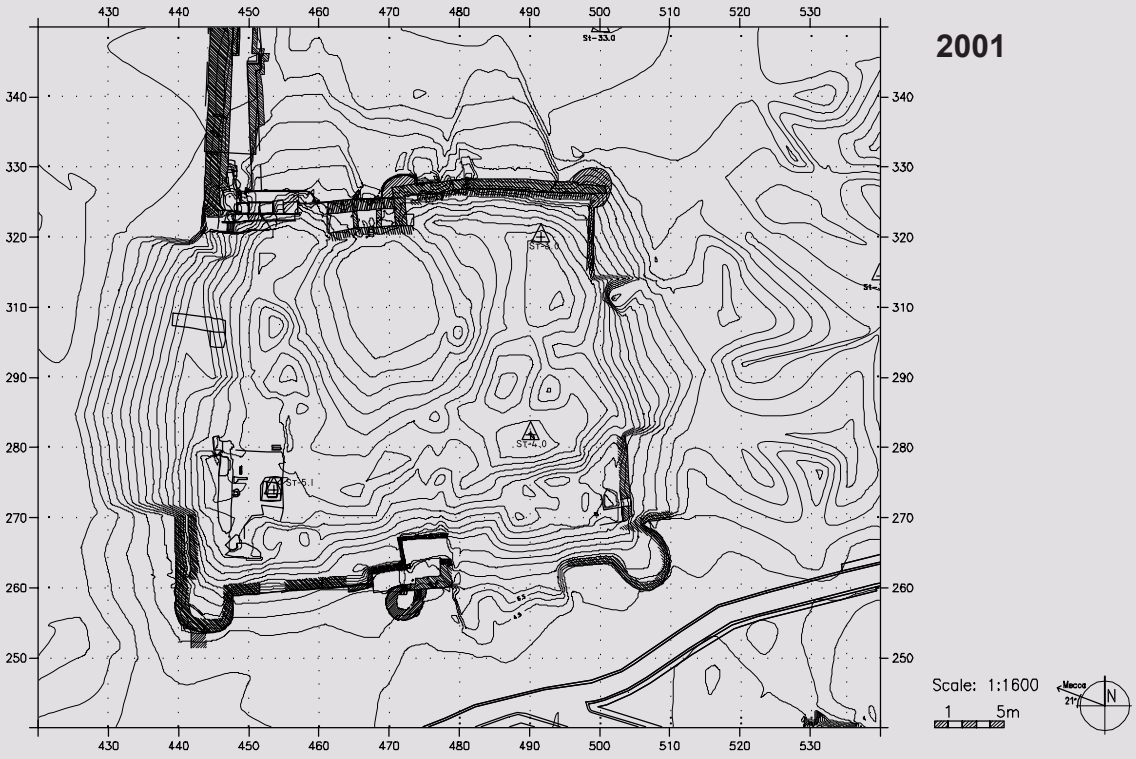
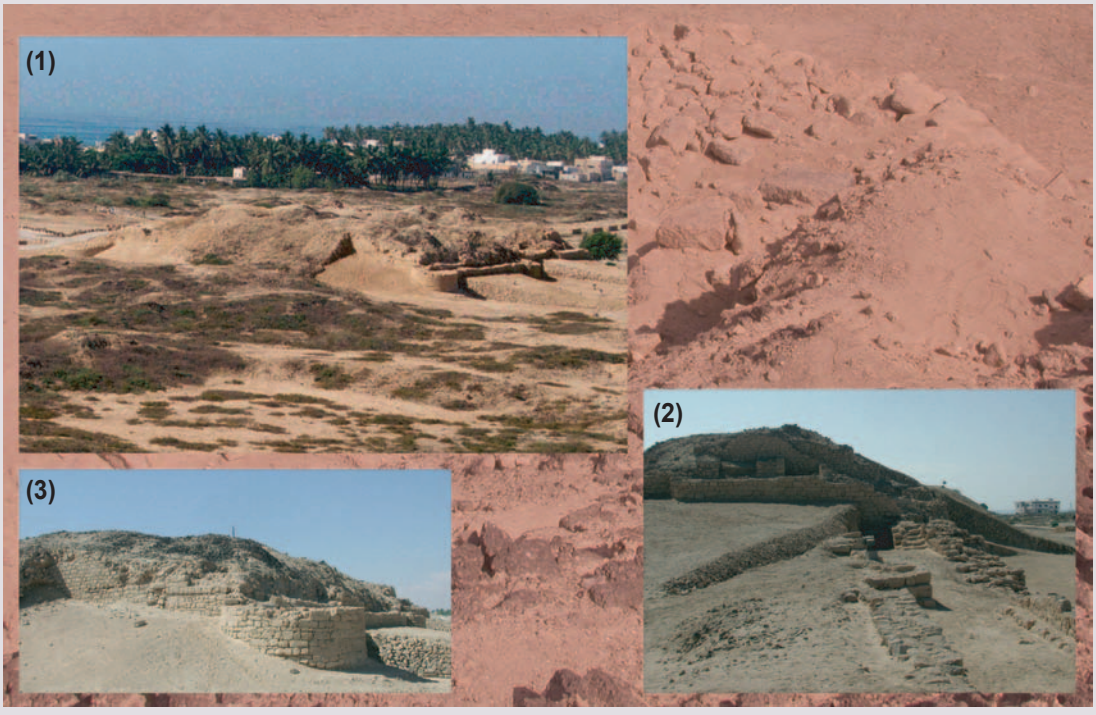


Figure 55: phases of conservation, example in the excavation process of the Citadel. Author.

Excavation works at the Citadel in al-Baleed started in 1997 and they are still being carried out, the documentation consisted in recording each stage of work





(1) General View from the Northeast (2000) (2) Northfront and junction wall (2001)
(3) Northeast front (2001)

DOCUMENTING EXCAVATION WORKS
3D Metric Survey tools (EDM Total Station - CADR-DTM application)



Figure 56: 3D models showing the stages before and after excavation works. Author.

GREAT MOSQUE





CHAPTER II

CASE STUDY

Conservation of Built Heritage:
Preparing a proposal for the Restoration of the Roman Theatre of Jebleh, Republic of Syria

CHAPTER II

CASE STUDY: CONSERVATION OF BUILT HERITAGE: PREPARING A PROPOSAL FOR THE RESTORATION OF THE ROMAN THEATRE OF JEBLEH, REPUBLIC OF SYRIA

This part presents the efforts for the preparation of the metric survey dataset aimed at understanding the actual state and history of the roman theatre of Jebleh and its 'urban and archaeological context'[1], specifically in the use of digital recording tools.

The '*Syro-Belgian mission for the research and restoration of the Jebleh roman theater*' (Patrício, T., 2002, pp. 3)[2] consists of an interdisciplinary and international team of experts lead by Karel Van Lerberghe Professor of Assyriology and Near Eastern Archaeology (Katholieke Universiteit Leuven) , Koenraad Van Balen, Professor at the R. Lemaire International Centre for Conservation (Katholieke Universiteit Leuven) and Architect Teresa Patrício, researcher at the R. Lemaire International Centre for Conservation (Katholieke Universiteit Leuven) in cooperation with the director general of antiquities in Syria.

The application of electronic distance measurement tools and image-based applications in this specific case were concentrated in the tasks:

- Establishing a local reference system of coordinates: three-dimensional metric reference system for controlling and ensuring the integrity in the combination of the different metric survey tools.
- Topographic and urban geometry
- Acquisition of the building geometry to prepare an architectural analysis recording excavation works at the eastern part of the scene

2.1 ROMAN THEATRE OF JEBLEH, SYRIA

The roman theater is located in the northwest part of Syria in a coastal town called Jebleh,

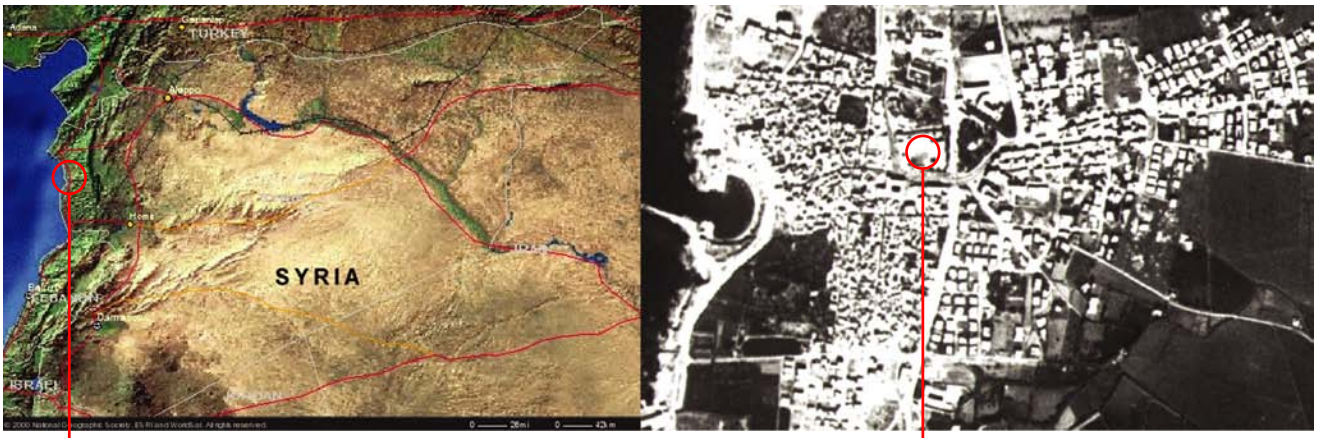


Figure 57: location of the roman theatre of Jebleh, Syria

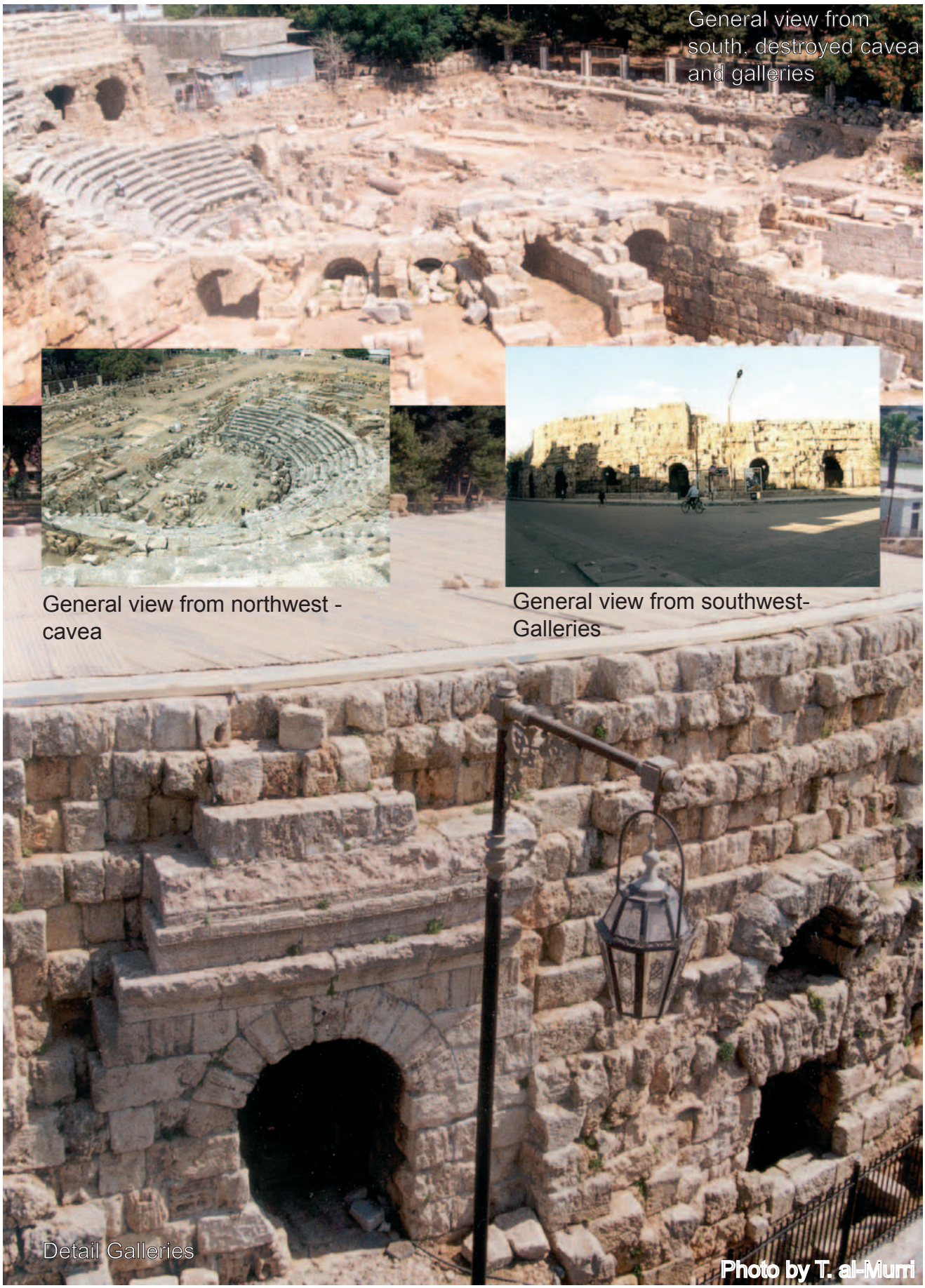


Figure 58: views of the roman theatre of Jebleh, Syria

REDM POINT COLLECTION
USING A TOTAL STATION

Examples

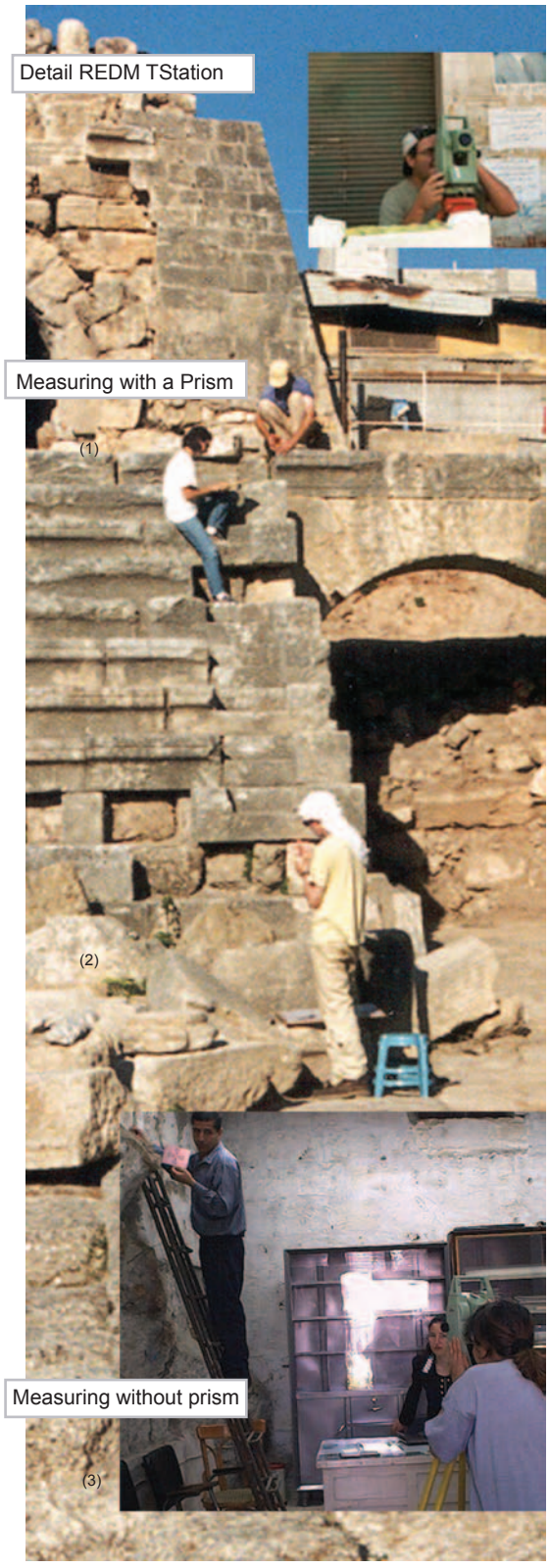


Figure 59: using reflectorless electronic distance measurement point collection technique to record the fabric of the building. Author.

around 40 km. South of the city of Lattakia (see figure 57).

> *'The date of the construction is still not clear. Same authors state that the theatre was built by the emperor Justiciano[3]. From the Architectural details from the first results of the excavations we are convinced that the theatre was built during the 3rd century AD, probably in the first half' (Patrício, T., 2002, pp. 3)[4].*

2.2 METRIC SURVEY TOOLS

Metric survey in conservation is used to provide a highly complete and reliable set of measured representations for mapping the actual condition of conservation, history and therefore to understand the relevance of the object and weathering factors affecting its fabric.

In the case of the roman theatre of Jebleh, the preparation of the metric survey 'dataset' demanded recording a high possible amount of information about the geometry and texture of the object and its context in a relative short time and with a constrained budget. The results of this study will be use to trace the phase of construction and modifications of the monument, as well as to apply anastylosis study to reconstruct some areas.

The final measured representations should provide evidence about the fabric components, identification of the masonry details (jointing pattern), breaks in the masonry, alignment of structures, type of material used and patterns in the different surfaces, identification of modifications, etc.

Combining the variables associated to the object (accessibility, local facilities, budget, etc) and variables associated to the Recording Tool (Measuring range, operability,

price, etc) it was decided to combine the use of three different tools:

- Reflectorless point collection tools: consisting of a REDM Total Station, a computer aided drafting (CADR) and digital terrain modeller (DTM) packages: this tool was used to prepare the local three-dimensional metric reference system, topographic and urban geometry, building geometry, and recording excavation works at the theatre's scene.
- Conventional hand-survey techniques: it was used to complement the building geometry, in recording fragments in the theatre's scene for anastylosis.
- Close-range bundle adjustment photogrammetric package: it was used to complement the building geometry to record the main façade of the building.

2.2.1 DEFINITION FRAMEWORK IN THE SELECTION OF METRIC SURVEY TOOLS

Applications

In this case study, and according to the needs of the project, the use of metric survey tools have been concentrated in preparing a 'measured dataset' that can be use for the preparation of a conservation project.

The target audience of this application is 'professional', members of an interdisciplinary group of experts studying the history and actual state of conservation of the site.

Subsequently, this application in the intervention of an interdisciplinary team provided a higher emphasis in the collection and dissemination of the measured dataset using different representation tools.

Expected Quality and task definition

The 'metric survey study' is composed of measured representations with a reliable completeness of information and that are of the highest possible quality. The tasks of the 'metric study' are of a higher possible quality, which permits the preparation of a conservation project aimed at safeguarding the monument for future generations (see chart 49).

The output should be capable of giving metric information about:

- A general measured set of representations of the site, consisting of measured plans of the different levels, cross sections, and a survey of the main façade.
- Recording all the fragments of the building disperse around the stage and scene of the theatre.

These representations will serve to map the different construction materials, the weathering forms, structural behavior, and different historical stratification of the building.

Variables in the identification of restrictions in the use and selection of metric survey tools

The variables are ordered according to their relevance in the application (See Chart 49).

<u>Budget and expected quality</u>

The metric survey tools used in recording the theatre of Jebleh were chosen for being cost-effective, in relation with a limited amount of funding available for the whole project, where the metric survey study is just a fraction. This budget also covered hand-survey works aimed at recording in more detail small fragment located in the scene of the theatre and measurements carried out

ROMAN THEATRE OF

Jebleh

DEFINITION FRAMEWORK

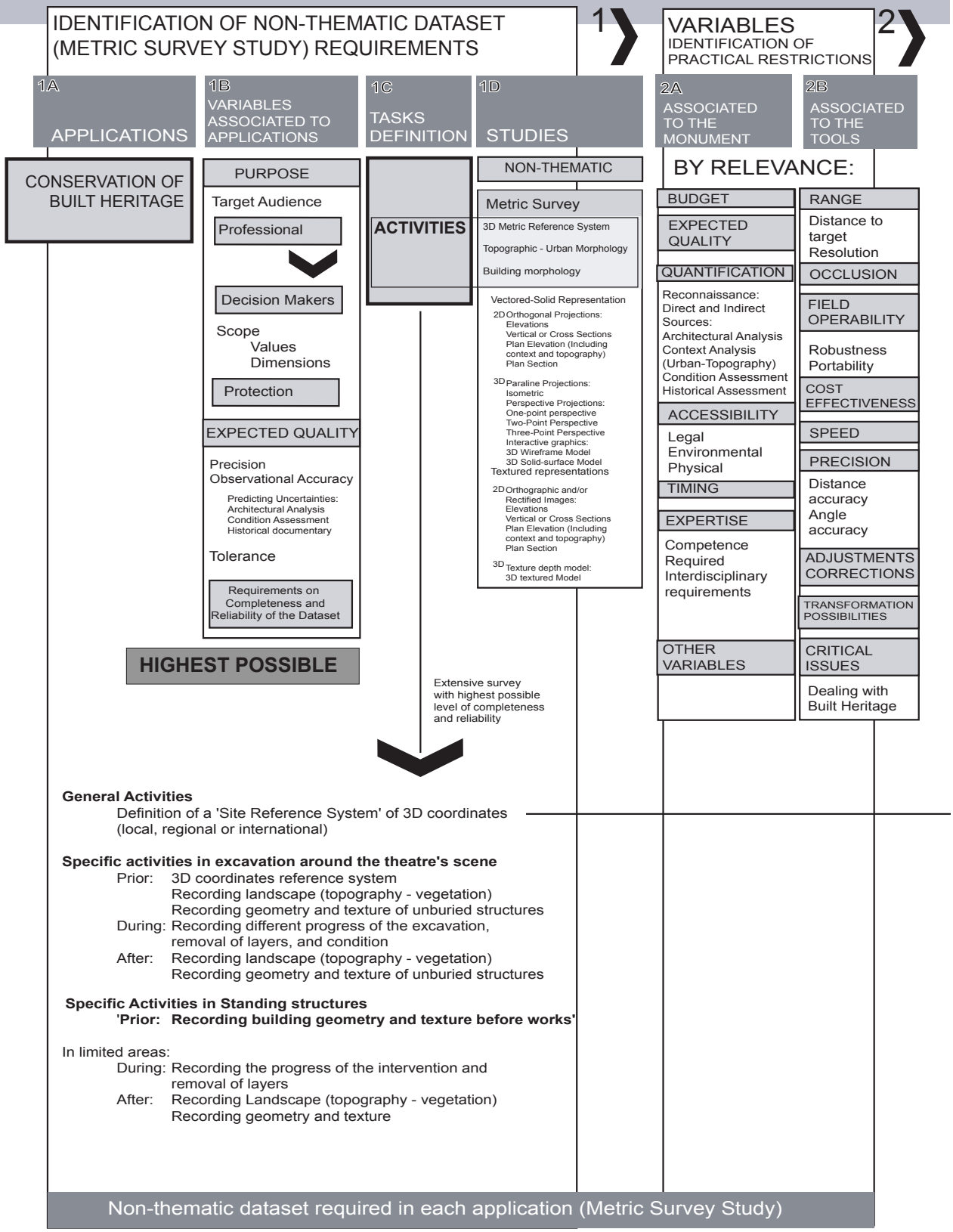


Chart 49: application framework applied to this case study.

SELECTION FRAMEWORK

SELECTION OF A COMBINATION OF TOOLS - IMPLEMENTATION OF THE METRIC SURVEY STUDY

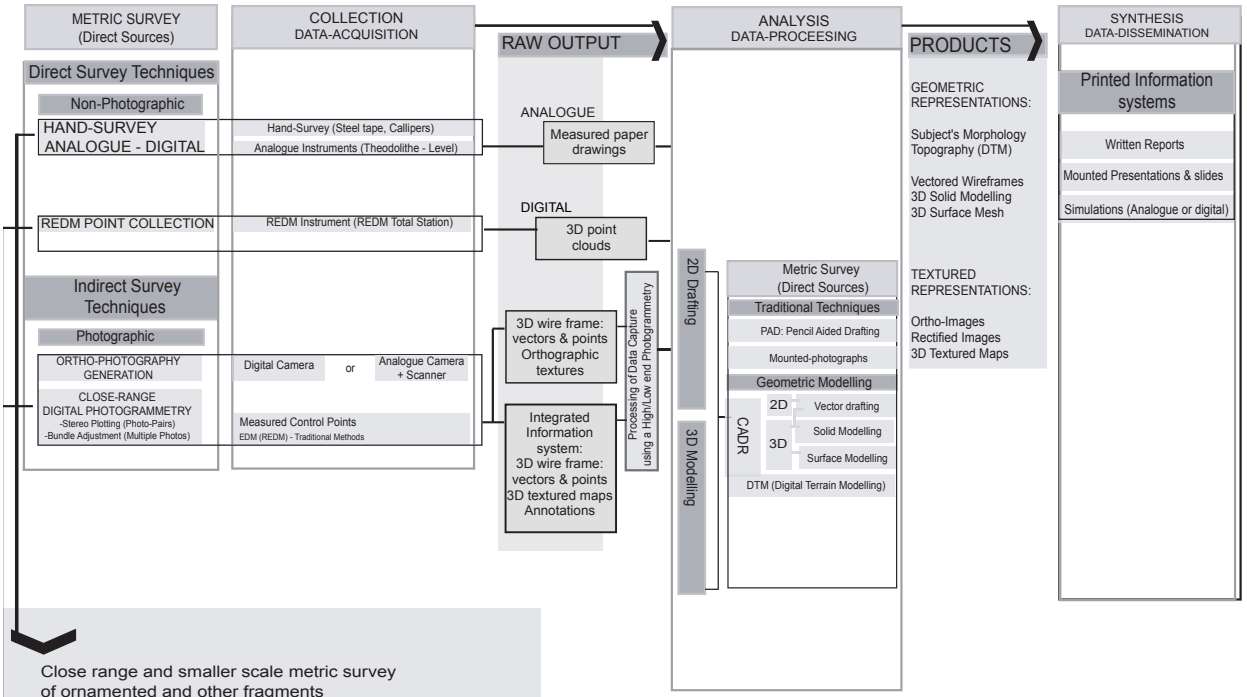
3

METRIC SURVEY STUDY OUTPUT (NON-THEMATIC)

MEASURED DATASET

TOOLS

INSTRUMENTS
(DOCUMENTATION AND DISSEMINATION TOOLS - CLASSIFIED BY PRODUCT DELIVERED AND PERFORMANCE)



Close range and smaller scale metric survey of ornamented and other fragments

Large scale metric survey of the building geometry and texture

THEMATIC

Spatial-Typological Analysis
Building Morphology Analysis
Topographic - Urban Analysis

Historical Assessment
Historical Documentary research
Stratigraphy

Condition Assessment
Condition Mapping
Structural Analysis

Other Studies

4

THEMATIC DATASET

CORE DATA

5

CRITICAL AND ANALYTICAL REPORT

Selection and implementation of the Metric Survey Tools

by the archaeologist working on parts of the stage.

The relation between the budget and the expected quality associated to the project of study of the monument influenced the following variables associated to the tool selected:

Range and precision: the instrument's capacity to measure unreachable areas with a relative good precision expressed in millimeters of the building was limited by the amount of funding available. However, the selection was done also according to the quality required in measuring historic sites and the reputation of the brand selected.

Occlusion and field operability (including adjustment and corrections): the budget affected the selection according to the potential of the tool to overcome obstacles (e.g. height), which is also related to range. In terms of operability, the budget available provided sufficient funds to acquire an instrument with two days of battery power capacity and a portable computer to avoid sudden power cuts in Jebleh.

Expertise

The uses of digital tools were appropriate to the need of having an interdisciplinary team of professional that could help building up a 'measured dataset' adapted to the needs. The property of digital technology to be modified and upgraded during the whole process was very successful to produce a good set of representations.

This variable associated to the monument affects the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, field operability and their capacity to deal with critical issues in recording built heritage. But especially attention should be concentrated in their requirements in adjustments-corrections.

Timing

The interdisciplinary team of experts has been working in the site for a period of one to two months, one time a year. This restriction affected the selection of metric tools that could deliver sufficient data in a relative short time.

This variable provided elements to find a technique that could collect on-site a large amount of collected data in a short time and that could be reliable enough to be further processed off-site, when the team returned to Europe.

Quantification

The metric survey study has been adapted each campaign to fulfill the needs of the specific tasks. During the first year an extensive geometric mapping of the theatre was performed to produce a working plan of the physical condition, limits and urban context.

Furthermore, the technique was used to document the excavation works in the stage of the building and small conservation interventions carried out to repair urgent problems affecting the stability of the building.

This variable associated to the monument affects the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

Other variables

Since the project was made in cooperation with local authorities, accessibility was not restricted.

Training of local experts can be included as a variable to consider, since a lot of effort was made to make accessible the procedures and tools used in preparing the measured dataset, this certainly limits a bit the action of the recorder but ensures the successful transition of the methods to local staff to carry out them during a longer period of time.

These variables associated to the monument affect the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

2.2.2 RECORDING THE ACTUAL STATE OF CONSERVATION

In this project, structurally speaking, the documentation of the fabric's geometry and texture was performed by the combination of 'metric survey techniques'. These techniques were implemented to cover the whole building according to the level of detail required and time frame. The resulting 'measured dataset' of orthogonal projections will be used to prepare a series of restoration proposals for the monument.

An important conclusion of this work is that while methods for recording 3-D measurements of the fabric using a reflectorless electronic distance measurement total-station have been proved to be extremely effective and precise, conventional hand survey was more efficient to record individual fragments of the stage in order to prepare an Anastylosis study.

At the same time, low end closed-range photogrammetry programs has been proved sufficient in relation to generate an orthogonal approximate survey tolerance for the identification and study of surface structures such as stone by stone lying in a irregular surface (e.g. rounded surface of the main façade).

The information gathered is recorded and produced simultaneously to the works through the use conventional and sustainable off-shelf application and instruments widely available in the market, such as a total station, computer-aided drafting applications, digital and analogue cameras, scanner, and orthogonal raster image produced by photogrammetry.

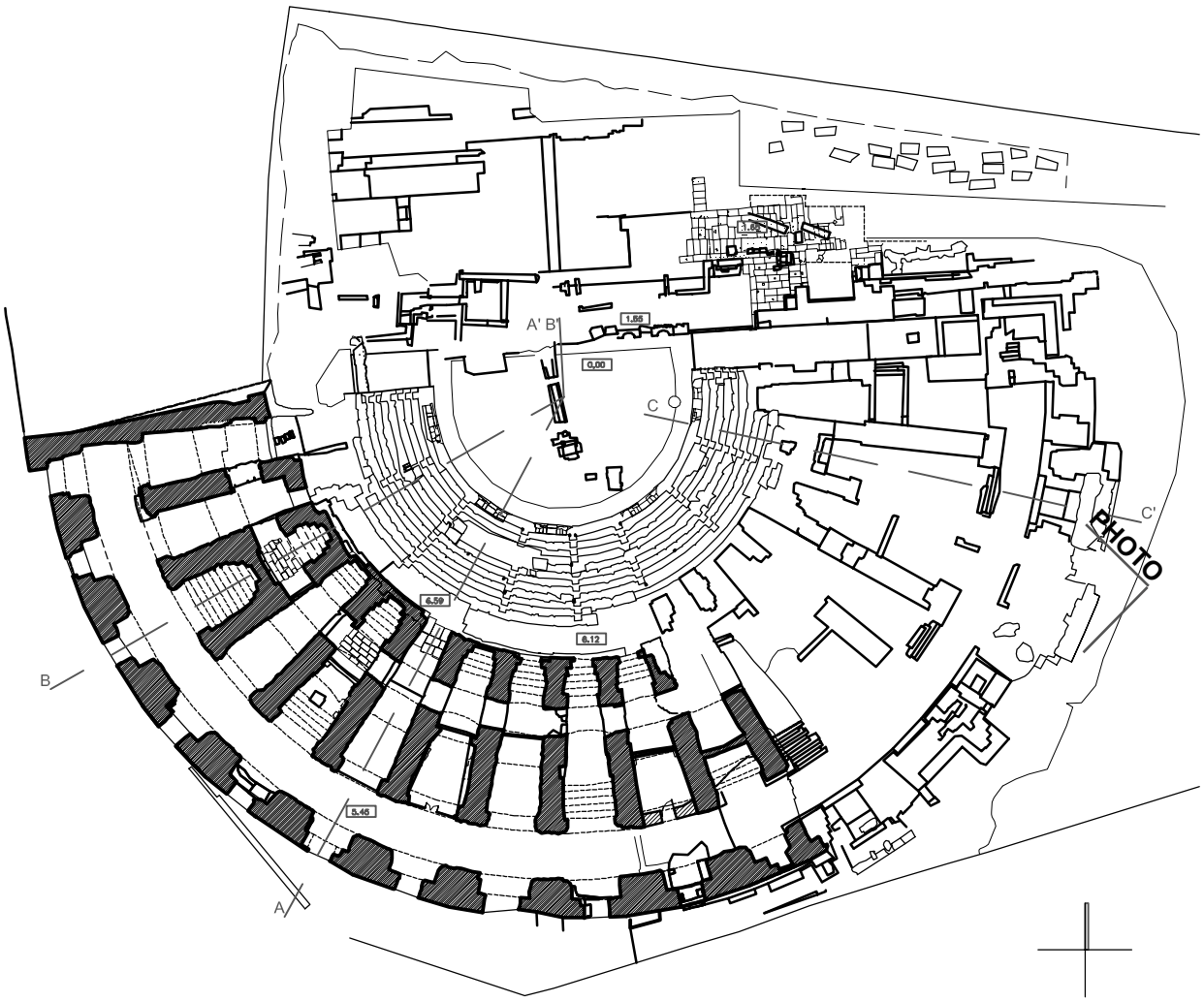
Establishing a local reference (coordinate) system: **a three-dimensional metric reference system (for control and integrity of the measurements)**

A system covering the whole site, according with a local three-dimensional coordinate system orientated to the relative north (magnetic north)[5], and with 'vertical datum' assigned in relation with a relative height of the Theater's scene. The precision of the coordinates of the fix points was improved with the calculation of a close traversing[6]. The system of coordinates would be linked to regional or international systems in a later stage.

Topographic and urban geometry

The emplacement of the building in the urban context (shape and dimension) and the characteristics of the landscape (topography and vegetation) have been recorded with the metric survey tools.

MEASURED DATASET 'METRIC SURVEY STUDY'
LEVEL 01 - ARCHITECTURAL SURVEY



METRIC SURVEY OF LEVEL 01:

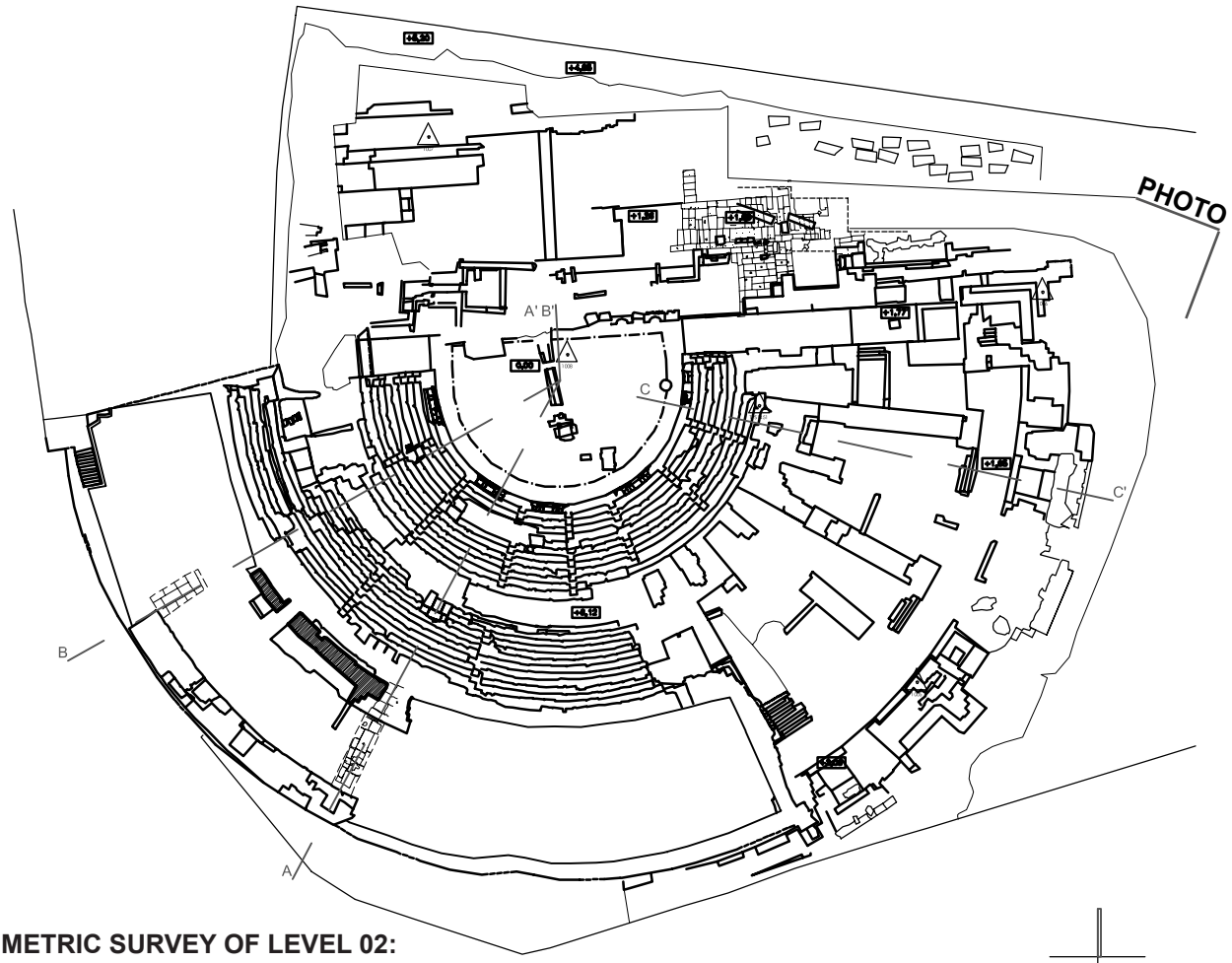
Actual state of conservation, this map shows the inner galleries and other structures laying in the survey.



VIEW OF THE THEATRE FROM THE SOUTHEAST

Figure 60: level 01 - architectural survey of the theatre for the preparation of a critical and analytical report of the actual state of conservation (drawing by Patrício, T. - Santana Quintero, M. - Stevens, T.).

MEASURED DATASET 'METRIC SURVEY STUDY'
LEVEL 02 - ARCHITECTURAL SURVEY



METRIC SURVEY OF LEVEL 02:

Actual state of conservation, this map shows the inner galleries and other structures laying in the survey.



GENERAL VIEW OF THE THEATRE FROM THE SOUTHEAST

Figure 61: level 02 - architectural survey of the theatre for the preparation of a critical and analytical report of the actual state of conservation (drawing by Patrício, T. - Santana Quintero, M. - Stevens, T.)

MEASURED DATASET 'METRIC SURVEY STUDY'
SECTION A-A' - ARCHITECTURAL SURVEY

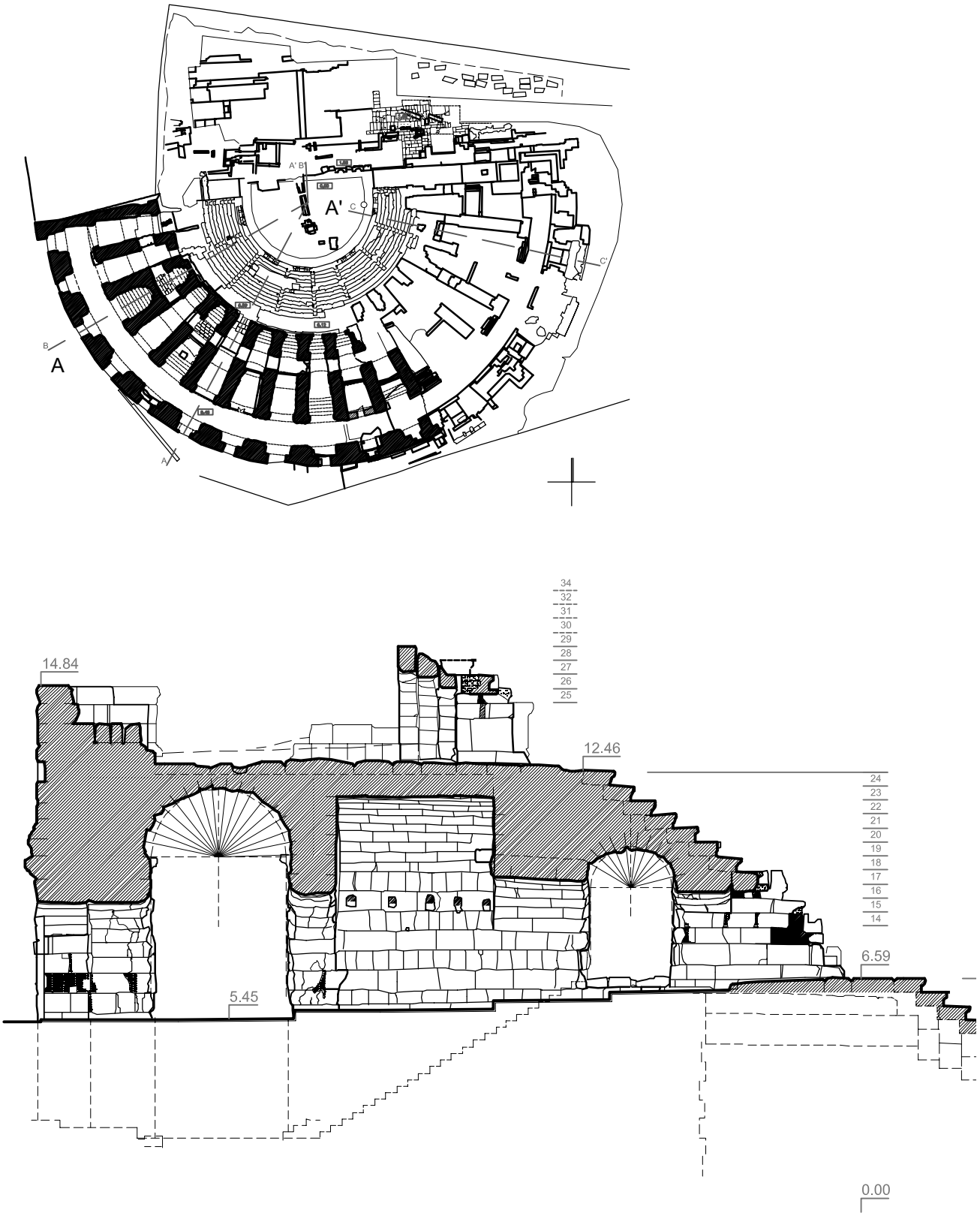
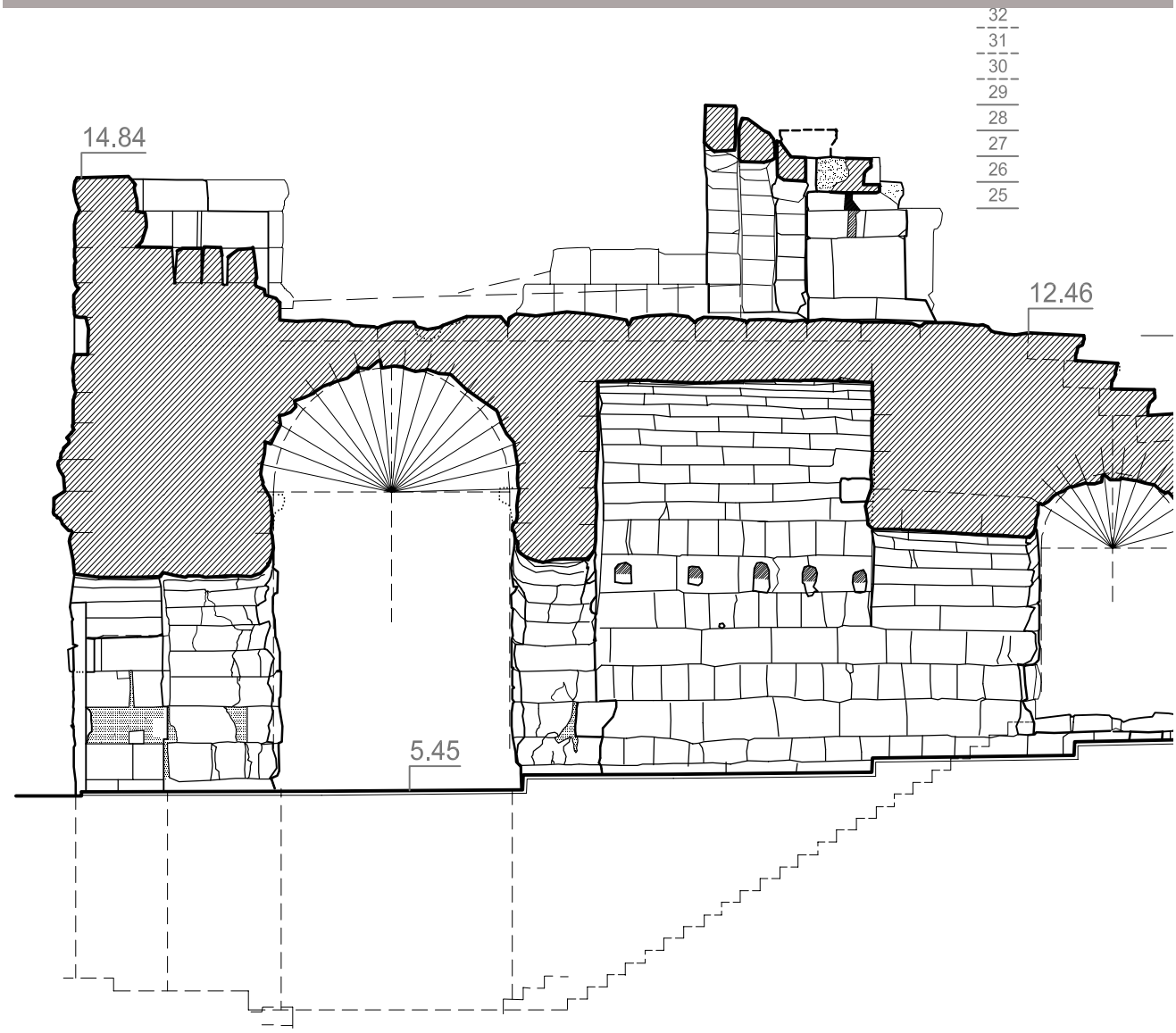
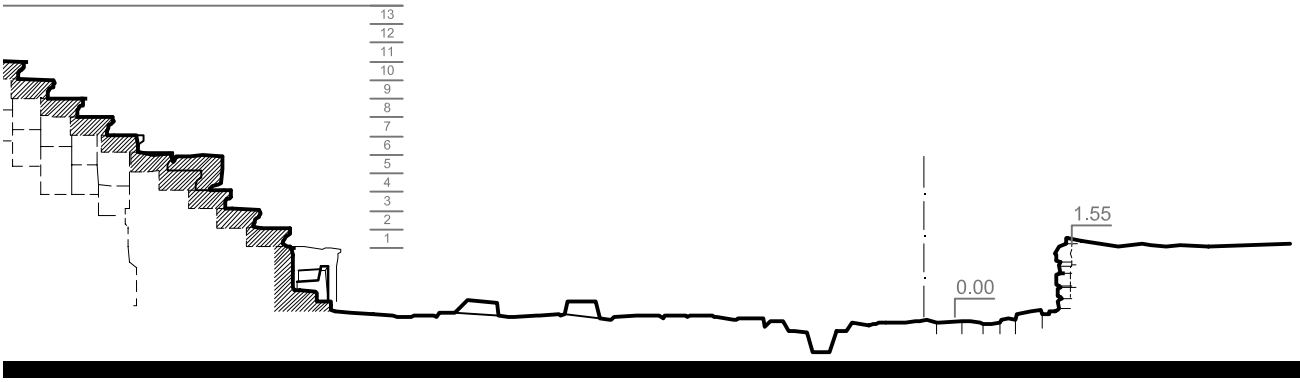


Figure 62: cross section A-A' - architectural survey of the theatre for the preparation of a critical and analytical report of the actual state of conservation (drawing by Patrício, T. - Stevens, T.).

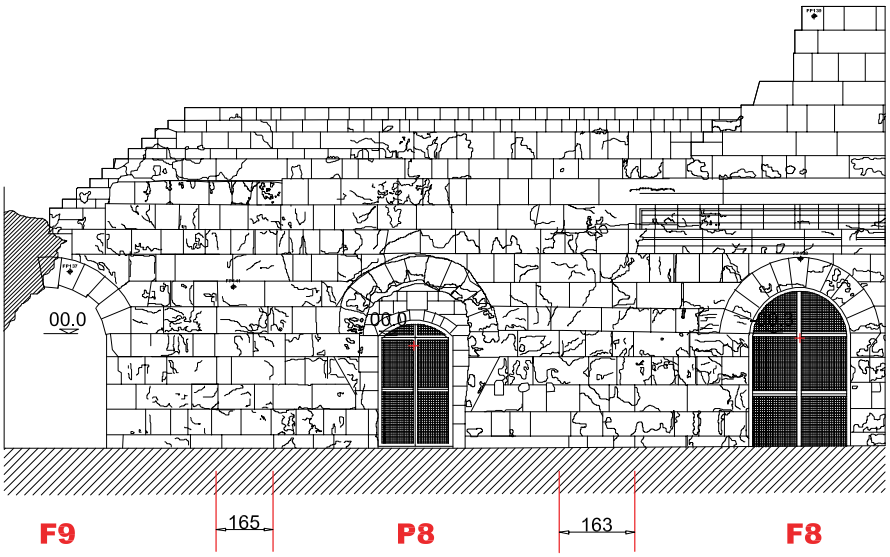


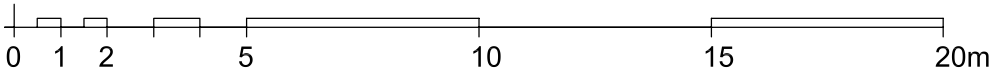
METRIC SURVEY SECTION AA':

Actual state of conservation, this map shows a section thru galleries and other structures

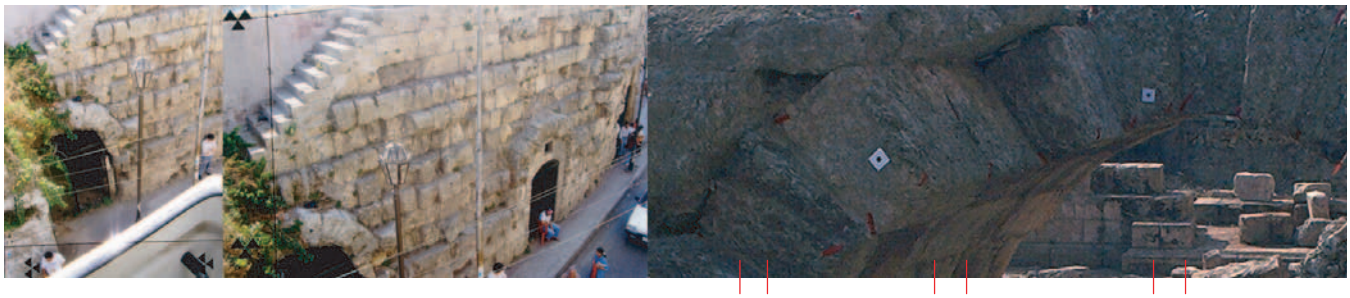


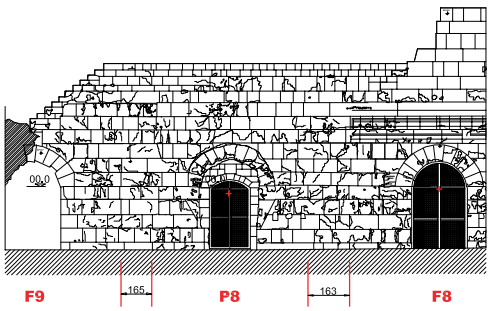
MEASURED DATASET 'METRIC SURVEY STUDY'
RECORDING THE MAIN FACADE - ARCHITECTURAL SURVEY

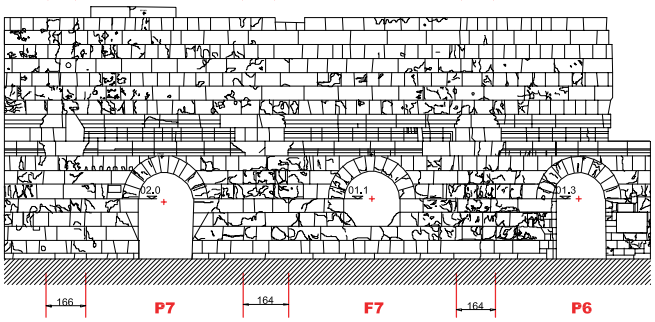


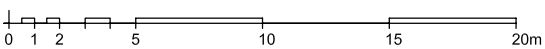


Photographs for photogrammetric restitution Targets for photogrammetric restitution



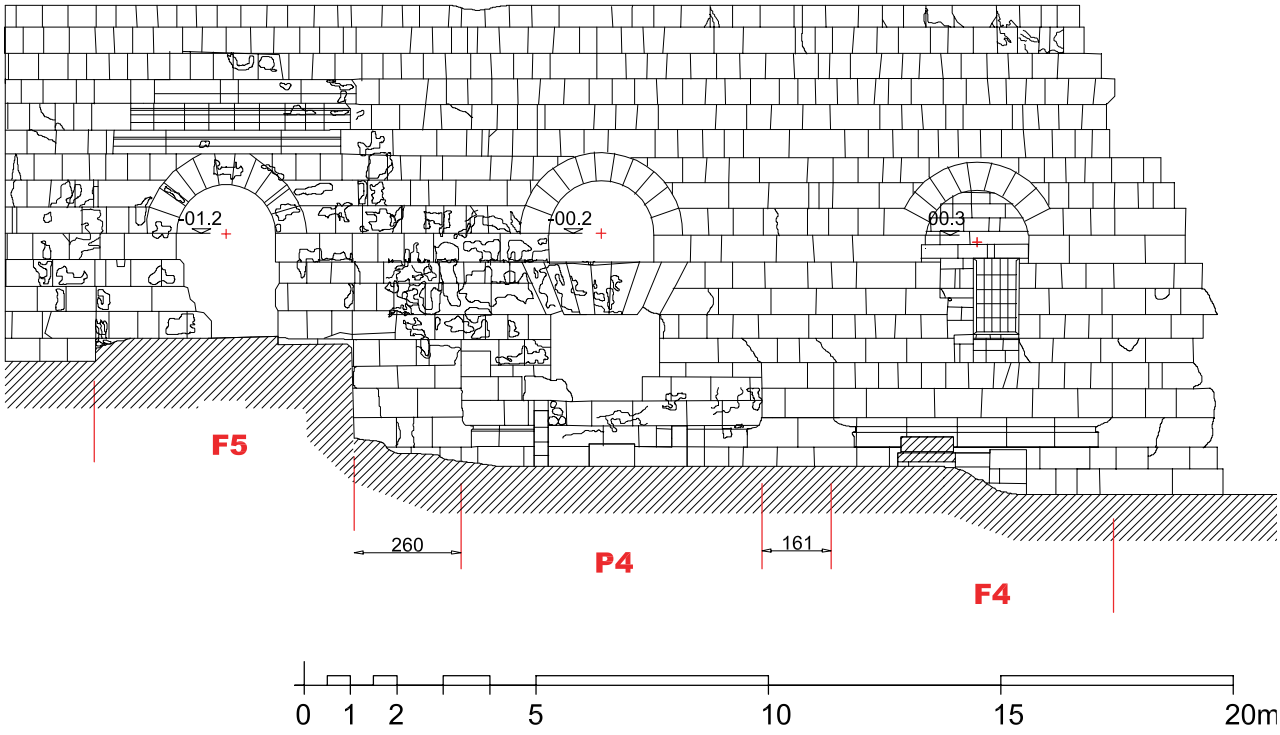






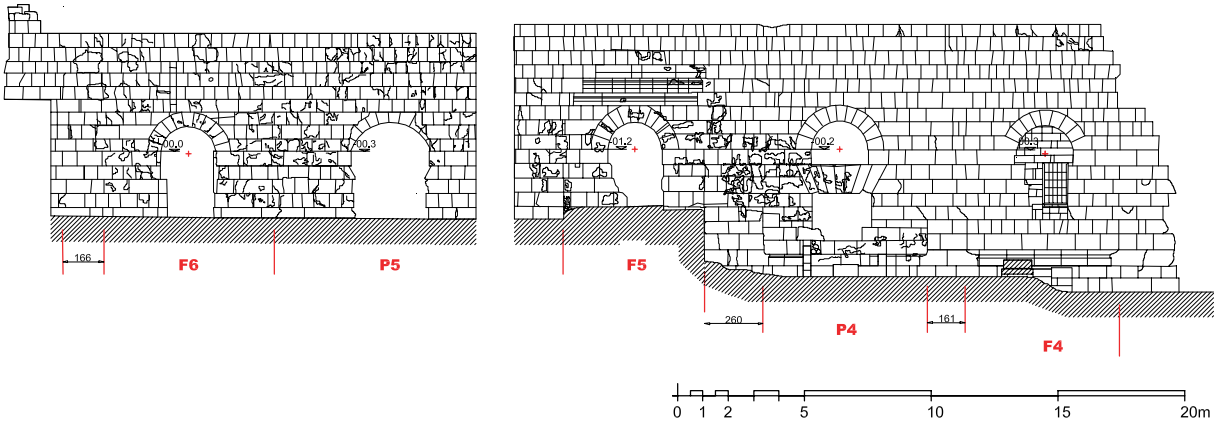
Drawing by: T. al-Murri, T. Patricio, R. Hendrickx

Figure 63: example of the photogrammetric survey of the main facade - architectural survey of the theatre for the preparation of a critical and analytical report of the actual state of conservation.



Photographs using an amateur camera from a lift





Acquisition of the building geometry: preparing the architectural analysis: (Survey of in-situ remains: shape, colour, and dimension)

A complete set of orthogonal maps were prepared for the 'architectural analysis of the remains' (Patrício, T., 2002, p. 37)[7] , including:

- Plan sections of the context and building, including the existing situation of the theatre organized in levels, identifying the apparent traces of different phases of constructions and modifications (see figures 60 and 61).
- Vertical or cross sections through peculiar or mostly complete parts of the building in order to illustrate the differences in level and shape of the fabric (see figure 62).
- Plan elevation of the main existing façade of the Cavea in order to yield information to prepare hypothetical reconstructions of the theater (see figure 63).

These maps were complemented by making emphasis in evidencing the '*original form*' of the object and the historical phasing occurred, '*materials and construction' (ICOMOS, 1990, pp. 31)*[8].

This survey with serve for the location of artifacts and other movable objects important for the thematic assessments (Survey of the "membra disjecta").

Photogrammetric survey of the main facade

The need of applying this tool deals with recording in relative short and using cost-effective actions the whole geometry of the main façade in order to produce a measured representation or vectored map that can be used for condition and historic assessments aimed at preparing an 'analytical and critical report' of the subject (see figure 63).

Process

A set of control points was prepared covering the whole surface using a REDM Total Station. Each point was set at the top of each entrance in the facade.

A large number of photographs with sufficient overlapping and obliqueness were taken covering the subject with an analogue camera; the negatives were scanned after processing.

The application called PhotoModeler was used for this action, this programme is very cost-effective and intuitive in its use. This work was carried out by architectural engineer Tarik al-Murri.

Furthermore, a sequence of orthogonal images of the photographs was generated according to different point views covering the perimeter of the rounded surface. Each of this projections clipped in AutoCAD were vectorized.

Subsequently, the vector maps were corrected 'in situ' and a final version was produced. These maps were used for condition mapping of type of materials and weathering forms; as well as to identify the different modifications giving information about the stratification of the building; this study is currently used by Architect Teresa Patrício to prepare a hypothetical reconstruction.

Recording excavation works at the eastern part of the scene

The excavations in this particular part of the theater can provide evidence about the 'placement of its foundations'[9]. This activity consisted in recording the area's geometry prior, and after excavations are carried out, in order to prepare a record showing evidence for the historical assessment of this part (stratification), where no documentary is available. As well as, to record the removal in order to map the layers of information without

MEASURED DATASET 'METRIC SURVEY STUDY'
CONSTRUCTION OF A 3D MODEL OF THE GALLERIES - ARCHITECTURAL SURVEY

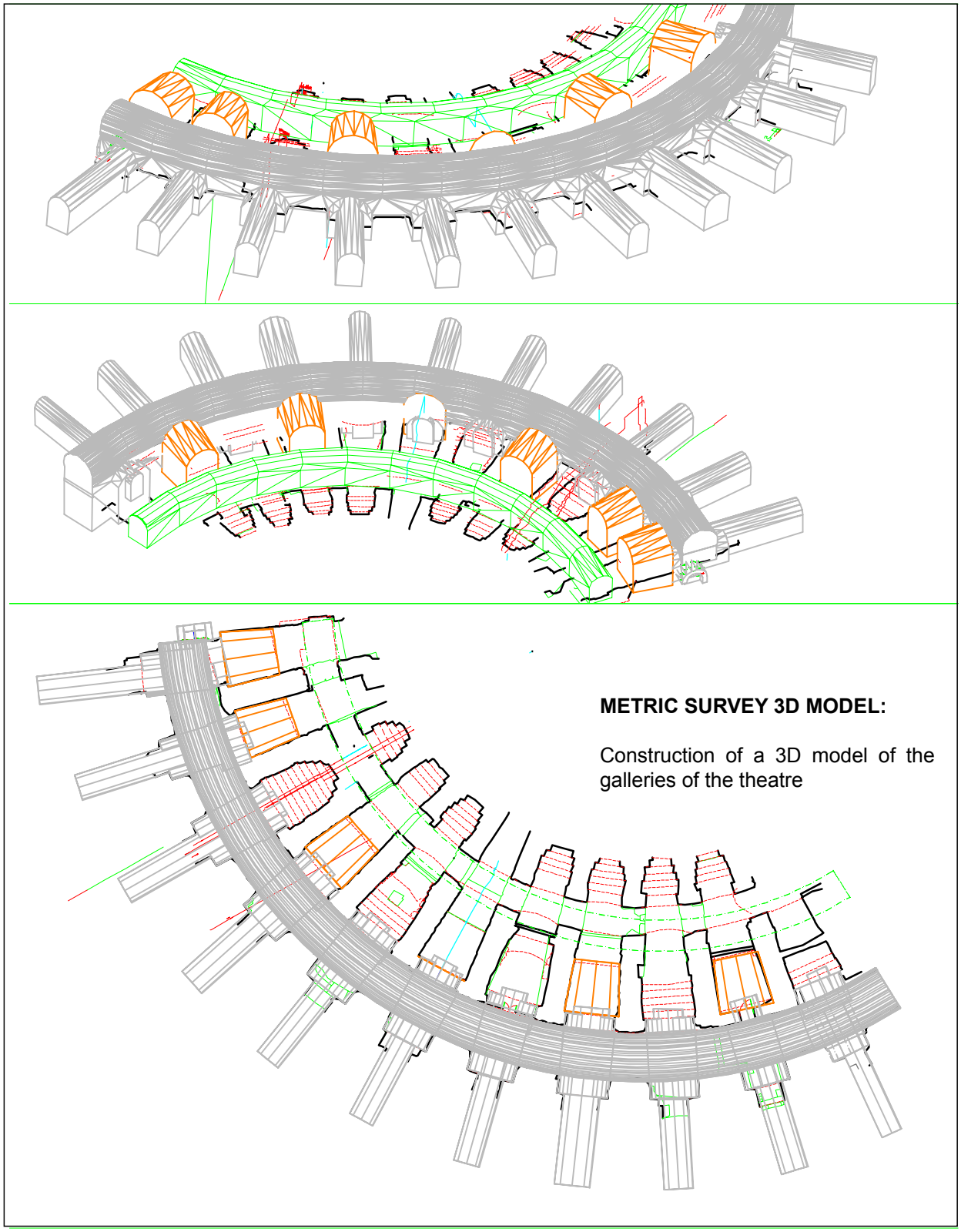


Figure 64: preparing a 3D model of the galleries - architectural survey of the theatre for the preparation of a critical and analytical report of the actual state of conservation. Author.

losing important information, safeguarding the process. The Metric Survey study should serve has an information system to link other graphic, textual, or visual sources of information, such as photographic recording, analytical sketches, etc.

2.3 CAPACITY BUILDING: TRAINING OF LOCAL EXPERTS IN METRIC SURVEY TECHNIQUES

In addition to the objectives of preparing a set of measured representations of the building and its context, the R. Lemaire International Centre for Conservation provided the opportunity to local experts to interact in the process of documentation.

These interactions enable to exchange ideas and to allow an effective training in the objectives and application of advanced digital recording tools in studying built heritage for its understanding.

The main areas of training in recording tools consist:

- Concepts and principals in recording built heritage.
- An appropriate balance among the quality of the records to be prepared, budget available for the survey, and variables of the recording techniques available
- Practical execution along with the expert, experiencing the problematic and finding solutions together.
- Guidelines for preparing an adequate set of measured plans of the site, including three-dimensional topographic models and orthographic representations, rectified photography of standing and buried structures, and other relevant measured representations required.

2.4 CLOSING REMARKS

This case study demonstrates that the adapted used of sustainable tools of documentation with specific precision and quality requirements of the measured representations adjusted to the specific needs of a problem and the desired dissemination product are appropriate for the developed of tools for the preparation of conservation reports for built heritage.

Furthermore, it proposes a model for the development of metric survey datasets that can yield information to prepare scientific hypothetical graphic reconstructions of the building and its context where the researcher is confronted only with material evidence in the lacking of no documentary sources are.

Notes:

[1] Patricío, T. Kherbek, I. Santana Quintero, M Gebauer, J. 'The Restoration and Excavation Project at the Roman Theatre of Jebleh, First Results', . J.A.S. in print, Leuven 1999.
[2] Patrício, T. 'Syro-Belgian Mission: Restoration of the roman theatre of Jebleh: Report on the restoration and excavation project', R. Lemaire International Centre for Conservation, KU Leuven, June 2002. p. 3.
[3] Jacquot, P. 'L'etat de alaouites. Terre d'art, de souvenirs et de mystère', 1927, pp. 225-234; Patrício, T. 'Syro-Belgian Mission: Restoration of the roman theatre of Jebleh: Report on the restoration and excavation project', R. Lemaire International Centre for Conservation, KU Leuven, June 2002. p. 3.
[4] Ibid 2, pp. 12.
[5] 'Magnetic north is often sufficient orientation for architectural surveying'. Hewitt, R.; Guide to Site Surveying; Architectural Press, London 1976. p. 20.
[6] Close Traversing: is a method of fixing the location of a series of station points by means of measuring the distance and bearing from each point including the initial station.
[7] Ibid 2, p. 37.
[8] ICOMOS; Guide to Record Historic Buildings; Butterworth Architecture, London 1990. P. 31.
[9] Ibid 1.

CHAPTER III

CASE STUDY

EXPERIENCES IN TRAINING ARCHITECTURAL-CONSERVATORS IN THE USE OF METRIC SURVEY METHODS:

MASTER STUDENTS AT THE R. LEMAIRE INTERNATIONAL CENTRE FOR CONSERVATION 1997 - 2002 (BELGIUM)
ALMATY WORKSHOP 2002 (REPUBLIC OF KAZAKHSTAN)
SANCHI WORKSHOP 2001 (INDIA)
UNIVERSITÉ D 'ÉTÉ IN CHINON 2001 (FRANCE)

CHAPTER III:

CASE STUDY: EXPERIENCES IN TRAINING ARCHITECTURAL-CONSERVATORS IN THE USE OF METRIC SURVEY METHODS:

This case study describes the incorporation of digital three-dimensional recording techniques in the education programme of an interdisciplinary group of professional in the framework of the following activities:

- Master in Conservation of Historic Towns and Buildings (R. Lemaire International Centre for Conservation): is an advanced postgraduate programme in conservation and restoration of urban and rural architectural heritage.
- Sanchi and Almaty Workshop (UNESCO – RWTH Aachen University): is a training workshop for local experts working in national institutions dedicated to the protection of built heritage in India and in Kazakhstan.
- Université d'été in Chinon (WHC/ UNESCO – CDV/UC Berkeley): is a training on digital recording techniques and the use of multimedia in the dissemination of built heritage for an interdisciplinary team of experts in a conference devoted to the management of heritage sites.

The combination of these experiences helped to prepare a methodology for the incorporation of these techniques into the contents of a training programme designed with a theoretical approach in combination with a practical work, which consisted in a number of practical exercises.

The theoretical approach comprises the presentation of 'the state of arts' and potentials of digital recording techniques in the documentation and dissemination of built heritage.

At the same time, the practicał framework deals with applying the concepts and principals explained in the theoretical courses in a real conservation project.

3.2 THEORETICAL FRAMEWORK

The theoretical framework provides an overview, combining recent technological developments in documentation techniques, principles in the use of these tools, and its adapted application by explaining first-hand built heritage documentation projects.

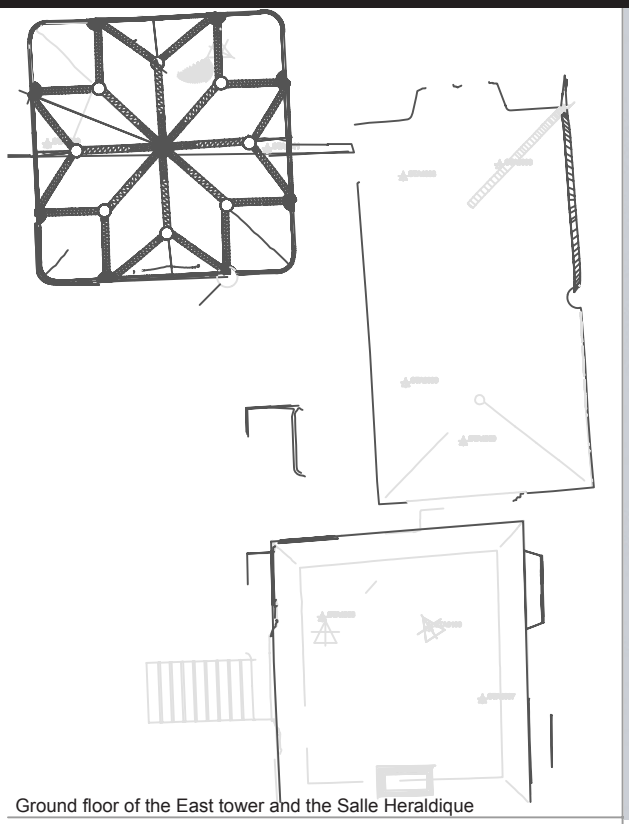
Furthermore, the theory and application of these tools is based on a particular number of principals exposed in the ICOMOS '*guidelines on education and training in the conservation of monuments, ensembles and sites*' (ICOMOS, 1993, pp.89-90)[1]:

- *understand the history and technology of monuments, ensembles or sites in order to identify, plan their conservation, and interpret the results of this research;*
- *understand the setting of a monument, ensemble or site, their contents and surroundings, in relation to other buildings, gardens or landscapes;*
- *find and absorb all available sources of information relevant to the monument, ensemble or site being studied;*
- *understand and analyze the behavior*



Figure 65: An example of a Practical exercise in the archaeological site Barhat in the Republic of India during the Sanchi Workshop organized by UNESCO and the Aachen University RWTH in 2001. In this exercise the trainees are confronted to the documentation of a complex topography in a period of two days. The resulting 'Measured dataset' of graphic representations was presented to the authorities as a contribution for the conservation of this site. Author.

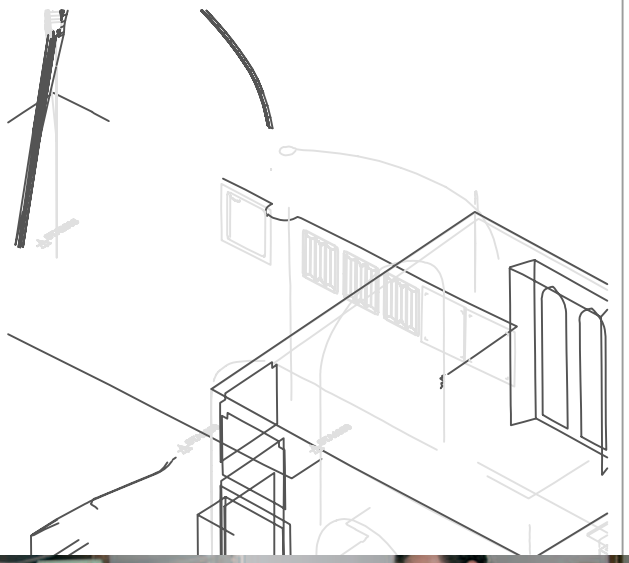
Work by students of the R. Lemaire Centre for Conservation using a REDM tracing tool for recording the geometry of the castle of Arenberg

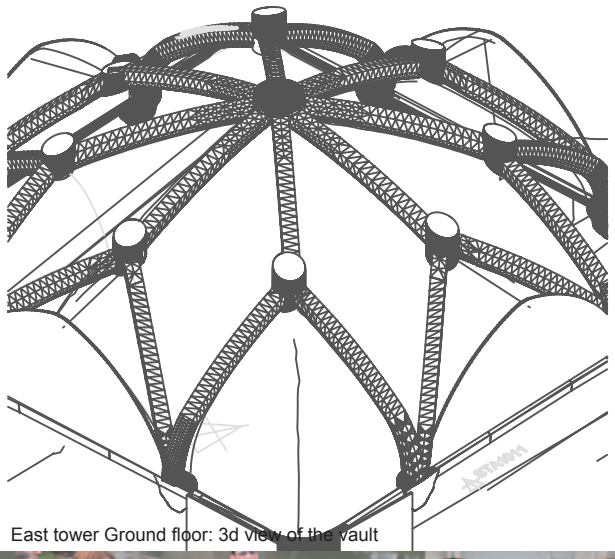


Ground floor of the East tower and the Salle Heraldique

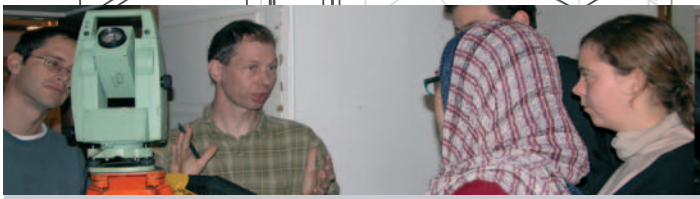


Chapel: 3d view of the vault





East tower Ground floor: 3d view of the vault



Explaining the use of a REDM total station to a group of students at the R. Lemaire Centre for Conservation by Bill Blake (English Heritage, metric survey team).



Explaining the use of stereo photogrammetry to a group of students at the R. Lemaire Centre for Conservation by Yves Egels (ESGN



Students measuring an architectural element with hand-survey techniques

Figure 66: examples of a workshop organized in the R. Lemaire Centre for Conservation on the use of REDM tracing tools in recording historic buildings. Author.

of monuments, ensembles and sites as complex systems;
- *diagnose intrinsic and extrinsic causes of decay as a basis for appropriate action;*
- *document works executed and make same accessible.*

These principals and the fundaments of the use of these tools are integrated in the course, which is focused on capturing and representing the geometry and texture of a site and its context.

Moreover, the ranging of tools explained consists of electronic distance measurement instruments (reflectorless electronic distance measurements devices) and long-range mapping scanners to image-based methods (stereo close-range architectural photogrammetry and rectified photography).

Specific emphasis is giving to explain:

Collection tools:

- Collection of three-dimensional measurements using a reflectorless distance measurement device or reflectorless total station.
- Collection of three-dimensional measurements using plane parallel Photography, roughly and absolute rectified photography.
- Introduction to the collection of three-dimensional measurements using a low-end Digital Photogrammetric application.

Processing tools (Analysis):

- Computer-Aided Drafting applications for processing of the data-collected using previous techniques, making emphasis in tools adapted to the needs of studying built heritage.
- Digital terrain modeling application sin combination with CADR software for processing and modeling the topography of the site being studied.
- Introduction to three-dimensional modeling



Figure 67: a student using a REDM Total Station to record the interior of a Chapel, Monastery of Carthusian Monks, Antwerp 2002, Belgium, IPW3. Author.

Dissemination tools (Synthesis)

- Plot of paper maps presenting the measurements collected and processed in previous phases.
- Introduction to more advanced dissemination tools, such as online systems of Information (e.g. geographic information systems, virtual representations, walkthroughs, etc).

In addition, to explaining the available instruments, the contents are enhanced by the confrontation of their use with principals in documentation of built heritage.

Furthermore, the techniques are explained

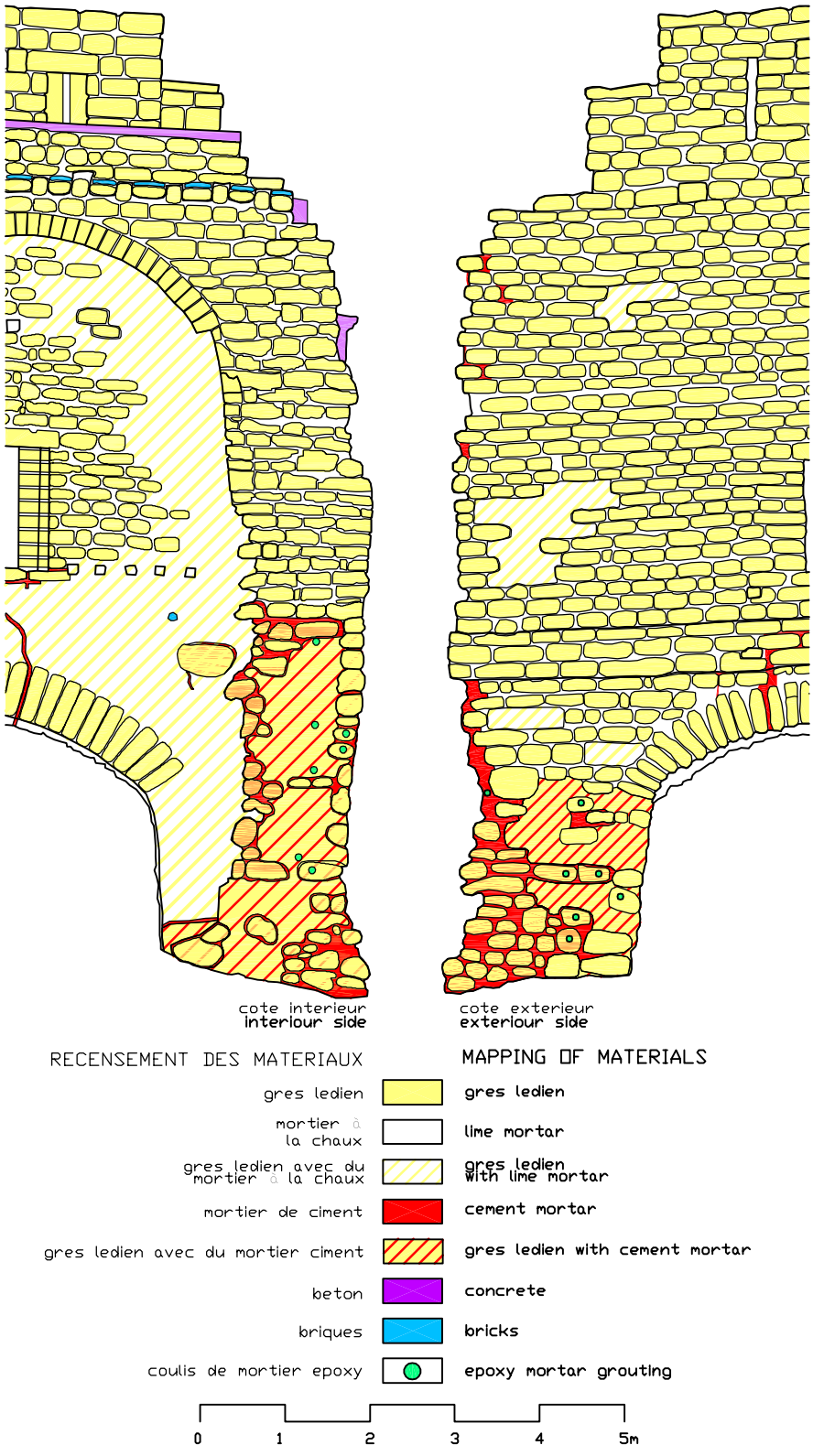


Figure 68: a plan elevation prepared with the combination of REDM Total Station and plan parallel Digital Rectified Photography, the resulting CADR drawing prepared presents an assessment about the actual condition of the building using a chart explaining the different weathering forms affecting the fabric of the building, IPW3 Assessments Tower and Part of the First City Wall of Brussels, Belgium [Purcar, C. et al, 2002].

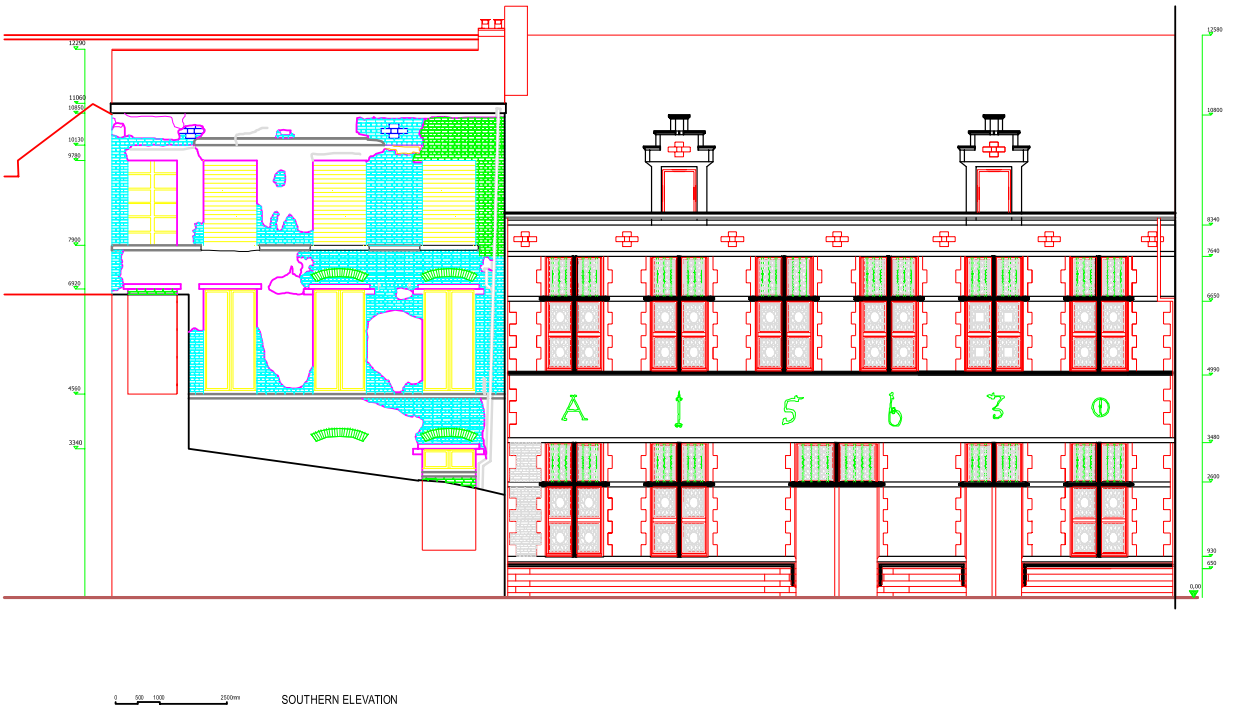


Figure 69: a plan elevation prepared with the combination of REDM Total Station and plan parallel Digital Rectified Photography, the resulting CADR drawing prepared presents an assessment about the actual condition of the building, IPW3 Former Property Vandenpeerenboom, Anderlecht , Belgium [Devolver, R. et al, 2002]

showing real first-hand cases to demonstrate their effectiveness.

3.3 PRACTICAL FRAMEWORK

The practical framework provides the students the opportunity of exploring and applying directly the 'theoretical insights' (RLICC, 2002)[2] extracted from the theoretical framework.

In addition, the students are assisted in the use of these techniques, selecting the most sustainable methods in their own practical exercises within this framework.

The exercises undertaken involve the preliminary preparation of a 'dataset' of measured representations of the building geometry, texture, and urban-topographic context.

The Student guidance, timing, and extend in the use of selected digital three-dimensional methods, including reflectorless electronic distance measurement devices (REDM) and rectified photography is undertaken by specialized members of the teaching staff and by the guest professors, chosen according to the difficulty of the task.

In addition, this practical part focuses on explaining common critical issues in the use of these more advanced techniques for capturing and computer-aided drafting applications in representation historic buildings, including (see chart 50):

- **Notion of scale:** referring that even if CADR drawings are prepared 1: 1 in the computer, the surveyor is required to think about the plotting scale before performing the survey.
- **Density of measurements:** the use of electronic and image-based techniques provide sufficient tools to acquired more measurements of the object than a hand-survey tool, therefore the student needs to be aware of the fact that a higher density of measurements will provide a higher quality to the survey (e.g.; avoiding

COURSE FRAMEWORK

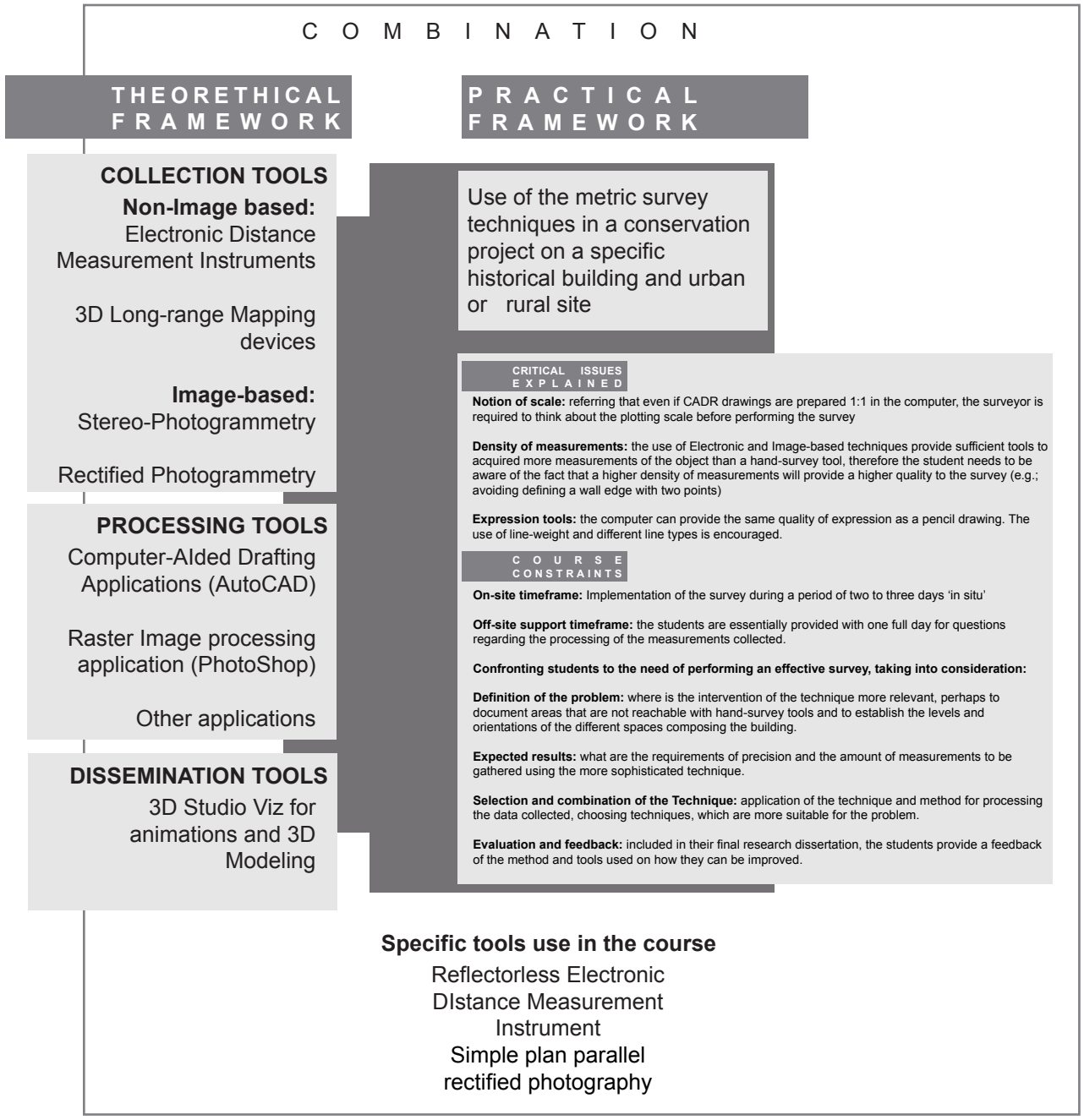


Chart 50: example of the course framework for the training of architectural conservators in the use of these techniques in recording historic buildings.

defining a wall edge with two points).

- **Expression tools:** the computer can provide the same quality of expression as a pencil drawing. The use of line-weight and different line types is encouraged.

Subsequently, the students are provided with a number of constraints:

- **On-site timeframe:** implementation of the survey during a limited period of time.
- **Off-site support timeframe:** the students are provided with support during the practical framework for

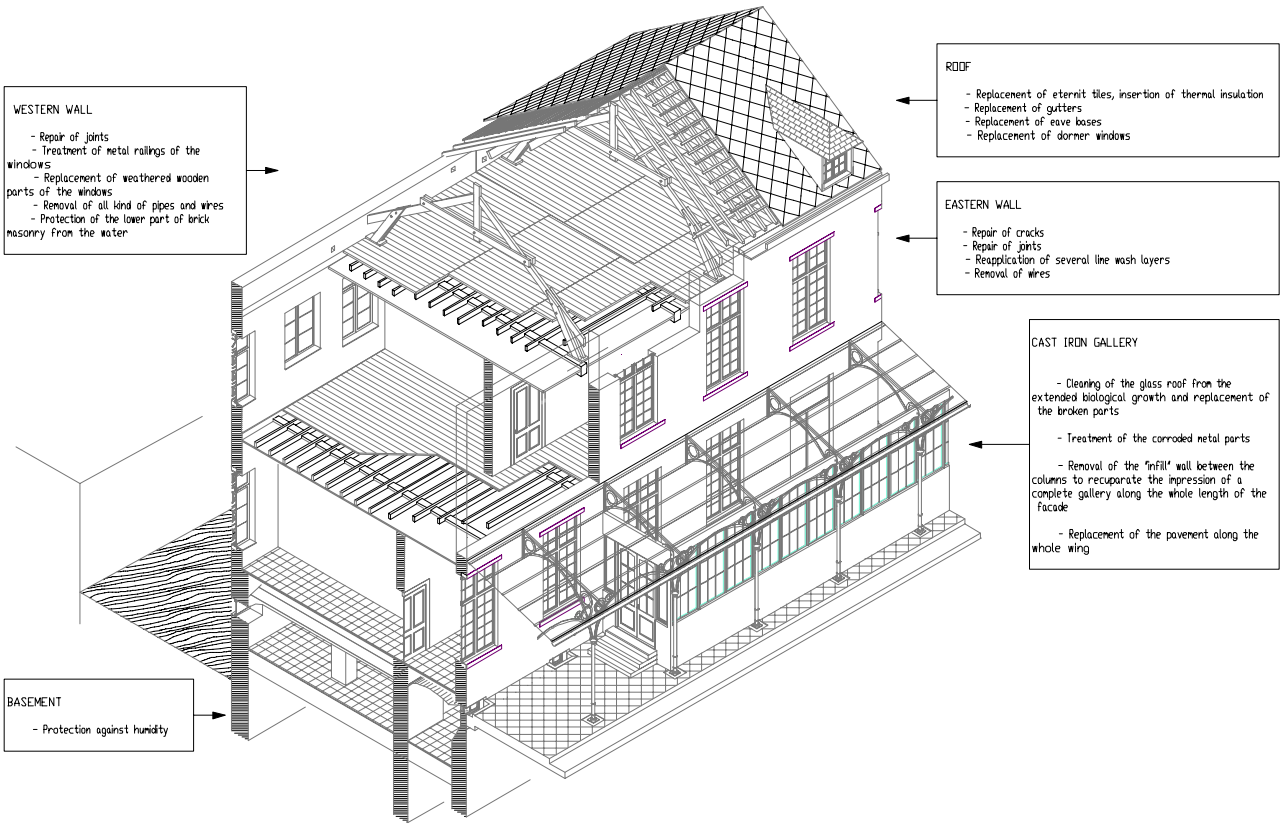


Figure 70: a CADR 3D section drawing prepared to present possible interventions for the conservation of the building, IPW3 Convent of the Black Sisters, Leuven, Belgium [Privitera, L. et al, 2002]

questions regarding the processing of the measurements collected.

These limitations are very useful, because the students are confronted to the need of performing a very effective survey thought the definition of a methodology, taking into consideration the:

- **Definition of the problem:** where is the intervention of the technique more relevant, perhaps to document areas that are not reachable with hand-survey tools and to establish the levels and orientations of the different spaces composing the building.
- **Expected results:** what are the requirements of precision and the amount of measurements to be gathered using the more sophisticated technique.
- **Selection and combination of the Technique:** application of the technique and method for processing the data collected, choosing techniques, which are more suitable for the problem.
- **Evaluation and feedback**: included in their final research dissertation, the students provide a feedback of the method and tools used on how they can be improved.

The resulting measured plans are used by the students to carry out thematic assessments about the condition of conservation and history of the subject and context, including:

Spatial and typological study (context and architecture): deals with the analysis of the Building morphology and its context (topographic – Urban morphology). The analysis is carried out basically using the dataset prepared in the Measured representations 'dataset'.

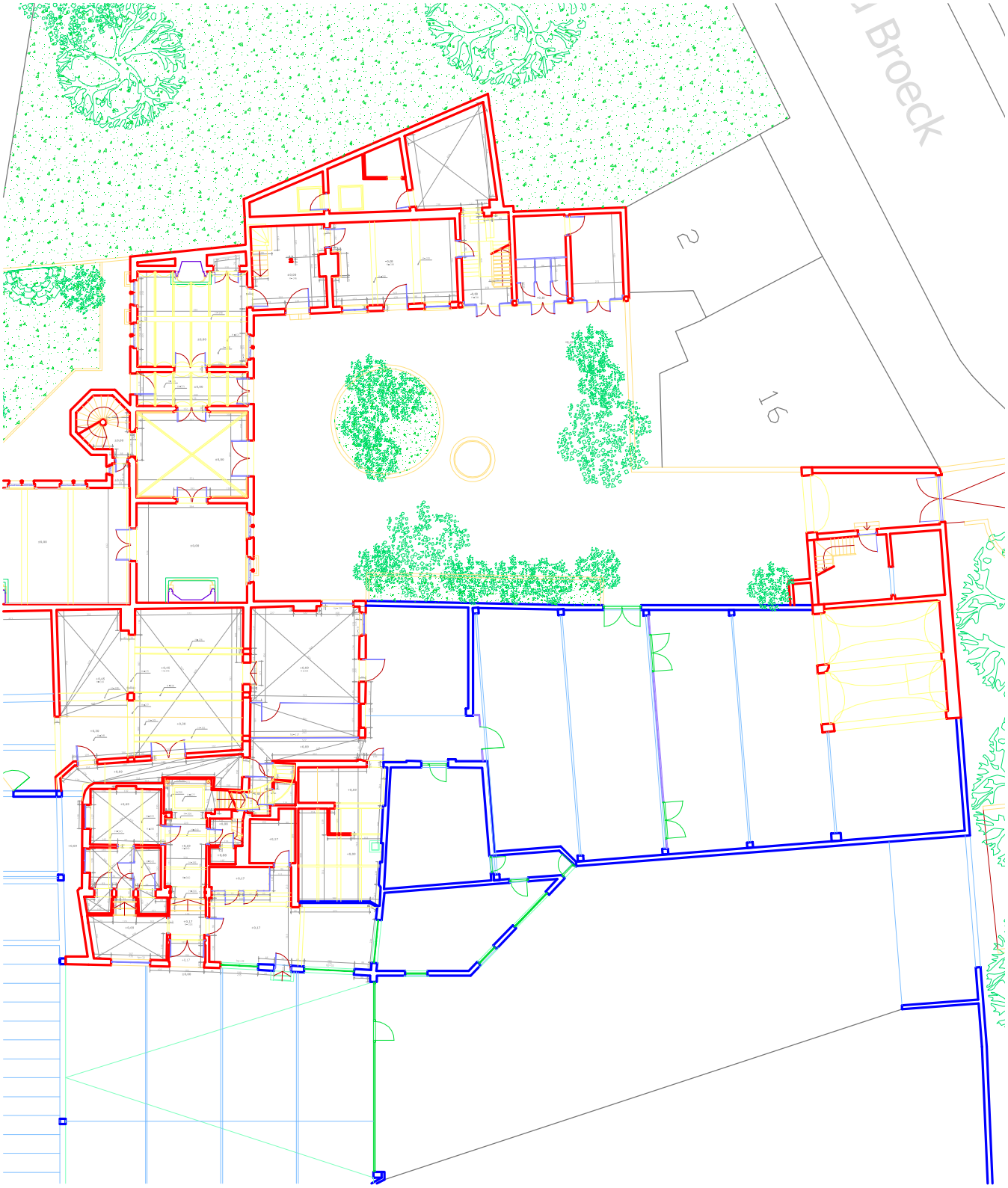


Figure 71: the general ground map of the building, prepared with the combination of REDM Total Station and hand-survey measurements, the resulting CADR drawing prepared presents an assessment about the actual condition of the building, IPW3 Former Property Vandenpeerenboom, Anderlecht , Belgium [Devolver, R. et al, 2002].

Historical assessment: deals with the comparative study of historical documents and the answers to be found evidenced in the stratigraphy of the object, in order to clarify the historical chronology of the object, providing facts about the history of the building and historic context, in relation with the characteristics of the built environment surrounding it in past and present.

In this case, the measured survey plans are used as mapping instruments to identify the construction phasing, evidenced both in the documentary research sources and in the fabric of the subject; it is a comparative study that analyses and verifies these facts in the fabric to define a stratigraphy of the object.

This assessment makes use of different techniques, such as historical documentary research (map regression, iconographical research, and archival-bibliographical research) and study of the stratigraphy of the fabric.

Condition assessment: deals with the study of the fabric of the object by mapping the materials and weathering forms and its causes (Condition Mapping); as well as the Structural Analysis (Deformation, crack analysis, stability, etc). The metric survey dataset is used as base for this mapping process, monitoring of the mechanism of change in the fabric of the building, and to study the anatomy of the structural design.

The study of the anatomy of the object deals with the analysis of the structural support design and changes, masonry sequence, jointing characteristics, materials used, and other relevant subjects associated with the construction.

3.4 FRAMEWORK FOR THE SELECTION OF METRIC SURVEY TOOLS

3.4.1 APPLICATIONS

In this case study, the metric survey tools are explained to architectural conservators, a group of techniques are explained and another group is actually presented in a practical exercise.

These tools are mainly selected according to their potentials in producing a cost-effective ‘measured dataset’ that can be use for conservation works.

The architectural conservations are considered as a target audience: ‘professional’.

Expected Quality and task definition

The ‘metric survey study’ is composed of measured representations with a reliable completeness of information and that are of the highest possible quality. The tasks of the ‘metric study’ are of a higher possible quality, which permits the preparation of a conservation project aimed at safeguarding the monument for future generations (see chart 51).

Variables in the identification of restrictions in the use and selection of metric survey tools

The variables are ordered according to their relevance in the application (see chart 51).

Budget and expected quality

The metric survey tools used in the course were chosen for being cost-effective, related to the aim of the course and the application of the tools in first-hand projects, where the

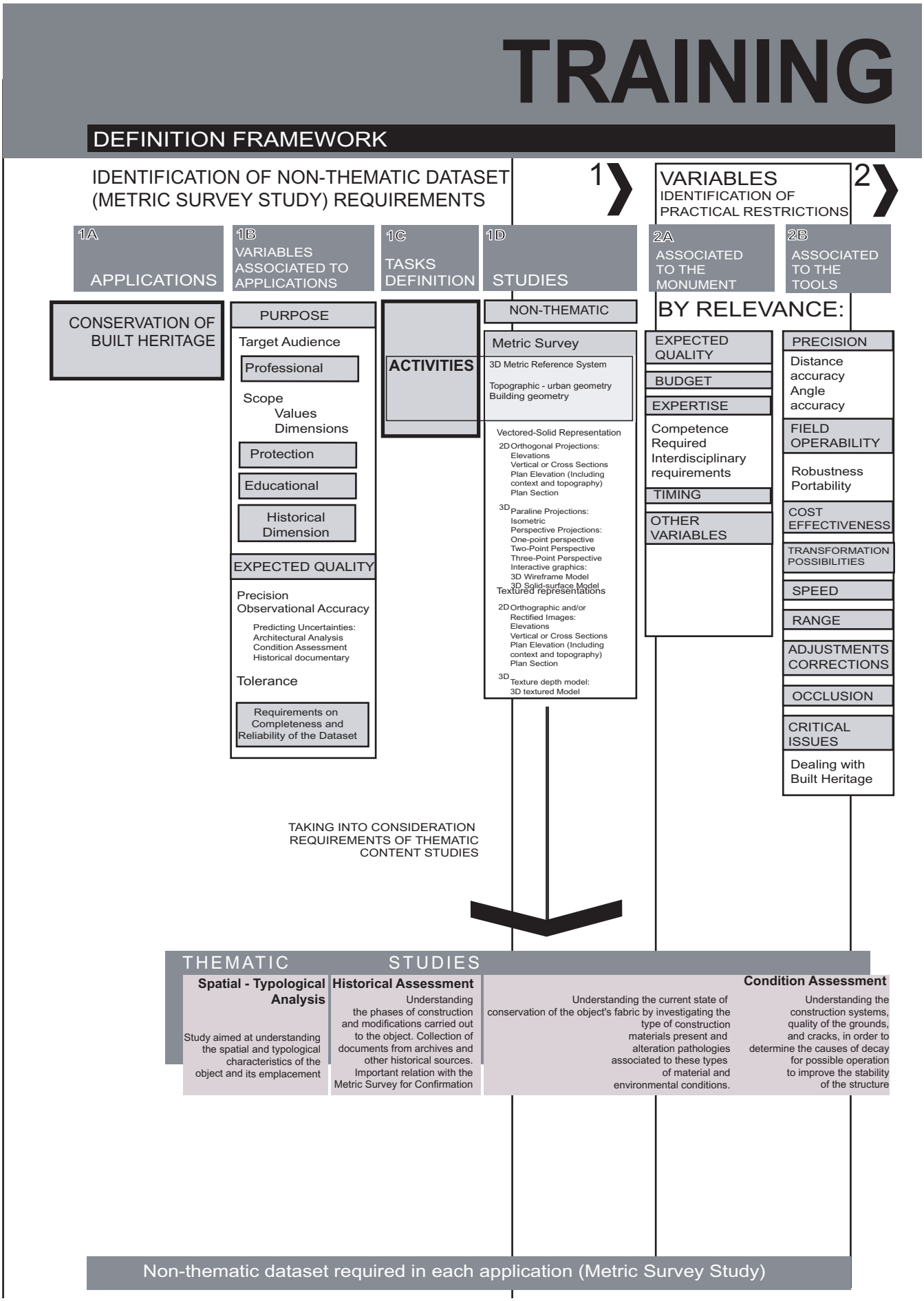
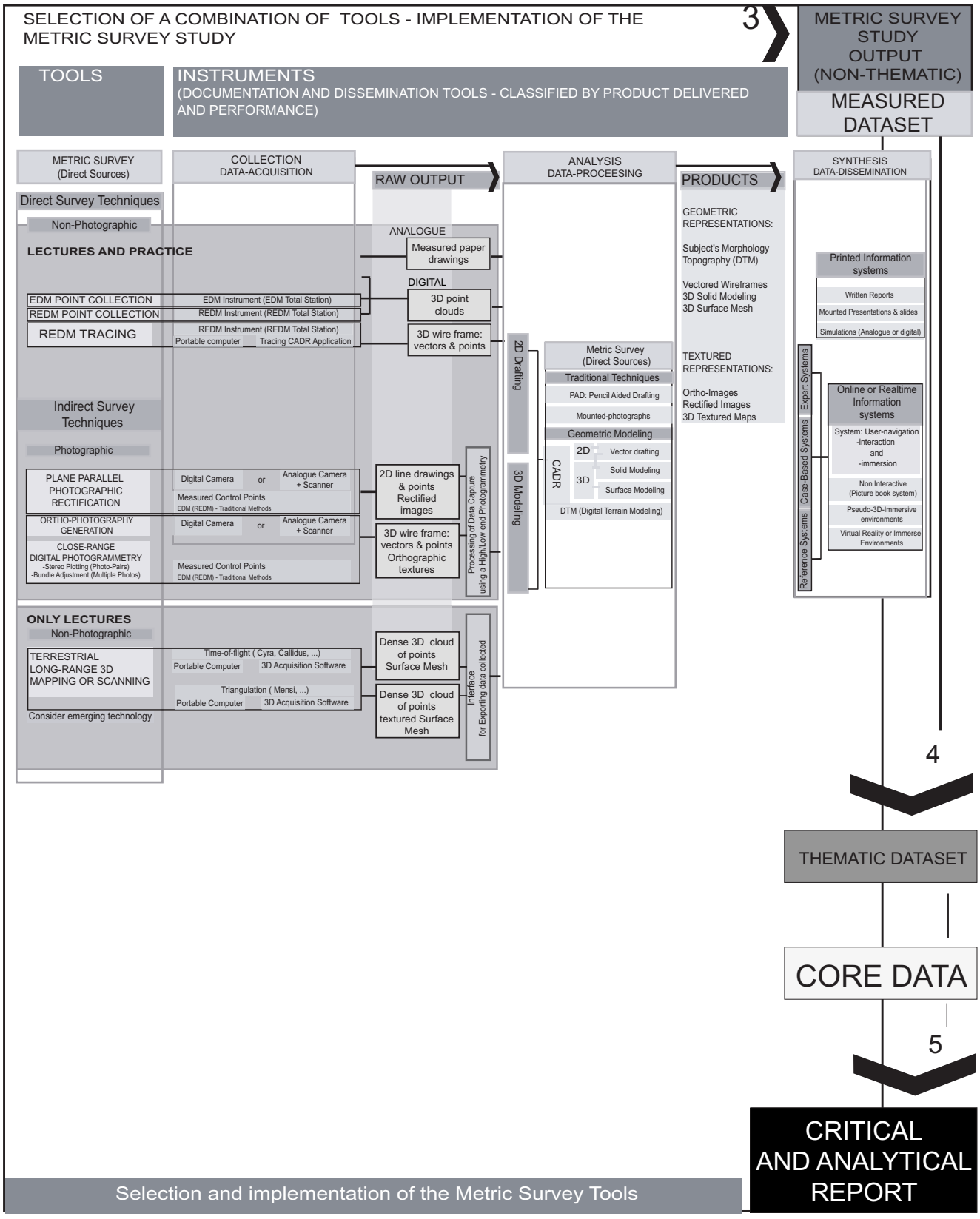


Chart 51: application framework applied to this case study.

EXPERIENCES

SELECTION FRAMEWORK



Selection and implementation of the Metric Survey Tools

metric survey study is just a fraction of either the training course and/or the project in which the tools will be use.

On the one hand, in the masters programme, metric survey tools are integrated into the module called 'analyzing and registration techniques' that is among other teaching modules, including: conservation of the architectural heritage, conservation of urban sites and landscapes, building materials and conservation techniques, conservation policies and integrated project work (exercises, visits and study trip).

On the other hand, in field projects, the training's budget on metric survey tools is share among capacity building in building materials, conservation, and excavation techniques.

The relation between the budget and the expected quality influences the selection of tools according to:

Range and precision: the instrument's capacity to measure unreachable areas with a relative good precision expressed in millimeters of the building was limited by the amount of funding available. However, the selection was done also according to the quality required in measuring historic sites and the reputation of the brand selected.

Occlusion and field operability (including adjustment and corrections): the budget affected the selection according to the potential of the tool to overcome obstacles (e.g. height), which is also related to range. In terms of operability, the budget available provided sufficient funds to acquire an instrument that is both efficient and simple to operate.

Expertise

The tools should be reliable and easy to operate. The Leica TCR307 was selected, this instrument has a very simple approach for levelling and surveying, it provides a sequence of menus that guides the operator to efficiently operate the machine.

In addition, the software selected is widely supported in the world and it is easy to learn.

This variable associated to the monument affects the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different applications, field operability and their capacity to deal with critical issues in recording built heritage. But especially attention should be concentrated in their requirements in adjustments-corrections, since the should be easy to understand.

Timing

The exercise with the students is limited, several other course are also provided. The selected tools should be efficient and reliable to record a relative large amount of measurements in a short time.

This variable affects the selection of the tools in:
Transformation possibilities: the data collected in a short time should be sufficient and reliable to be use as framework to be combined with other metric survey techniques, such as hand-survey.
Range, speed and precision: the instrument's capacity to measure high areas with a relative good precision and in a short time.

Quantification

The metric survey study has been adapted to fulfil the needs of training course and the field work.

In relation with training, the tools should be use as framework to establish the control network (combining control with a site reference system) and carry out task where conventional hand-survey techniques are not efficient and insufficient.

This variable associated to the monument

affects the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

Other variables

Since the training course and projects were these tools were used are made in cooperation with the university and local authorities, accessibility was not restricted.

Although training is the purpose of this case study, it is also consider a variable, since a lot of effort was made to make accessible the procedures and tools used in preparing the measured dataset; as well as, the effort put in preparing the guidelines.

3.5 SELECTION OF TRAINEES

In order to achieve good results, a group should be of a maximum of 6 students per instructor and set of equipment (e.g. PC, EDM Instrument, etc) is recommended.

At the same time, the group should be divided into different categories according to their previous experience in the use of the instrumentation. It is preferably to have a group of people with different professional background in order to make an interdisciplinary environment, to discuss and exchange ideas about the use of the presented techniques in documenting built heritage.

In addition, in case of working with trainees from government institutions, it is advisable to prepare criteria before the course starts for the selection of participants.

3.6 USER GUIDES EXPLAINING THE USE OF THE METRIC SURVEY TOOLS

A folder with user guides explaining the metric survey tools was prepared during the courses. These guides were made with the assistance of the participants and were tested during the course. The relevance and organization of the guides and contents reflect the needs of the participants. They explain the theory of documentation, the use of specific software in combination with the instruments. The main different of these guides with the booklet or help menus accompanied the off-the-shelves software is that it provides the user a methodology adapted to recording monuments.

The idea behind is in the future to improve the guides, adapting the contents to each of the applications it will be use in dealing with documentation of sites and to teach the trainees the use of preparing guidelines (see figure 72).

3.7 EVALUATION OF THE TRAINEES: EXAMINATION

The evaluation should be a group examination instead of individual. The results should be achieved by the interdisciplinary group.

At the same time, the evaluation criteria should take into account critical issues in recording and representing built heritage sites, including:

- Final results in relation to the timeframe available.
- The quality of the resulting ‘measured representations’ in relation to the output scale selected.
- The collection of an adequate number of measurements, in relation with the ‘density of records’.

Preparation of user guides: Almaty Workshop organized by UNESCO and the University of Aachen RWTH

User guide for plan parallel rectified photography



Figure 72: Almaty workshop: example of the preparation of a user guide for plan parallel rectified photography with the trainees. Author.

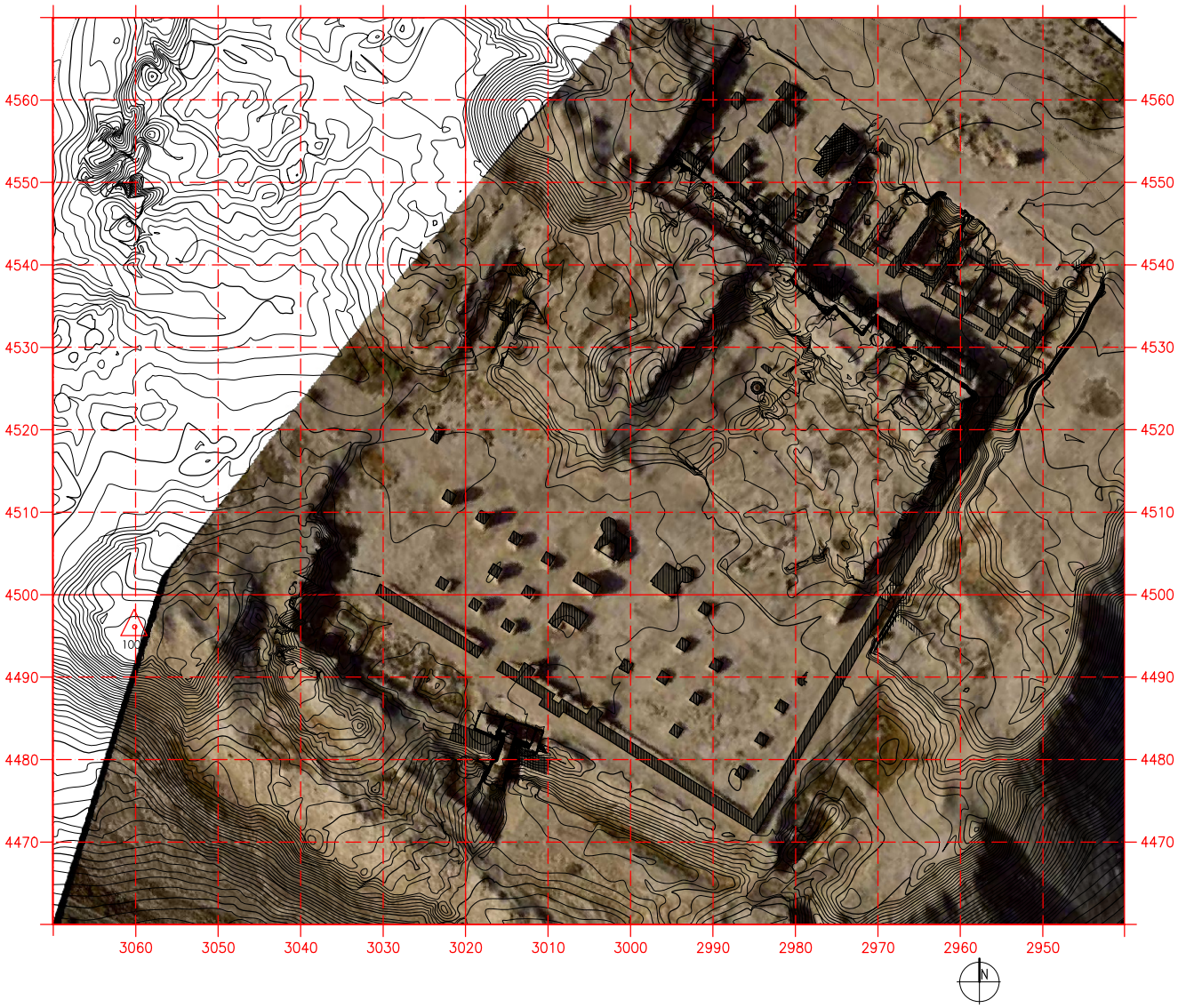


Figure 73: Almaty workshop: example of the a rectified image prepared during the course with the help of the trainees. Author. Aerial photograph courtesy of J.M. Deom and R. Sala.

- Details in relation with expression tools in CADR drawings (e.g. line-weight, different line types, colours, etc).
- The effectiveness of the 'measured dataset' in relation with the requirements of other thematic studies (e.g. mapping of weathering forms on the fabric, historical stratigraphy, etc).

Furthermore, other criteria should be established for the evaluation in relation to the specific case exercise and restrictions on the use of the metric survey techniques.

3.8 CLOSING REMARKS

The results of exercises prepared during the term of the workshops showed a high degree of understanding of these recent developments in three-dimensional documentation techniques and their adequate adoption of their potential and the needs in recording architectural heritage in view of its conservation.

3.9 FUTURE PERSPECTIVES

The tendency on looking for ways to incorporate more advanced three-dimensional recording techniques in the

training of experts working with built heritage is a challenge that can be overcome by experiences such as the one presented here.

Future tendencies should include the incorporation of three-dimensional information systems and application of these techniques to prepare monitoring instruments of historic sites

Student Integrated Project Work (IPW) at the R. Lemaire International Centre for Conservation credits:

Devolver, R. Heirman, K. Suciu, E. Lascar, L. Integrated Project Work 3 Former Property Vandenpeerenboom, Anderlecht 2002

Fellin, V. Gomes, J. Misson, J.S. Lemineur, P. Integrated Project Work 3 Former Monastery of Carthusian Monks, Antwerp 2002

Privitera, L. Wuyts, V. Cufi, D. Mikrou, T. Saito, A. Flores de la Cuba, J. Integrated Project Work 3 Convent of the Black Sisters, Leuven 2002

Purcar, C. Debonne, V. Olivier, F. Gauthier, P. Integrated Project Work 3 Anneessens Tower and Part of the First City Wall of Brussels, Brussels 2002

Notes:

[1] ICOMOS 'Guidelines on education and training in the conservation of monuments, ensembles and sites', Petzet, M. Ziesemer, J. Ed. 'International Charters for Conservation and Restoration' Monuments and Sites I, Munich 2001. Pp.89-90.

[2] Raymond Lemaire International Centre for Conservation – Master Programme 2000 - 2001

CHAPTER IV

CASE STUDY:
HISTORICAL RESEARCH OF BUILT HERITAGE:
CASTLE OF ARENBERG, LEUVEN BELGIUM

CHAPTER IV:

CASE STUDY: HISTORICAL RESEARCH OF BUILT HERITAGE:CASTLE OF ARENBERG, LEUVEN BELGIUM

This case study deals with the application of digital three-dimensional modelling techniques for the creation of an information system providing information about the history of the monument. In which a virtual environment is used as platform to browse, consult and understand the relevant sources of an historic building, including its history and its actual state of conservation.

In addition, it explores the pro's and con's of using these kinds of techniques, in relation to the documentation of historic buildings and to provide a number of recommendations to improve their utilization in the future are given.

4.1 THE CASTLE OF ARENBERG

The Castle of Arenberg, constructed in the sixteenth century (Vlaardingerbroek, P. 1996)[1], is an important historic landmark in the city of Leuven.

This monument has been the subject of study at the Raymond Lemaire International Centre for Conservation, during 3 years several parts of the castle has been documented in the framework of a practical exercise for the training of future architectural conservators.

4.2 PURPOSE

The purpose of constructing a model of the castle of Arenberg in the computer is to convey the functional and physical transformations, which have taken place over a period of four centuries and to present in a synthetic way its actual state of conservation, as well as allowing one to evaluate the application of this technology in managing and representing the built heritage.

The 3D model was constructed in the framework of a master thesis to study and demonstrate that computer drawings and surveys should not considered to be mechanic, static and inappropriate, but that digital tools provides sophisticated tools to represent, store, retrieve and manage historical information. It also provides a wider range of access to the information through either CD-Rom media or the Internet.

This research is consider the grounds of the current dissertation, specially in the study of techniques for managing graphic and written historical information on monuments in order to avoid the misunderstanding and the misuse of the actual state of the monument.

The model presented is based on rigorous scientific information from metric survey studies conducted by several students of the R. Lemaire Centre for Conservation in a period of three years.

These works were aimed at having an adequate interpretation of the building and therefore avoiding the falsification of its actual state by the attractive results produced by the visualisation tools these applications offer today.

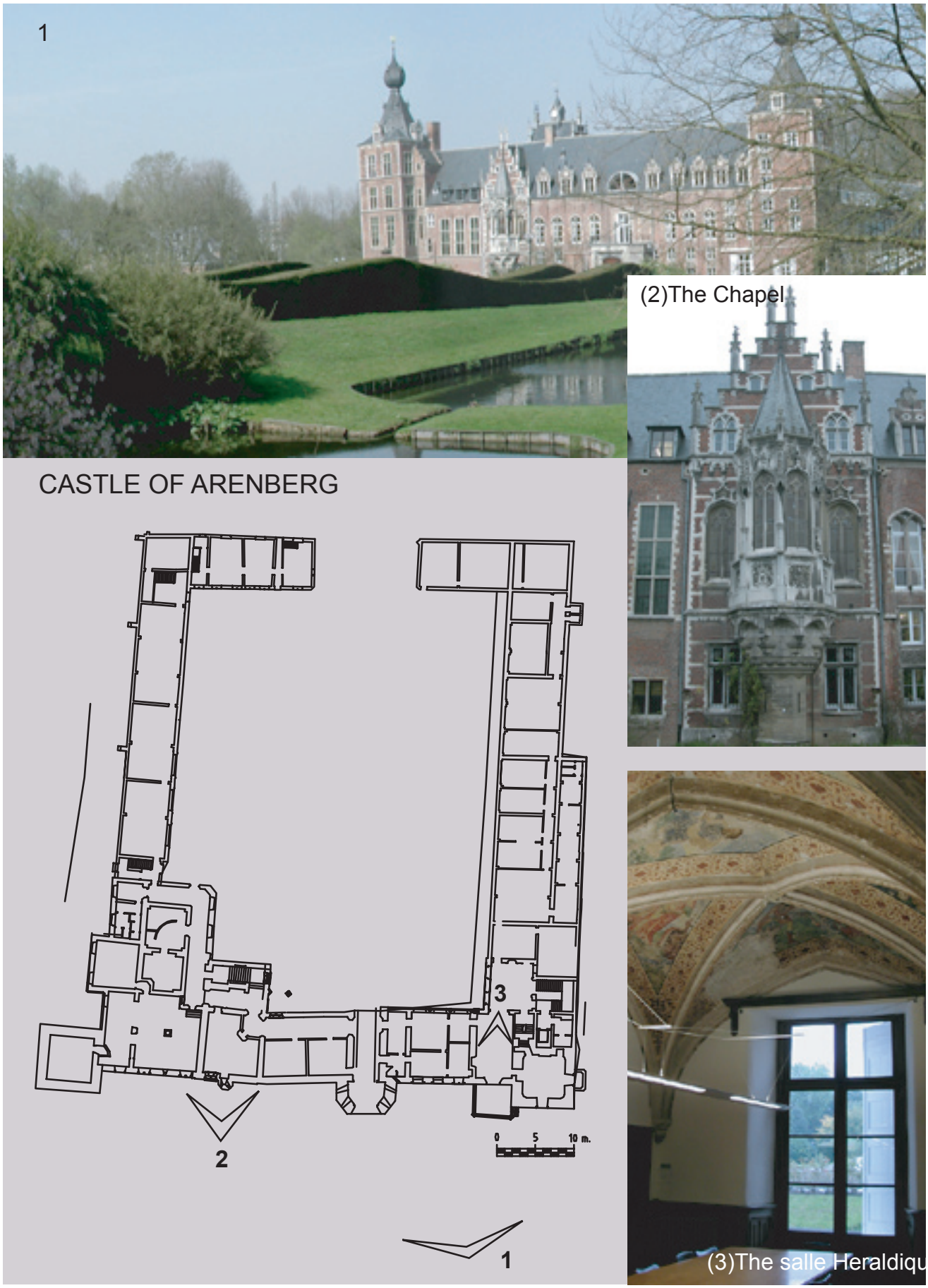


Figure 74: views of the castle of Arenberg, Leuven 2002. Author.

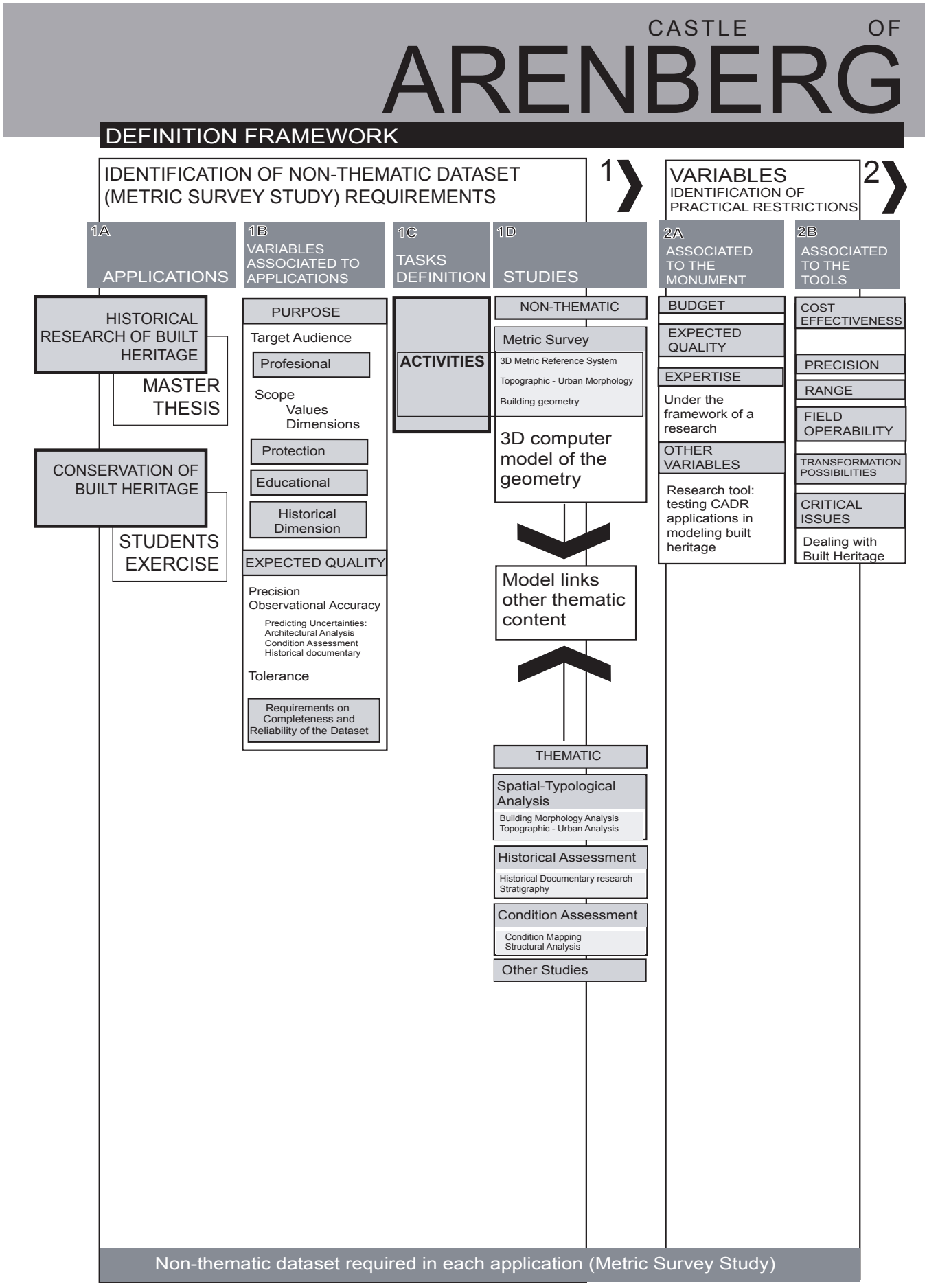
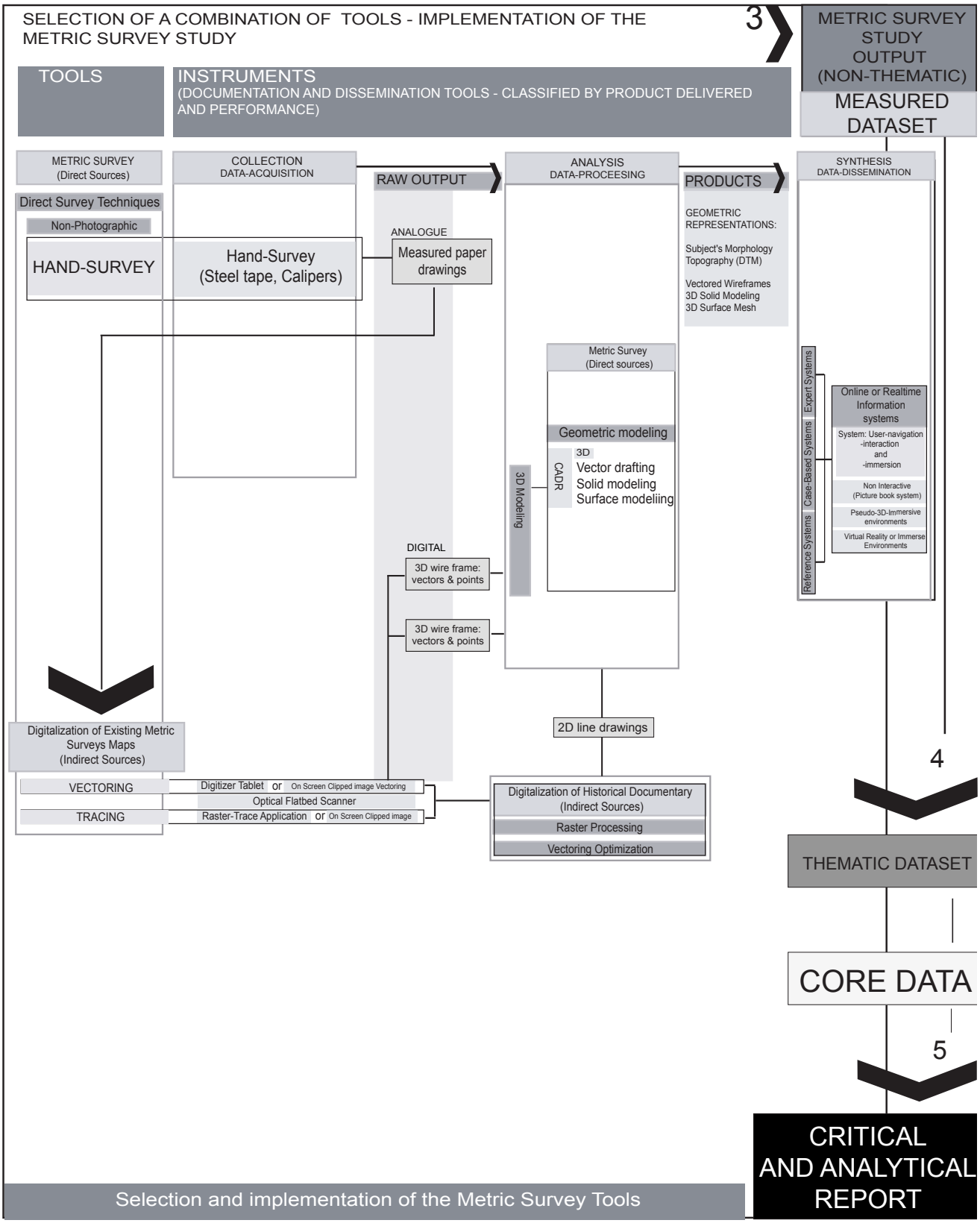


Chart 52: application framework applied to this case study.

SELECTION FRAMEWORK



4.1 FRAMEWORK FOR THE SELECTION OF METRIC SURVEY TOOLS

4.1.1 APPLICATIONS

In this case study, the metric survey was limited to digitize measured maps from different groups studying the castle recorded using hand-survey techniques and to prepare a 3D model that can combine all these measurements.

This case study was based in proving the efficiently of CADR applications in the modeling and representation of historic buildings. Certainly the purpose of this application is professional, tailored to present a graphic interface to access historical and geometric information about the building.

The scope is concentrated in the historical and architectural dimension of the building.

These tools were mainly selected according to the budget available for the thesis. The tools were not the most cost-effective tools to produce a 'measured dataset' that can be use for conservation works, but they provided sufficient judgment to evaluate computer modeling for built heritage.

Expected Quality and task definition

The model was expected to be of metric level of detail. Where all the elements of the geometry will be shown (see chart 52).
However, due to time constraint a small part of the castle was modeled in detailed, other parts were modeled using lower level of abstraction, this permitted to have an overview of the use and need of different levels of detail in 3D modeling.

Variables in the identification of restrictions in the use and selection of metric survey tools

Budget and expected quality

The budget was limited to produce a 3D model by mechanically digitizing hand-survey maps.

These limitations affected the selection of tools, especially in the search for cost-effective techniques accessible to a university student.

Precision and field operability: were important considerations in choosing modeling and dissemination applications, they should provide tools for accurate modeling of elements and be widely used

Transformation possibilities: the application selected should be widely used and allow transformation in other software for presentation and to create virtual environments.

.

Timing

The tools selected and the period of time available for learning, modeling and presenting should be sufficient.

Expertise

Since this case study was developed as a research exercise to test modeling techniques of CADR application, the main expertise required was specialist in recording built heritage with knowledge on CADR software.

4.3 THE CONCEPT OF AUTHENTICITY IN DEFINING THE NEEDS OF THE MODEL

The creation of virtual environments that will enable one to make an adequate instrument of understanding a historic building, should firstly take into consideration the concepts used to analyse the built heritage, such as authenticity, documentation (metric survey studies), and the application of digital information systems in studying built heritage. This study will aim to prepare a theoretical framework that deals with the analysis of the specific subject in its context and culture.

The Nara document on authenticity explains that the understanding of authenticity deals with the understanding of the values that makes a historic building credible or truthful. These values are evaluated through the available sources of information concerning aspects of form and design, materials, function, construction techniques, location, as well as the spirit and feeling of the building.

Subsequently, the ability to manipulate the different computer tools to implement colours, light, perspective, use photographic paths and other visual features will aim to create a representation that will simulate and communicate those sources without making a fake sense of reality, and therefore enforcing the understanding of its values.

On the other hand, bauforschung '*involves the first investigative phase of architectural historical research, combining the analysis of archaeological, historical and iconographical source material with the complete recording of a building's appearance and pathology' (RLICC, 1196)*[2].

This concept presents the principles of the methodology to construct the model of the building in the computer, related to the digitalisation of measured plans, photo-reconstruction or the use of electronic distance measurement (EDM) instruments. All the architectural elements should be included in the model although they might seem trivial or difficult to be simulated by the computer.

In this case the use of adequate computer-aided drafting (CADR) systems for three-dimensional modelling and the application of reliable measurements recorded using conventional hand-survey techniques will enable one to simulate the complexity of the structure and its relationship with other architectural elements of the building.

Finally, historical documentation is related to the classification and presentation of the different documents in a simulation, such as old photographs, recent articles, pathological mapping, survey plans and other historical documents, and their links to the graphic interface.

4.4 CONSTRUCTING THE COMPUTER MODEL

The research conducted in the Castle of Arenberg has provided a vast amount of documentation, ranging from measured representations, historical researches and assessments about the state of conservation of the building that is readily available to complete the compilation of information for public viewing.

First an inventory of the available documents, pictorial images, survey plans and state of conservation (assessments) studies were made.

Secondly, the two-dimensional measured representations already prepared of the castle were digitised and vectorized to create the three-dimensional model using a solid modelling extension of a CADR programme (part I - chapter III presents a detail explanation about modelling techniques).

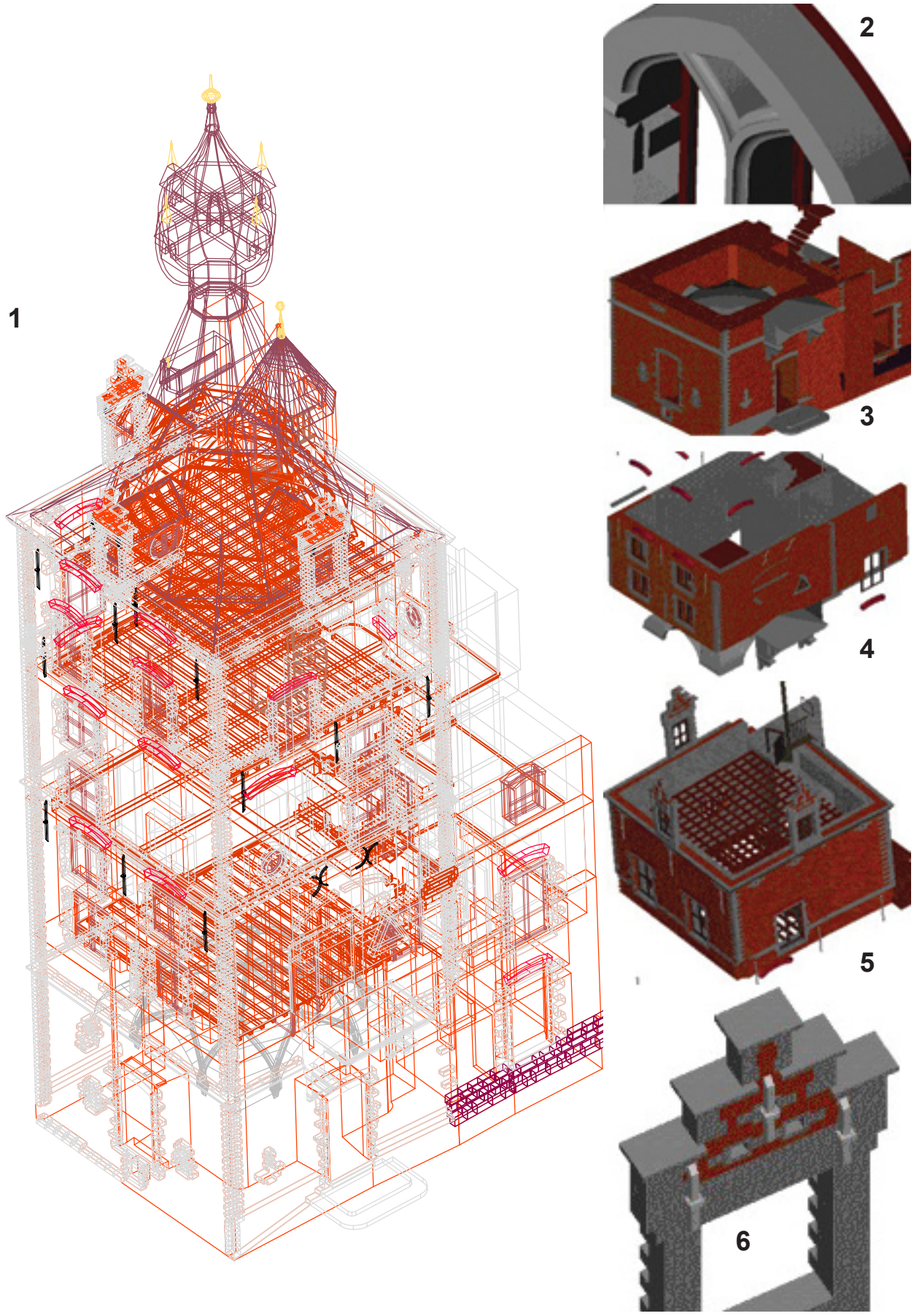


Figure 75: example of the construction of the model, castle's east tower : (1) wireframe model, renders: (2) a window, (3) Ground floor, (4) First floor, (5) Fourth floor and a (6) window in the fourth floor. Author.

The phases of work consisted on:

- Evaluating the measured representations to be used to prepare the model.
- Preparing a horizontal section map, to be use as base for the model.
- Selecting and specifying limits to the model: vertical and horizontal limits.
- Digitizing the plans and translating the measurements into three dimensional shapes.
- Identifying the different entities to be represented in the model.
- Assigning a tag to each entity using layers.

In addition to this, some areas of the castle were surveyed in a more detailed way than others, enabling parts with different levels of abstraction to be created.

The general guidelines to developed the different phases was divided in the following steps:

The architectural components were created separately, such as walls, stones, windows, etc and not as a single structure.

On the one hand, the resulting solids were converted into a VRML model. The components constructed separately were linked to an HTML page containing photographs and information about their history and the state of conservation.

On the other hand, some of the textures of the actual components were attached to the elements using photographs to provide support to the representation of the actual state of conservation.

This virtual environment gives access to different types of historic documents through a graphic user interface, in which every architectural feature is directly linked to information about its history and to its state of conservation, as well as to its geometry.

4.5 ANALYSING THE RESULTED COMPUTER MODEL

The virtual environment simulating the castle provided a single platform, from which to link different types of historical information into a dynamic three-dimensional graphic interface.

Furthermore, the process to construct the building in the computer provided evidence of the accuracy of previously completed survey plans using traditional recording techniques and of the difficulty to use two-dimensional measurements to make a three-dimensional model.

The digital model partially simulates the real castle, due to the fact that in many cases it was necessary to regularise imperfect architectural features of the building to take them readable by the computer.

In the limited time available in order to prepare the model, only some areas could be constructed in detail. Due to the dynamic attribute of this digital model the less complicated parts can be replaced or updated by other more detail elements in the future.

4.6 LIMITATIONS AND ADVANTAGES

In spite of the important contribution of using computer-aided techniques to design and create new projects in architecture, the use of CAD systems in historic research seems to be quite limited.

These limitations are related to the simulation and understanding of *the real architecture, 'work with the imperfect, heterogeneous and often-incomplete material'* (Chalmers, A. et al., 1996)[3], when trying to make '*an impression of misleading accuracy*

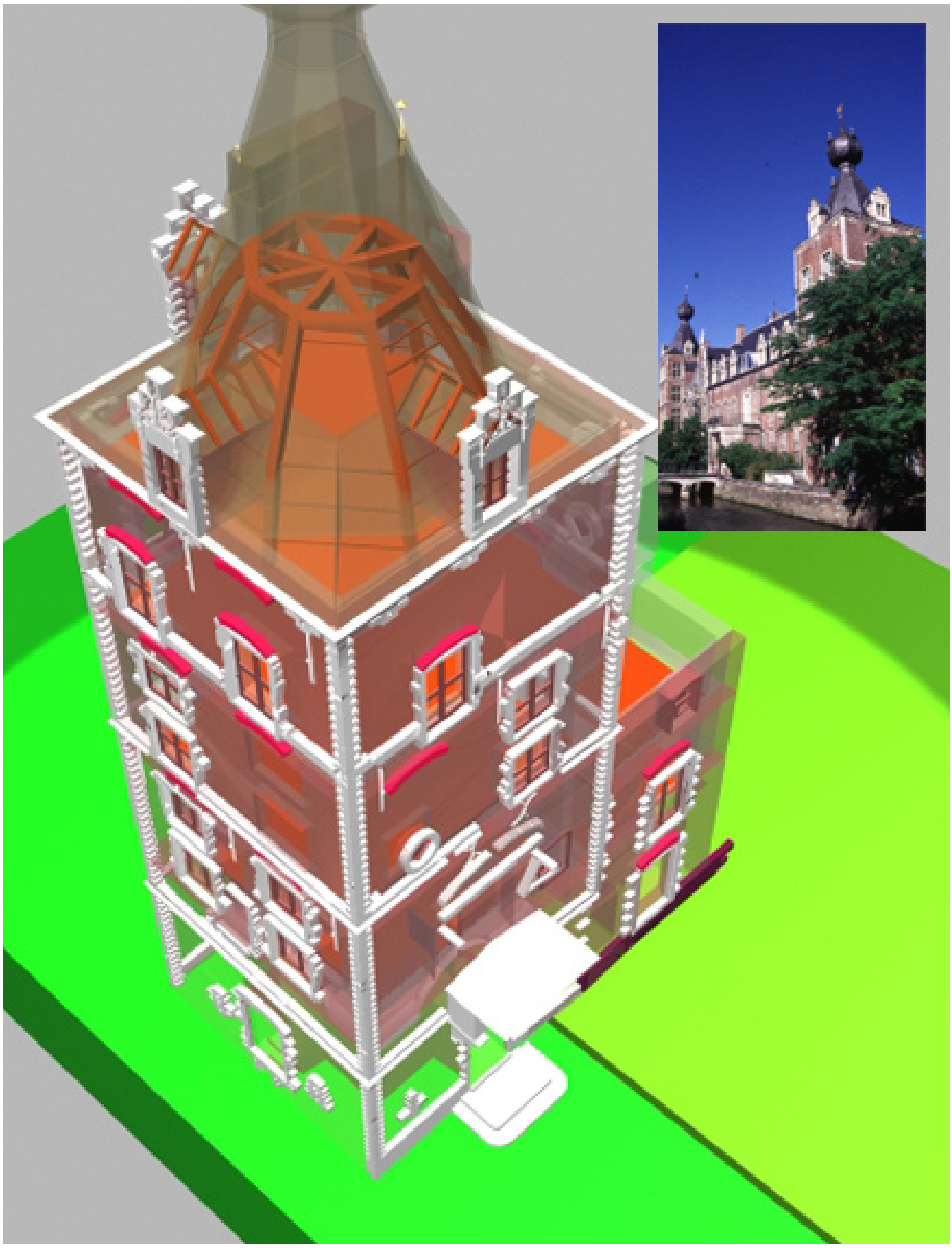


Figure 76: transparent render of the castle's east tower. Author.

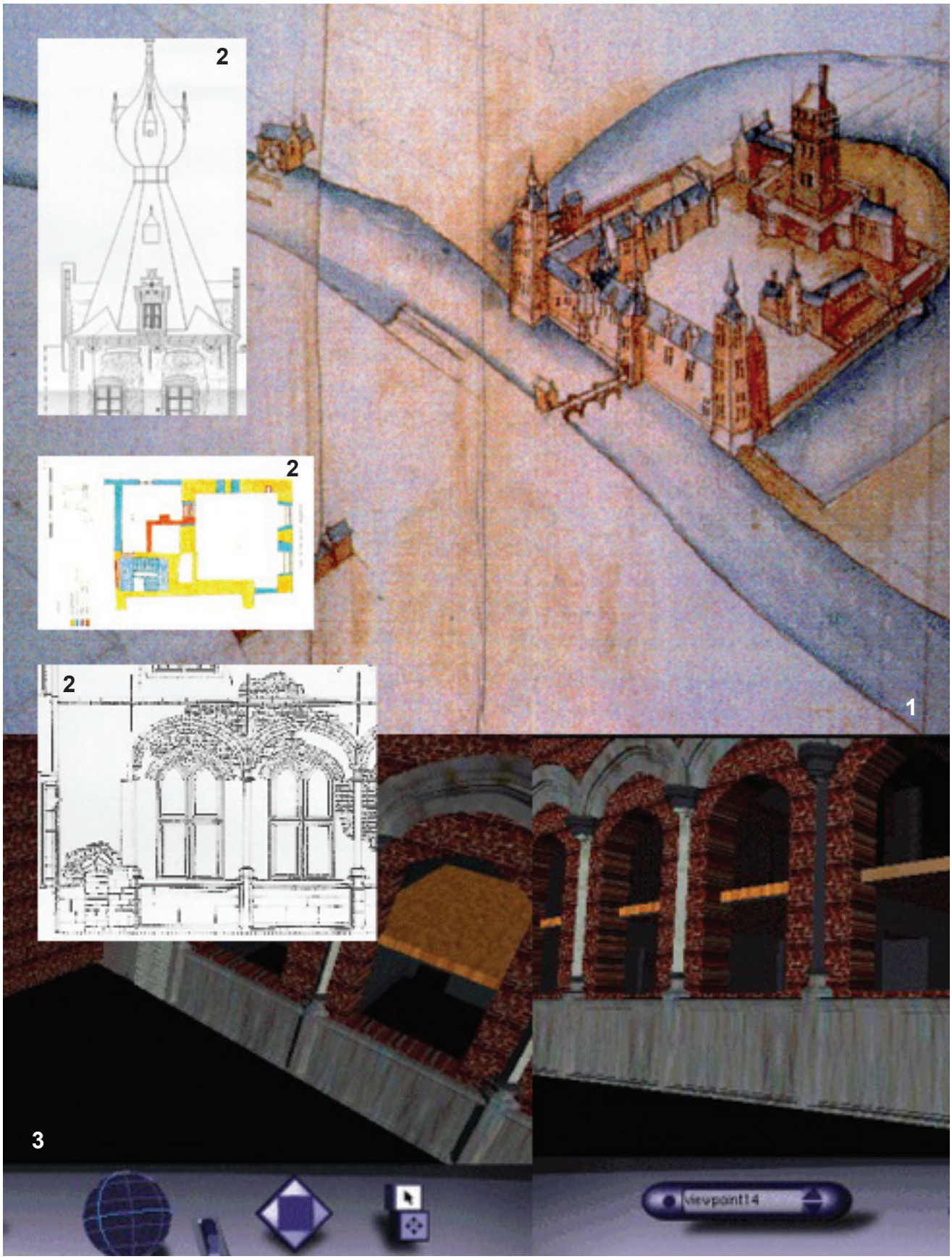


Figure 77: examples of the Virtual model: (1) Iconographical source linked to the model, (2) Measured maps prepared using conventional hand-survey techniques (3) a look to the virtual model (vrml). Author.

(Chalmers, A. et al., 1996)[4] of the reality of the built heritage, therefore producing a kind of ideal state of the historic building that can be use exclusively for educational purposes.

Furthermore, the access and investment to use the most adequate information system technology available is limited by the capacity of the computer interface to construct and visualize the model, as well as the price.

In order to share the historic information through an effective and accessible instrument it is necessary to construct simplified models capable to be reachable by a broader audience of people and therefore undermining the tools this technology offers to communicate the values of the built heritage.

In addition, without doubt the computer offers better alternatives to store, manage, and retrieve information than traditional techniques, as well as, a broader access to the information.

The digital representation and information system does not remains static, it is a dynamic instrument that can be modified and updated, in case of new discoveries or advance in technology used to construct it.

Furthermore, the interactivity in the three-dimensional visualization allows a direct understanding of the physical aspects of the building and the possibility to reach other types of information in a quicker and more accurate fashion.

This study proposes to make a further evaluation of the application of these technologies in managing different types of historical information using a single platform through three-dimensional models. This application permits the exploration and documentation of the built heritage in a correct scientific way, ensuring its protection.

4.7 CLOSING REMARKS

Multidisciplinary teams of specialist dealing with the conservation of historic buildings should take an active role in the development of applied CADR and information systems to improve their capabilities of representing and managing built heritage.

A methodology report should be prepared along with the model that explains the computer tools used and scientific evidence used for preparing the digital representation, in order to avoid misleading representations that will affect the understanding of the values of the monument.

The virtual environment should simulate reality, but not replace it; otherwise it will affect people's appreciation of the natural reality itself and with it the value of experience. This could lead to the loss of the spirit of the architect, as well as its historical message.

The purpose of using digital 3D information technology should be limited to present facts about the built heritage.

Notes:

[1] Vlaardingerbroek, P. 'Arenberg Castle in the Eighteenth Century', unpublished Master Thesis, R. Lemaire Centre for Conservation, KU Leuven, Leuven 1996.

[2] Introduction, Preparatory architectural investigation in the restoration of historical buildings. R. Lemaire Centre for Conservation, K.U. Leuven, Leuven 1996.

[3] Chalmers, A. *et al.* An Interactive Photo-Realistic Visualisation System for Archaeological Sites. Dept. of Archaeology, Univ. of Bristol. Internet article http: //www.cs.bris.ac.uk/~alan/Arch/INSITE/research/comvis/insite2.htm, Bristol 1996 (Last visited: 27/08/2002)

[4] Ibid 2

CHAPTER V

CASE STUDY

The use of metric survey tools in urgent recording:
Mussalah Complex Herat and
Minaret Jam, Afghanistan

CHAPTER V

CASE STUDY: THE USE OF METRIC SURVEY TOOLS IN URGENT RECORDING: MUSSALAH COMPLEX HERAT AND MINARET JAM, AFGHANISTAN

This case study presents the efforts to prepare a preliminary measured record of two sites located in the province of Ghor and Herat in Afghanistan:

- Mussalah Complex site (province and city of Herat)
- Minaret Jam (province of Ghor)

These two sites are in imminent risk of destruction for different reasons and they are currently in the focus of international efforts for safeguarding the built heritage of Afghanistan. The mission was composed by M. Santana Quintero and T. Stevens, consultants. It was organized by the section of heritage at UNESCO and under the coordination of Christian Manhart.

Furthermore, the mission was supported by the efforts and advice of Professor Andrea Bruno, Cultural adviser to UNESCO on Afghanistan and president of the R. Lemaire International Centre for Conservation. In addition, Prof. Michael Jansen from the University of Aachen RWTH provided logistic support to purchase the equipment necessary to execute the works of documentation. This case study has been written in cooperation with Tarcis Stevens.

5.1 OBJECTIVES

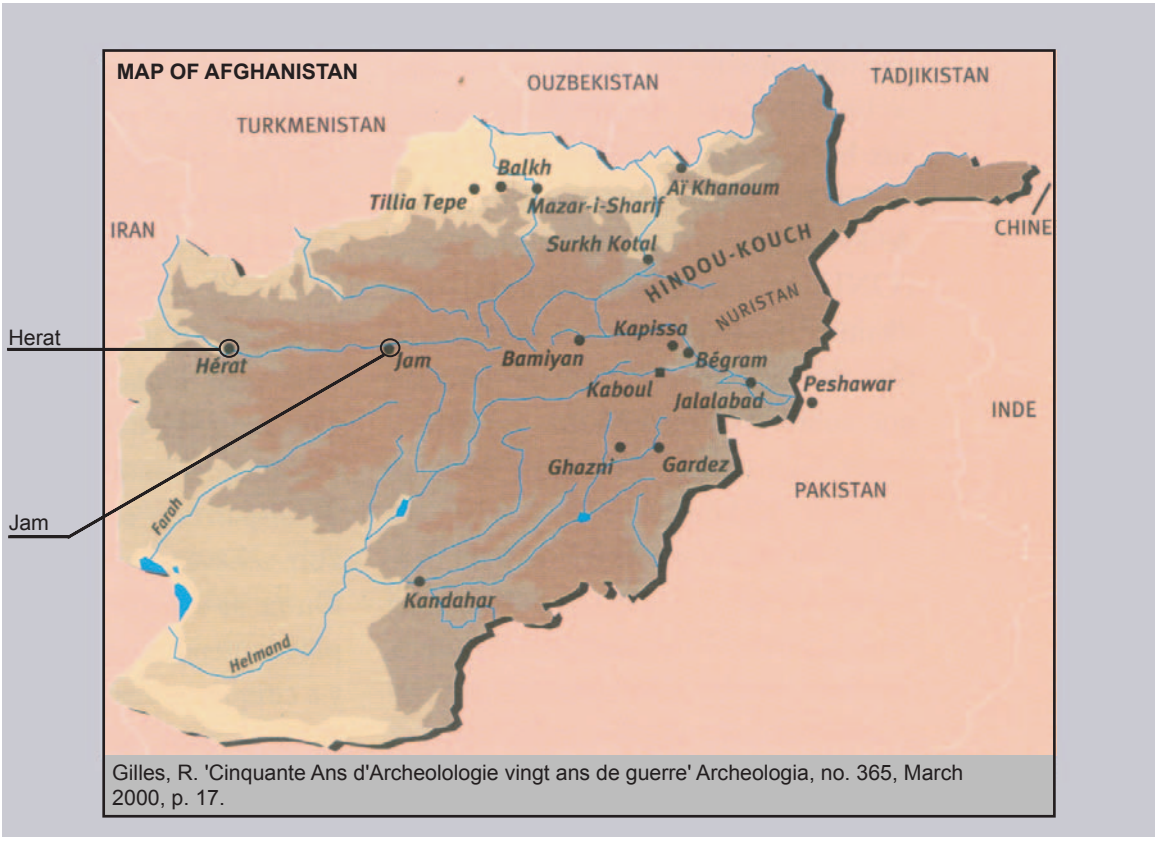
The role of the metric survey tools chosen for this mission is focused in producing a measured assessment or dataset that includes a preliminary record of the geometry and texture of the fabric of context and the subject.

This dataset of measured plans is of importance to prepare an assessment of the structural condition of the elements in most danger of collapsing and as reliable source of information for coming missions that will excavate and further study the monuments.

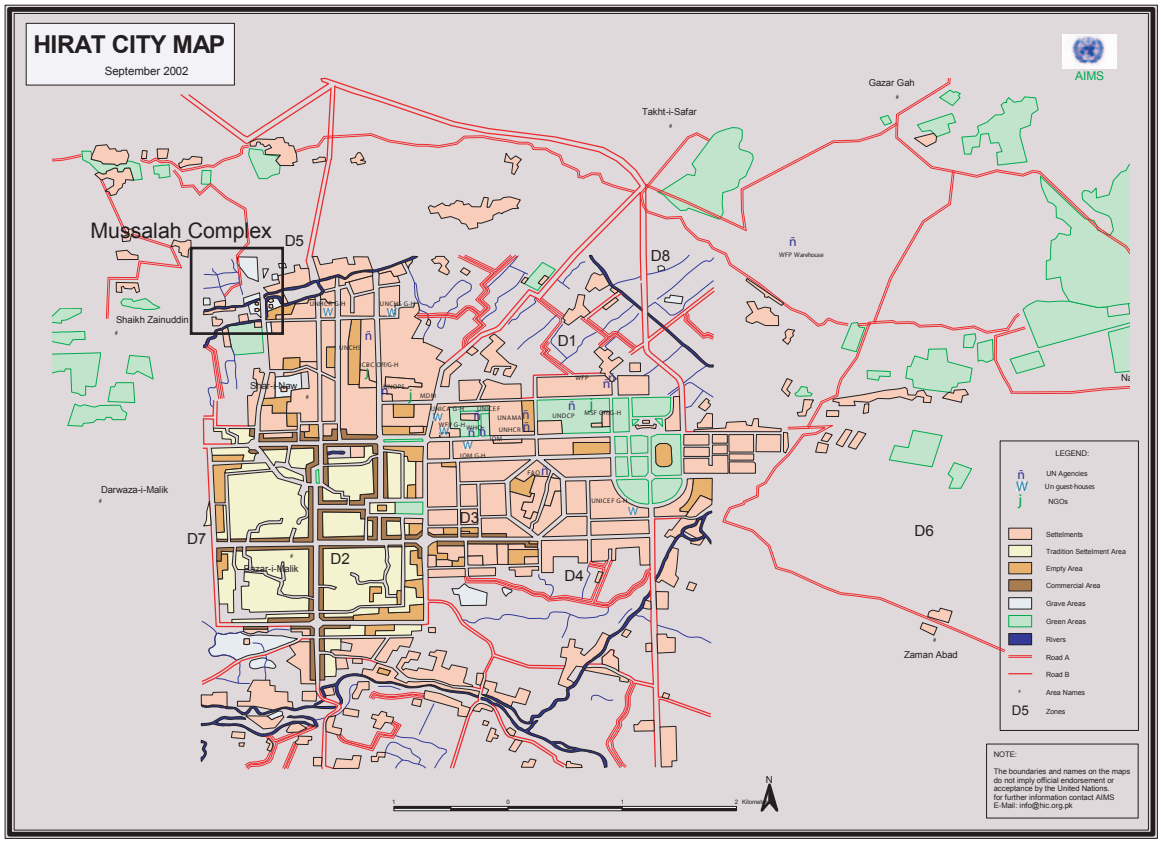
This case study presents the field work carried out in a period of three-weeks in situ in the two sites. Making emphasis in the methodology used, the results, and recommendation for future efforts in documenting Afghan heritage.

The tools used and developed in this example are conventionally used in geodesy and they have been adapted to the needs of the specific area and the available resources, making emphasis in the use of optimal and sustainable methods for the current condition of this country in terms of political, legal, and practical infrastructure for protecting built heritage.

In addition, the equipment used in this mission was donated to the Ministry of Information and Culture in Afghanistan for the documentation of built heritage. Therefore, UNESCO assigned a group of local experts to the mission that were giving a short but intense training in the use of these tools. The knowledge of the trainees will be reinforced by the organization of a series of training in



Gilles, R. 'Cinquante Ans d'Archeolologie vingt ans de guerre' Archeologia, no. 365, March 2000, p. 17.



Map by UNAMA-Herat

Figure 78: location of sites. Above map of Afghanistan, prepared by the UNDP (United Nations Development Program). Below: map of Herat, prepared by UNAMA (United Nations Assistance Mission in Afghanistan).

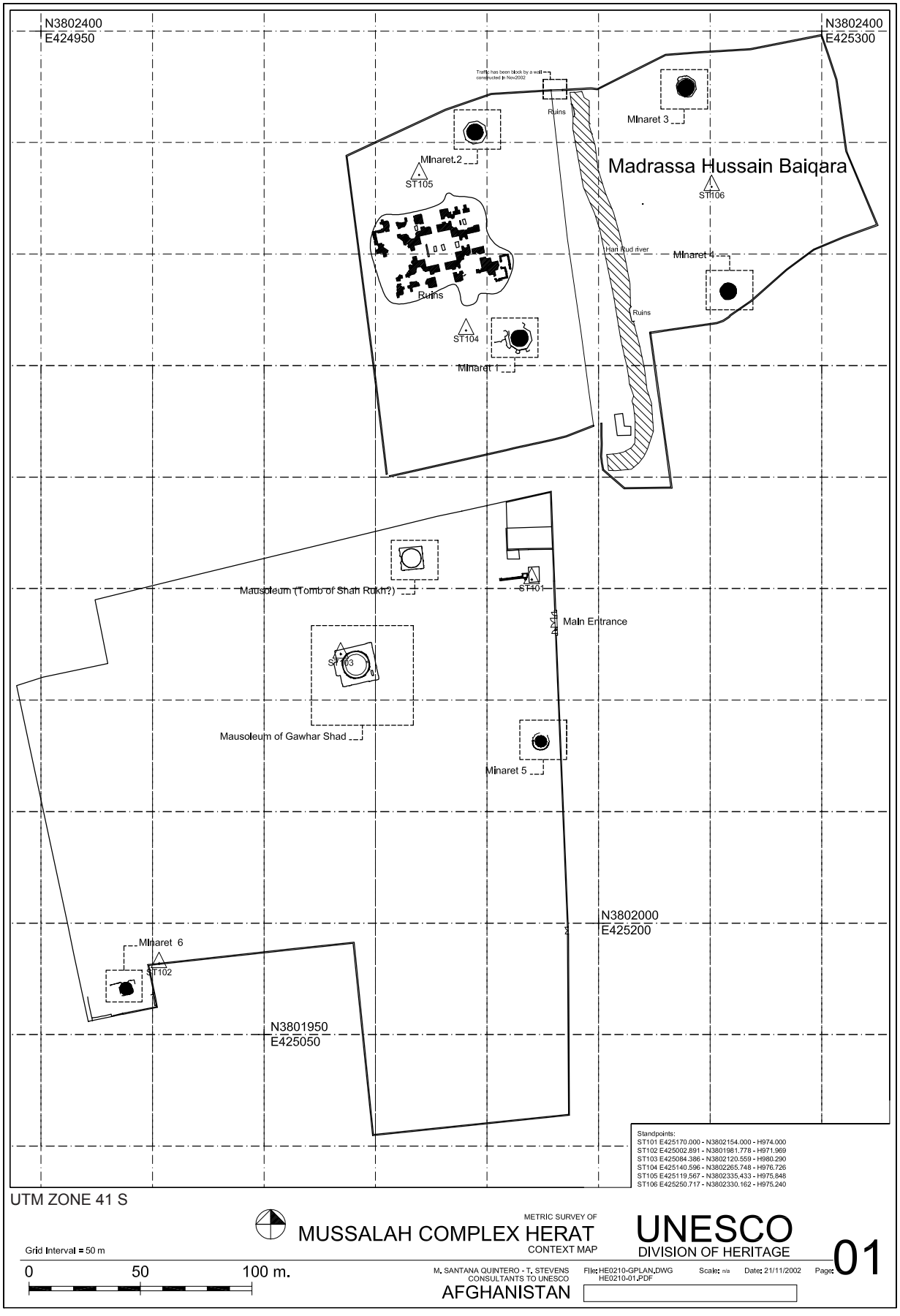
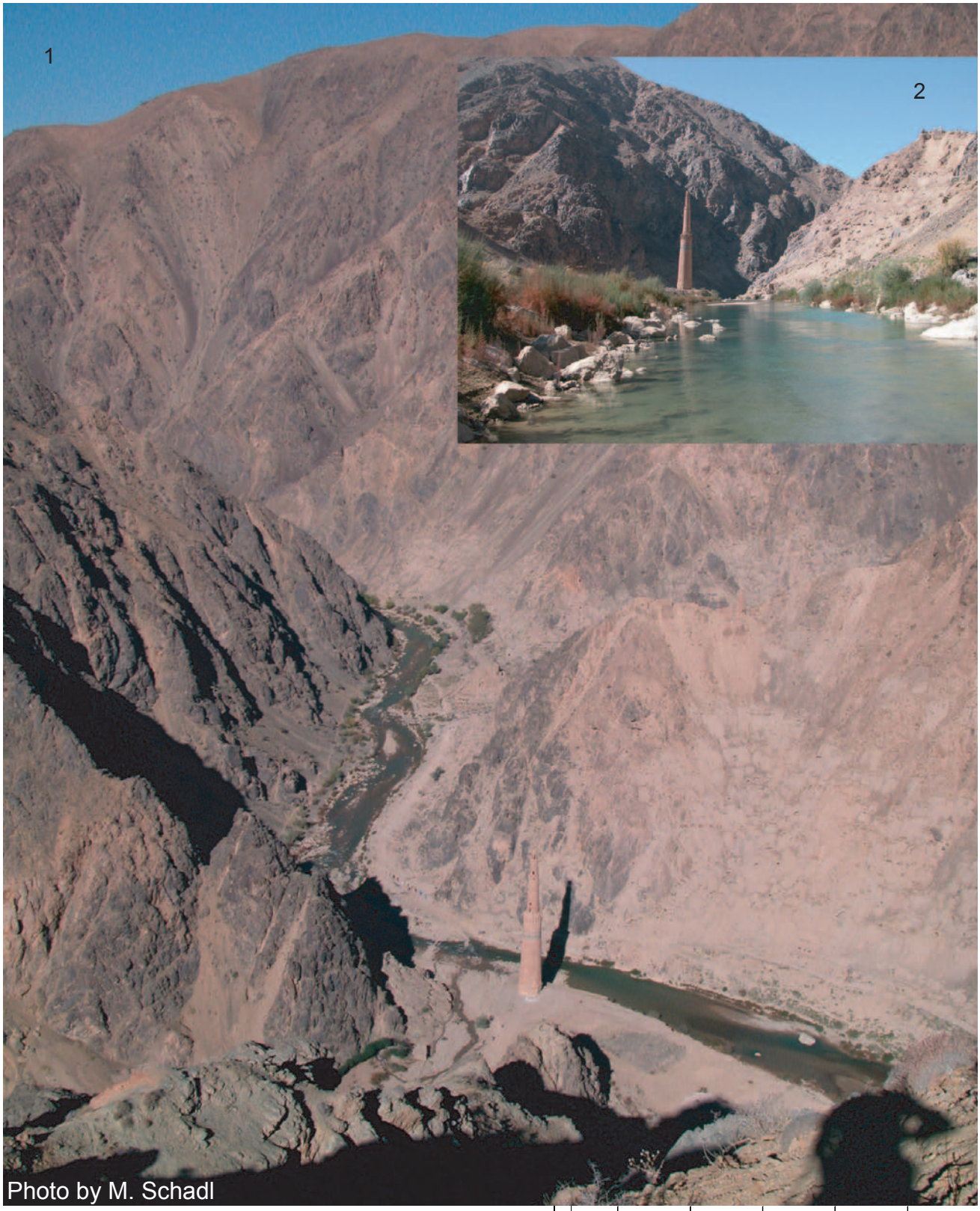


Figure 79: context map - Mussalah Complex in Herat. Author.



Figure 80: general views of the Massalah complex in Herat. Author.



General view of the site Oct 2002
southwest

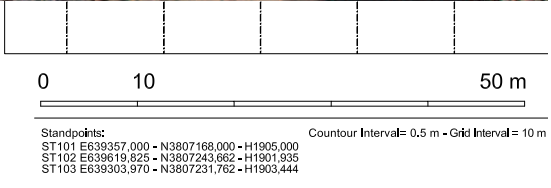
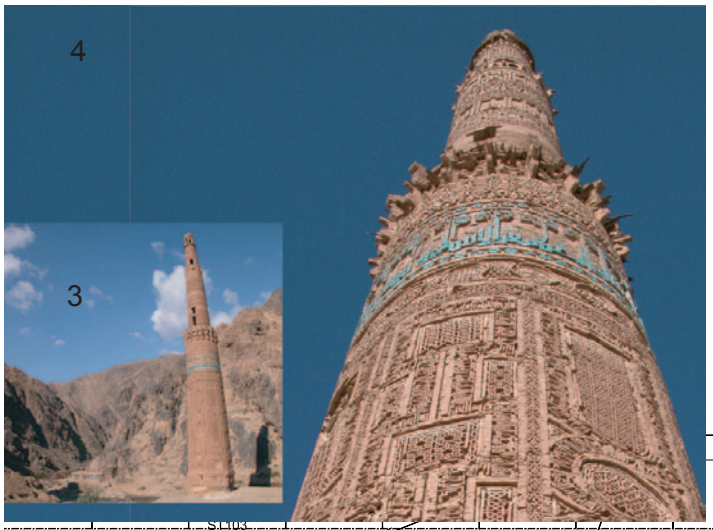
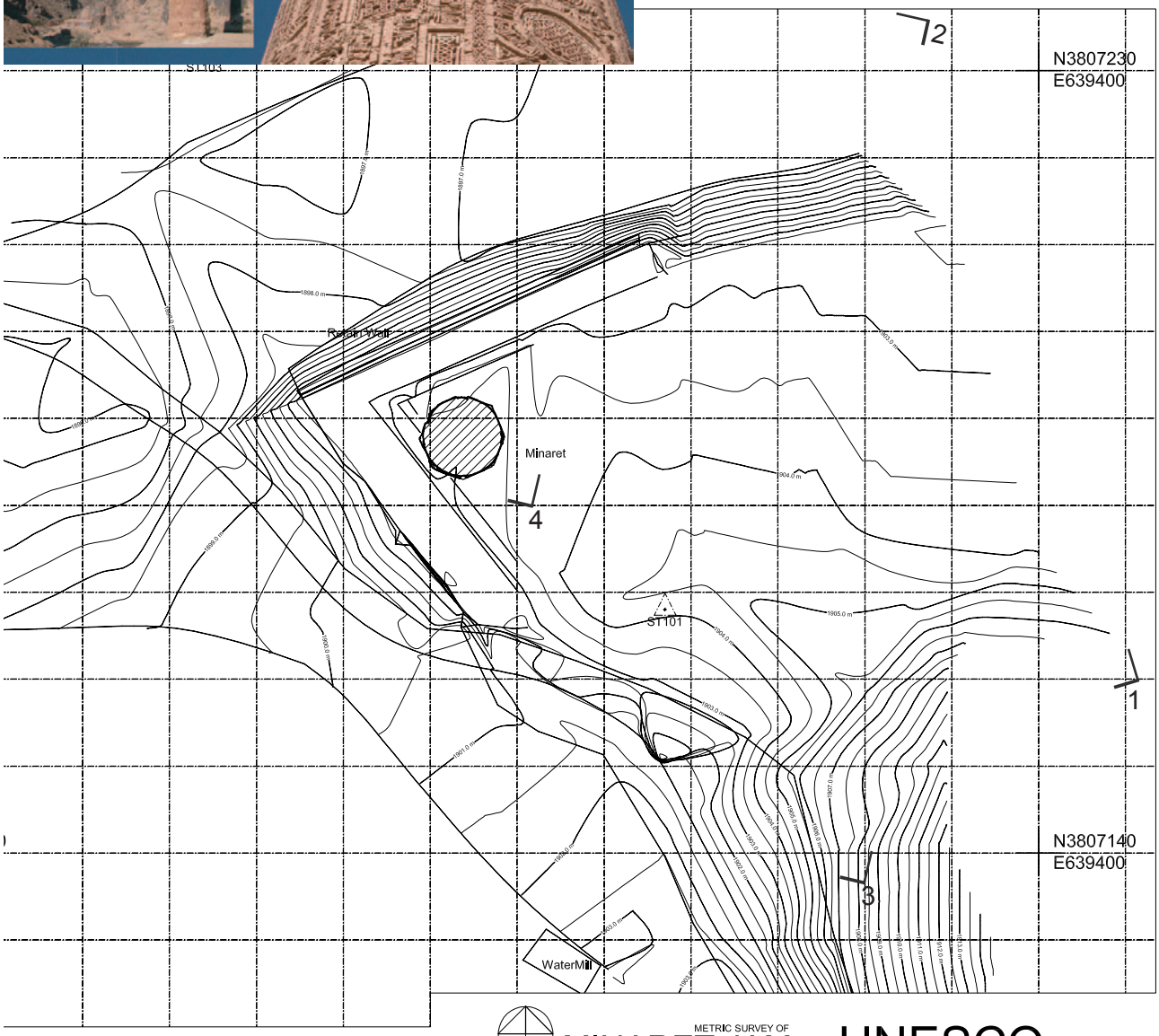


Figure 81: general views of the minaret site and context map. Author.



Left: General view of the site
Right: Details of the Minaret



METRIC SURVEY OF
MINARET JAM
CONTEXT MAP

UNESCO
DIVISION OF HERITAGE

01

M. SANTANA QUINTERO - T. STEVENS
CONSULTANTS TO UNESCO

File: MJ0210-GPLAN.DWG
MJ0210-01.PDF

Scale: 1:500 Date: 21/11/2002 Page:

the near future.

5.1.1 MUSSALAH COMPLEX SITE HERAT

The work was concentrated in archiving a geometrically correct measured map of the current situation of the Minarets and its context, including other buildings of historical importance.

The plans prepared are:

- Site plan, containing the location of Minarets, uncovered ruins and historic buildings.
- A study of Minaret no. 5, containing a number of horizontal sections and a cross-vertical section on the main axe of inclination.

Work carried out:

(a) Site reference grid based on a relative system of coordinates UTM orientated to the north calculated from two readings taken with a hand-held GPS unit.
(b) Preparation of the site map showing the position of the Minarets using a REDM Total Station, including main features of the site (river, walls, etc) and a preliminary topographic map.
(c) Measurement of the Inclination of Minaret no.5 using the REDM Total Station, including a vertical cross sections with the main inclination axes defined by the measurement of five horizontal sections, following the concepts described in the UNESCO Technical report on Restoration of Monuments in Herat 'Schematic profiles of minarets', p. 104.
(d) Measurement of natural targets for future photogrammetric restitution of Minaret no. 5.
(e) Digital photography of the four Minarets remaining and Minaret no.6 collapsed in the XIX c.

Available time: 10 days:

Day 1 – Task (a)
Day 2- Task (b)
Day 3 – 4- 5- Tasks (c-d)
Day 6 -7-8– Task (e)
Day 9-10 Reserve to complete other tasks

5.1.2 MINARET JAM

The work was concentrated in archiving a geometrically correct measured map of the current situation of the Minaret and its context, including natural features and modern constructions surrounding the monument.

The plans prepared are:

- Site plan, containing the location of the Minaret and a topographic map of the site in a radius of approximately 50 m.
- A study of the Minaret, containing a number of horizontal sections and a cross-vertical section on the main axe of inclination. This plan has been combined with measurements made by hand-survey of the interior and the measured representations prepared by Prof. A. Bruno previously.

Work to be carried out:

(a) Site reference grid based on a relative system of coordinates UTM orientated to the north calculated from two readings taken with a hand-held GPS unit.
(b) Preparation of the site map showing the position of the Minarets using a REDM Total Station, including main features of the site (river, walls, etc) and a preliminary topographic map.
(c) Measurement of the Inclination of the Minaret using the REDM Total Station, including two vertical cross sections with predefined axes and five horizontal sections following the ones described in the report for the Mission

for SPACH, 1999 by Andrea Bruno on the Survey of Jam minaret.

(d) Measurement of natural targets for photogrammetric restitution.

(e) Digital photography of the Minaret (limited to the first two bodies of the structure, the third highest body can be recorded with a higher resolution camera later on), to be used in a future and possible second phase of work for photogrammetric restitution.

Available time: 3 days

Day 1 - Task (a – c)
Day 2 – Task (b)
Day 3 – Task (e)

5.2 BACKGROUND OF THE SITES

5.2.1 MINARET JAM

The minaret Jam is located in the Ghor province, *'about 100 km farther east up the valley of the Hari Rud', it is difficult to reach. The Minaret lays in complete isolation. It was discovered in 1957*' (Knobloch, E., 2002, p. 127)[1]. According to a GPS reading in the minaret site, the monument is around 200 km east of the City of Herat.

> *'Rises some 65 m. from an octagonal base some 8 m in diameter (SPACH, 2000, p.2)[2] 'across and three cylindrical stages. The first is decorated with geometrical patterns in fired bricks, arranged in panels separated by vertical bands of Kufic inscriptions. A wide horizontal band of blue tiles with a further kufic inscription runs around the top end in which, in a line of naskhi, the name of the calligrapher is given as 'Ali'. The second and third stages are decorated with horizontal bands of inscriptions again in fired bricks. The stages were originally separated by galleries, which have not survived, and the top was closed by a lantern which has also collapsed; an interior staircase leads up to the second stage.* The inscription confirms that the minaret was erected by Sultan Ghyat ud-Din Muhammad ben Sam, the ruler of Ghor. It was probably built, in all probability, in 1190 and is often linked with the legendary Ghorid capital, Firuzkuh, which was destroyed by Chingiz-Khan in 1222 and the site of which has never been found' (Knobloch, E., 2002, p. 127)[3].

However, according to the measurements of the mission, the diameter of the minaret in its octagonal layer is of 9,786 m. and the height is of 60.734 m (1964.537 m) relative to the 0,00 m of 1903.803 m of height calculated with a hand-held GPS.

The site of Jam was accepted by UNESCO as a World Heritage Site in 2002. It is the first afghan site to be included in the list. It also has been considered the second highest minaret in the world.

5.2.1.1 Current condition and critical issues

A protective Gabion retain wall has been constructed surrounding the west and south fronts of the Minaret along the Hari river by SPACH-HAFO[4] under the guidance of Prof. Andrea Bruno. However, just few meters from the south front of the retain wall a road with currently heavy traffic is in used and will be improved by a NGO called Afghan Aid in the coming months.

Major critical issues are:

- Inclination and current condition of conservation of the minaret should be studied.
- Looting: illegal excavations are a constant problem; the number of holes around the site is growing every day.
- New housing around the Minaret, heavy transport vehicles passing can cause damage to the structure and its unique natural surroundings

5.2.2 MUSSALAH COMPLEX SITE HERAT

This site consists of two main areas:

- Mausoleum of Gawhar-Shad, Kuhsan, containing the minaret M5, a second smaller mausoleum not identified and the Madrassah of Gawhar-Shad containing Minaret M6. This site is surrounded by a mud brick and cement wall repaired by SPACH-HAFO in 2000-2001.
- The Madrassah of Sultan Hussain Baiqara, composed by four minarets: numbered M1, M2, M3, and M4 and various uncovered excavations with ruins. It is surrounded by a mud brick wall constructed by SPACH-HAFO in 2000-2001. It is of around 11,000 square meters (Jawed, S. - SPACH, 2001, p. 13)[5].

Apparently, the Minaret site or also called Musalla '*is known from late fifteenth-century sources (Khondamir, Babur), that Gawhar Shad built a Musalla in Herat -but it is not quite clear what it consisted of. Babur speaks of three buildings -a mosque, a madrasa and a mausoleum while according to Khondamir, the mausoleum was inside the madrasa. Major Yate, in 1885, also speaks of three buildings:*

> *The Musalla consists in reality of the remains of three buildings running north-east and south-west and covering a space of nearly 600 yards from end to end. Of the eastern building -known generally, I believe, as the Madrasah or College -nothing but two high arches facing each other and four minarets remain. The arches must be from 60 to 80 feet in heightinside the arches the beautiful mosaic-work is still in many places almost perfect. The minarets of this Madrasah appear taller than the rest, and must be between 120 and 150 feet in height.*

Then, 'Between the Madrasah and the Musalla 100 yards or so from each other, is a domed building commonly called the tomb of Shah Rukh ...It is faced on the east by another archway and one solitary minaret.' The third building stood to the west of this 'tomb of Shah Rukh' and was the actual Musalla (Knobloch, E., 2002, p. 132)[6]

.

In addition, Madrassah of Sultan Hussain Baiqara, composed by four minarets and the uncovered ruins. According to Knoblocch:

> *The **minaret (M1 and M2)** with one gallery, which now stands inside a modern madrasa, stood in the western corner of the courtyard of the Musalla, which according to a reconstruction measured some 117 x 70m. The minaret can be best seen from the garden called Bagh-i Bihzad. Its octagonal base was once covered with exquisitely carved marble panels, and the whole tower was entirely covered with ornaments in mosaic faience in deep blue, azure and purple, with white marble moulding separating the panels and the bands of calligraphy, parts of*

which survived until recently. The minaret received a direct hit in 1984/5. Only a stump remains.

*The other **minaret (M3 and M4),** with two galleries and standing to the east of the mausoleum, was probably one of the flanking towers of the entrance iwan of the madrasa. The galleries are supported by lavishly decorated stalactite vaults (mukarnas). On the tower itself brick ornaments alternated with bands of tilework. It, too, was hit by a rocket and is leaning precariously. Both minarets have lost their tops.*

*The madrasa of Husayin Baykara occupied an area of some 100 x lOOm, the outline of which is marked by the **four** minarets.*

The ruins located at the west part of the four minaret site, between M1 and M2 and according to Van Eenhoge in 1981 are suspected to be from the Madrassah:

'Little remains of the 15th century religious complex which once stood to the north of the city: of the Musallah and the Madrassah built by Queen Gawhar-Shad, wife of Shah Rukh, only two Minarets and the mausoleum of the Queen are still standing; four tall minarets are all that remains of the big Maddrasah built by another Timurid, Sultan Hussain Baiqara, while of the numerous constructions built by his minister, Ali Sher Navai, and by other members of the Timurid dynasty, nothing remains'.

This work was carried out in the 70s by the UNDP-UNESCO project lead by Professor Andrea Bruno[7], the excavation work on the Madrassah yield important discoveries:

A sounding around the base of Minaret 1: '*the main result of this sounding I was the discovery that the lower part of the structures belonging to the Madrassah is still preserved, so that it is very likely, taking into account the topography of the site, that an excavation of the entire site would lead to the uncovering of a large part of the ground plan of the building. It was also established that originally the lower part of the minaret had been octagonal, with deep niches built against the exposed sides of the octagon, the other sides being incorporated in the walls of the building'*

This lower part of the minaret was decorated with a revetment _ of "haft rang" tiles, while the upper part was completely covered with very t mosaic panels, set in a lacelike network of white tiles. At the base of Minarets 2, 3 and 4, the erection of a scaffolding was preceded discoveries. At the base of Minaret 2, a black tombstone was found; the inscription on it attributes it to a daughter of Miranshah, son of Tamerlane. Equally exciting was the Ing, at the base of Minaret 4, of two carvea marble pilasters, and a fine wall decoration of hexagonal turquoise coloured tiles, part of which were still "in situ" . It is thus obvious that a full-scale excavation of the site would not only provide with the plan of a now destroyed but historically important Timurid building, but would also add to our knowledge of the later Timurid decorative arts. The result of such an excavation, and subsequent consolidation of the ruins, would be a monumentality of the four minarets' (Van Eenhoge, 1981, p. 26)[8]..

Current state of the site and critical issues

The site of Sultan

- Inclination and current general condition of Minaret 5 is critical. This Minaret near the Mausoleum of Ghawar Shad present damage in its base and a gap produced by military missile.
- The ruins of Minaret 6 are in danger, they are in an isolated area on the southwest corner of the protection wall sorrounding the Mausoleum of Ghawar Shad site and they are remains of different buildings that should be identified.
- The ruins at the site of the 'Madrassah of Sultan Hussain Baiquara' containing Minarets 1–4 is abandoned and decayed causing diminish of its social value to the community of Herat. Uncovered ruins are being dismantled and destroyed.
- Interventions that have use cement to repair the ornaments in the ruins performed in recent years are questionable.
- The Madrassah of Sultan Hussain Baiqara is constantly crossed by pedestrian, the protection wall should be repair. However, during our visit the traffic was stopped and a wall blocking the access of vehicles was constructed, the change is of significant importance for this area.

5.3 DEFINITION FRAMEWORK IN THE SELECTION OF METRIC SURVEY TOOLS TO ACQUIRE THE GEOMETRY AND TEXTURE OF THE SITE

5.3.1 APPLICATIONS

In this case study, and according to the needs of the project, the use of metric survey tools have been concentrated in preparing a rapid 'measured dataset' that can be use for immediate interventions in specific targeted areas in the sites and to prepare a general context plan that can be updated in the near future.

The target audience of this application is purely professional. Making emphasis in the use of metric survey representations to carry our immediate measures to protect the integrity of the fabric of the site.

The sets of representations are prepared for experts studying the stability of this critical areas in the sites and for constant monitoring of the condition of the building. In the site and interventions required to.

Expected Quality and task definition

The 'metric survey study' is composed of measured representations with a reliable completeness of information and that are of the highest possible quality. The tasks of the 'metric study' are of limited extend due to the short term of the mission but procuring the highest possible results (see chart 53).

Variables in the identification of restrictions in the use and selection of metric survey tools

The variables are ordered according to their relevance in the application (see chart 53).

Budget

The metric survey tools used in the works of documentation of these two sites were selected because of being cost-effective according to the limited budget assigned to the preliminary assessments for documentation, which also includes the fees of other specialist calculating the stability of the monument.

This variable associated to the monument affects the selection of tools that can effectively deal with:
Cost-effective, speed-range, field operability and the level of precision: they should be economically suited to the defined task, which has been limited to calculate the inclination of the minarets and carry out a preliminary of the sites.
Transformation possibilities: of the dataset collected to be use in different representations should be possible to transfer to other computer applications.

Quantification

This variable specially important in this case-study, because the metric survey study is conditioned and limited to fulfill the tasks defined by the measurements to be carried out to calculate the inclination of minaret Jam and minaret no.5 in the Mussalah complex.

During the short mission, the works was concentrated in achieving these tasks, taking into consideration the available time and local available facilities.

This variable associated to the monument affects the selection of tools that can effectively deal with: range of the instrument should be sufficient to measured without reflector the highest areas of the minarets and the field operability capabilities of the tool should be sufficient to operate under battery power for a extended period of time, since in Jam there is no electricity available.

Furthermore, transformation possibilities of the dataset collected to be use in different applications, level of precision should be sufficient for the task, speed should be sufficient to carry out an useful survey in two days, adjustments-corrections are of minor importance, and the capacity of the tool to deal with critical issues in recording built heritage.

To address these problems, two more batteries were purchased to obtain 4 days of power supply. As well as, a REDM total station was chosen that could deliver sufficient range, speed and field operability capacities for a limited budget.

Expected quality

See expected quality and task definition

This variable associated to the monument affects the selection of tools that can effectively deal with: cost-effective, transformation possibilities of the dataset collected to be use in different applications in the field of studying the structural behavior of the monument, level of precision, speed-range, field operability and their capacity to deal with critical issues in recording built heritage.

Expertise

The tools selected has been already tested and used by the experts of the mission, so no particular requirements were associated to this variable. However, the training component of the mission influenced the purchased of the equipment to choose relative simple tools for metric survey that can yield adequate results to the local experts.

This variable associated to the monument affects the selection of tools that can effectively deal with: cost-effective, transformation possibilities of the dataset collected to be use in different applications, level of precision, speed-range, field operability and their capacity to deal with

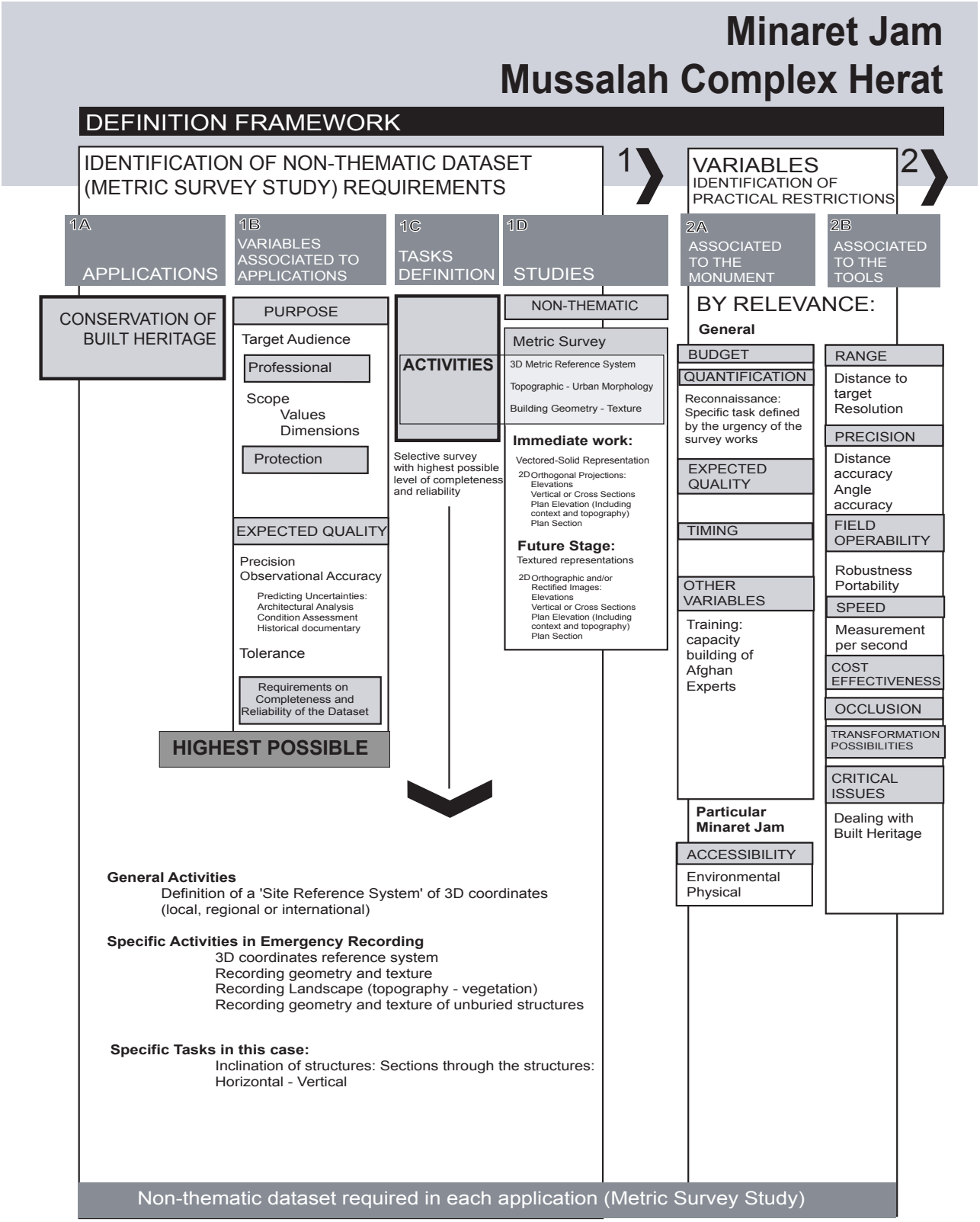


Chart 53: application framework applied to this case study.

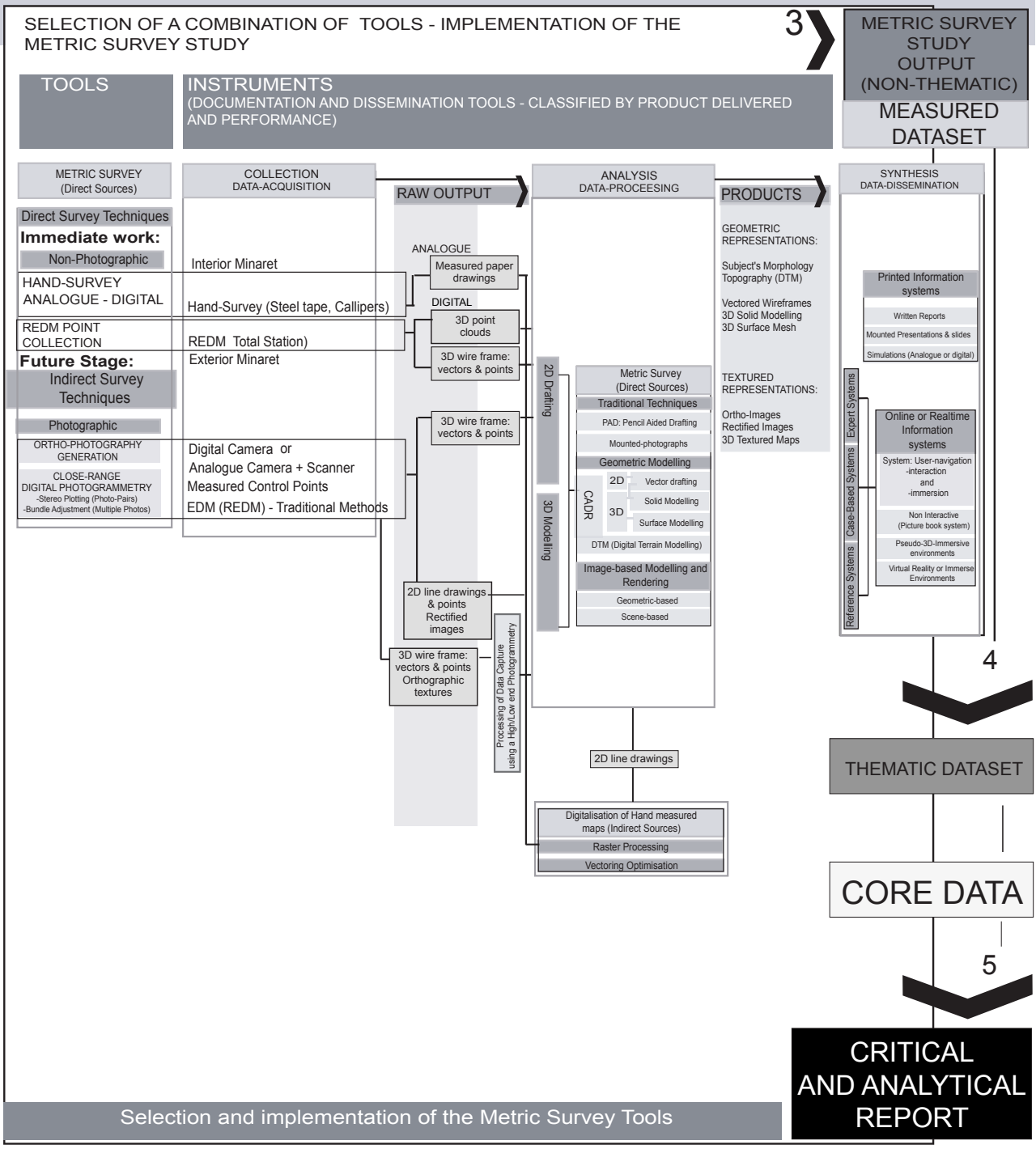
critical issues in recording built heritage. But especially attention should be concentrated in their requirements in adjustments-corrections.

Timing

This variable had a major impact in the selection of the tools and execution of the metric survey. The metric tools selected should deliver sufficient data in a relative

FRAMEWORK: SELECTION OF TECHNIQUES IN PREPARING THE METRIC SURVEY MEASURED DATASET

SELECTION FRAMEWORK



short time.

This variable associated to the monument affects the selection of tools that can effectively deal with: cost-effective, transformation possibilities of the dataset collected to be use in different applications, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

Accessibility

The particular remote location of minaret Jam is an important variable that was taken into account for the selection of the tools used to measure the monument. The tool should be easy to transport and should be able to operate with battery supply (see quantification).

This variable associated to the monument mainly affects the selection of tools according to: speed-range and field operability.

Other variables

Since the project was made in cooperation with local authorities, accessibility was not restricted.

Training of local experts can be included as a variable to consider, a lot of effort was made to make accessible the procedures and tools used in preparing the measured dataset, this certainly limits a bit the action of the recorder but ensures the successful transitions of the methods to local staff to carry out them during a longer period of time.

Furthermore, the selection of tools took into consideration that the equipment will be donated to the staff of the Afghan ministry of information and culture for capacity building and improvement of the current situation.

These variables associated to the monument affect the selection of tools that can effectively deal with: transformation possibilities of the dataset collected to be use in different representations, level of precision, speed-range, deal with occlusion interfering with the survey, adjustments-corrections required, field operability and their capacity to deal with critical issues in recording built heritage.

5.3.2 METRIC SURVEY TOOLS

The use of metric survey tools in the different sites is associated with the collection of mainly geometric information. The activity was concentrated in:

- Measurements for the conservation of specific areas of the site to calculate the structural behavior of the activities in imminent risk.
- Provide measured representation to prepare a general plan of action for the coming years.

Recording for the conservation of the site

A selective, but detail acquisition of the fabric masonry, horizontally as well as vertically. Identification of the loci of objects by an absolute 3-D co-ordinate system obtained from the REDM total station output thus allowing immediate 3-D identification of each record collected.

For a later phase, this work carried out can serve as based for the inclusion of more advanced metric survey tools, such as close-range digital photogrammetric and/or long range terrestrial three-dimensional laser mapping tools for acquisition of the geometry and texture of the whole site.

The information gathered is recorded and produced simultaneously to the works through the use conventional and sustainable off-shelf application and instruments widely available in the market, such as a the REDM Total Station, Computer-Aided Drafting applications, digital cameras, and raster image processing applications used for enhancing the photographs taken.

Establishing a local reference (coordinate) system: using an EDM Total Station point collection tool

Considering the local situation of Herat and Jam in relation with the non-existent of benchmarks or other features to establish an absolute coordinate system, it was decided to establish a local or relative coordinate system

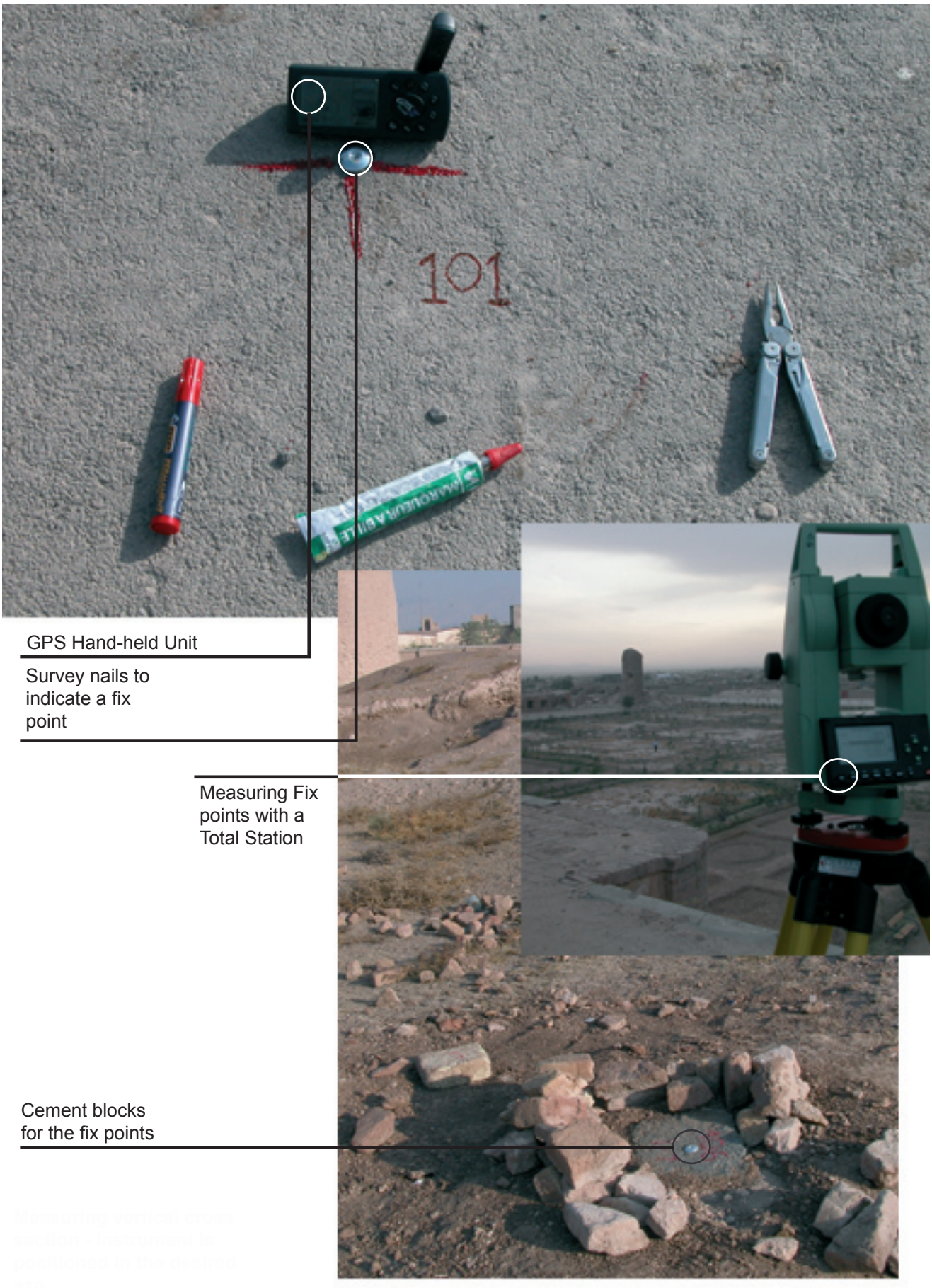


Figure 82: recording the site, preparing and measuring standpoints (fix points) covering the entire area. Author.

as site reference, based on UTM (Universal Transverse Mercator projection)[9], these coordinates measured will be measured in two standpoints using a GPS hand-held device.

These two positions had an interval of around 50 m, sufficient to ensure the best possible precision for the location and orientation of the system.

The complementary standpoints created to measure the whole sites will be based on the first to standpoints with UTM readings. These points were fixed in different areas covering the entire site and visible from each other.

In addition, for obtaining more precise measurements of the Minarets, a number of fix points were measured from the initial standpoint. These positions were used to calculate the current position of the instrument by a method called free-station, this programme consists of determining '*the instrument position from measurements to a minimum of two known points and a maximum of five known points, the final computed results are Easting, Northing and Height of the present instrument station*' (Leica Geosystems AG, 1999, pp. 51)[10], these calculation does not necessary needs to measured by metric tape the height of the instrument and therefore it helps to reduce the error involved in the position and height of the Total Station.

Musallah Complex Herat: site reference system

A set of three standpoints have been selected and identified with surveyor nails in order to ensure the preservation of the system in the future. It consists of:

- ST101 located on the top southwest corner of a small house containing the water pomp.
- ST102 is located on the corner of a column embedded in a wall near Minaret 6 (east side of the Minaret 6).
- ST103 is located on the northwest corner of the top of the Mausoleum of Gawhar-Shad, Kuhsan.
- ST104 is located at the Midwest bound of the Madrassah of Sultan Hussain Baiqara.
- ST 105 is located at the northwest of the Madrassah of Sultan Hussain Baiqara, near Minaret No.
- ST106 is located at the mid east bound of the Madrassah of Sultan Hussain Baiqara.

The system has been defined by two GPS readings taken on ST101 and ST102, the first reading provided a relative position, including east, north and height (altitude). The second reading was used to orientate the system(see figure 83).

ST101 GPS Readings: UTM region 41 S:

East (M)	41 S 0425170
North (M)	41 S 3802154
Height (M)	970

ST102 GPS Readings: UTM region 41 S:

East (M)	41 S 0425006
North (M)	41 S 3801985
Height (M)	958

Subsequently, the Total Station was placed in ST101, the standpoint and it was orientated using the readings from ST102.

When the instrument was ready, ST102 was measured again using the Total Station to ensure precision in the records, also ST103 measured from this point.

Coordinates:

Standpoint	East (m)	North (m)	Height (m)
ST101	425170.000	3802154.000	974.000
ST102	425002.891	3801981.778	971.969
ST103	425084.386	3802120.559	980.290
ST104	425140.596	3802265.748	976.726
ST105	425119.567	3802335.433	975.848
ST106	425250.717	3802330.162	975.240

A second system of temporary standpoints was measured from ST101, in order to be use for measuring the Minaret No.5 using a 200 numbering system.

Minaret Jam: site reference system

Two standpoints were constructed and measured with the hand-held GPS device, the had an interval of more than 50 m.

ST101 GPS Readings: UTM region 41 S:

East (M)	41 S 0639357
North (M)	41 S 3807168
Height (M)	1905

This position is located at around 10 m. of the eastbound of the Minaret, near the military post (see figure 84).

ST102 GPS Readings: UTM region 41 S:

East (M)	41 S 0639621
North (M)	41 S 3807244
Height (M)	1888

This position is located at around 300 m. from the north front of the Minaret, near the ruined research house in the stone area.

Subsequently, the Total Station was placed in ST101, the standpoint and it was orientated using the readings from ST102.

When the instrument was ready, ST102 was measured again using the Total Station to ensure precision in the records, also ST103 measured from this point.

Coordinates:

Standpoint	East (m)	North (m)	Height (m)
ST101	639357,000	3807168,000	1905,000
ST102	639619,825	3807243,662	1901,935
ST103	639303,970	3807231,762	1903,444

ST103 is located around 20 m. from the west front of the Minaret across the river, in a hill close to a large stone.

Methodology: recording with a REDM Total Station

The measurements were made using a Reflectorless Electronic Distance Measurement Total Station Topcon Leica TCR307, the records are stored in the internal memory of the instrument, which has capacity to store 8000 records (around 6000 measured points).

The total station records using two EDM (electromagnetic distance measurement mode) modes:

- By sending an infrared beam to a reflector device (prism or reflective sticker), the TCR307 has a range of 5 km using a reflector.
- By sending a laser beam directly to the surface (the return and range depends on properties of the material), the TCR307 has a range of 80 m but is affected by the material, in difficult situations the range can be reduce to 20 m.

These two modes allow measuring the three-dimensional co-ordinate of the point recorded and if required it can provide the horizontal angle, vertical angle, difference of height, horizontal distance, and absolute distance between the measured point and instrument standpoint.

Furthermore, the records stored in a memory, after surveying they can be transferred to a computer using a communication cable connected to the serial port. The Leica communication software allows generating a list of records in different formats that can be read by a CADR application. This tools has being define in this research as REDM point collection and can be further studied in part I - chapter V.

The survey and storage of the collected points were divided into different sets of measurements according to the

Massalah Complex Herat - standpoints

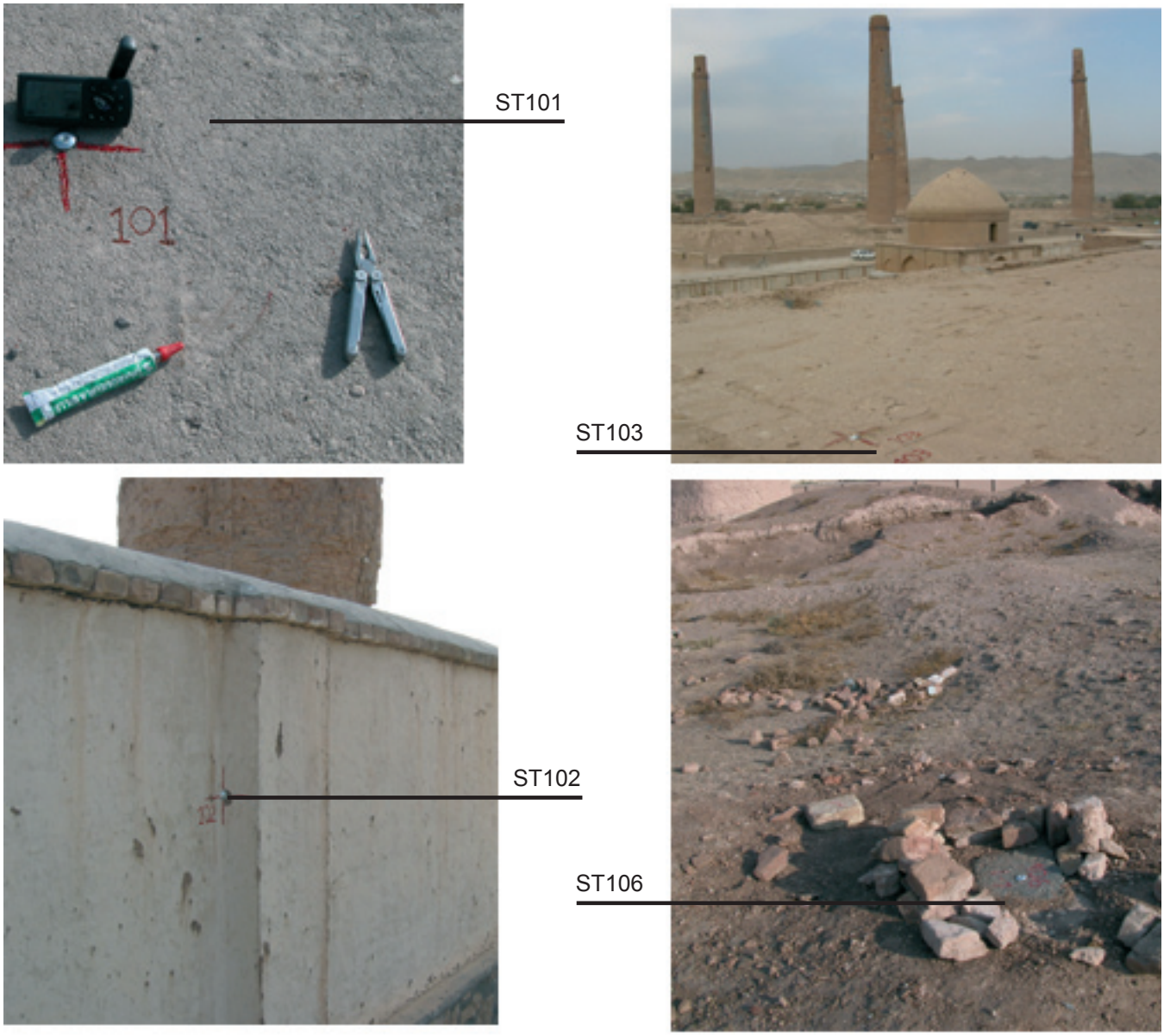


Figure 83: standpoint fixed in the Mussalah Complex in Herat. Author.

measurements executed and needs of the representation. Mainly a part was devoted to the geometry of the monument and another file containing measurements for Digital Terrain Modelling of the site topography. As well as, for surrounding structures and features of interest for the study.

Moreover, in uncovered ruins, the features are surveyed by placing the reflector in the top and bottom of the object thus providing two known points for it. The measured points will be use to create the elements using the solid or surface modelling extension in the CADR application.

In addition, the topography is surveyed by making a systematic measurement with a specific distance depending on the complexity of the slope. As for instance every 5m in a triangular schema.

Each day the information was transferred to the computer and process the data collected. The collected points were introduced into the CADR environment using AutoCAD Land development Desktop version 3 that enables the calculation and representation

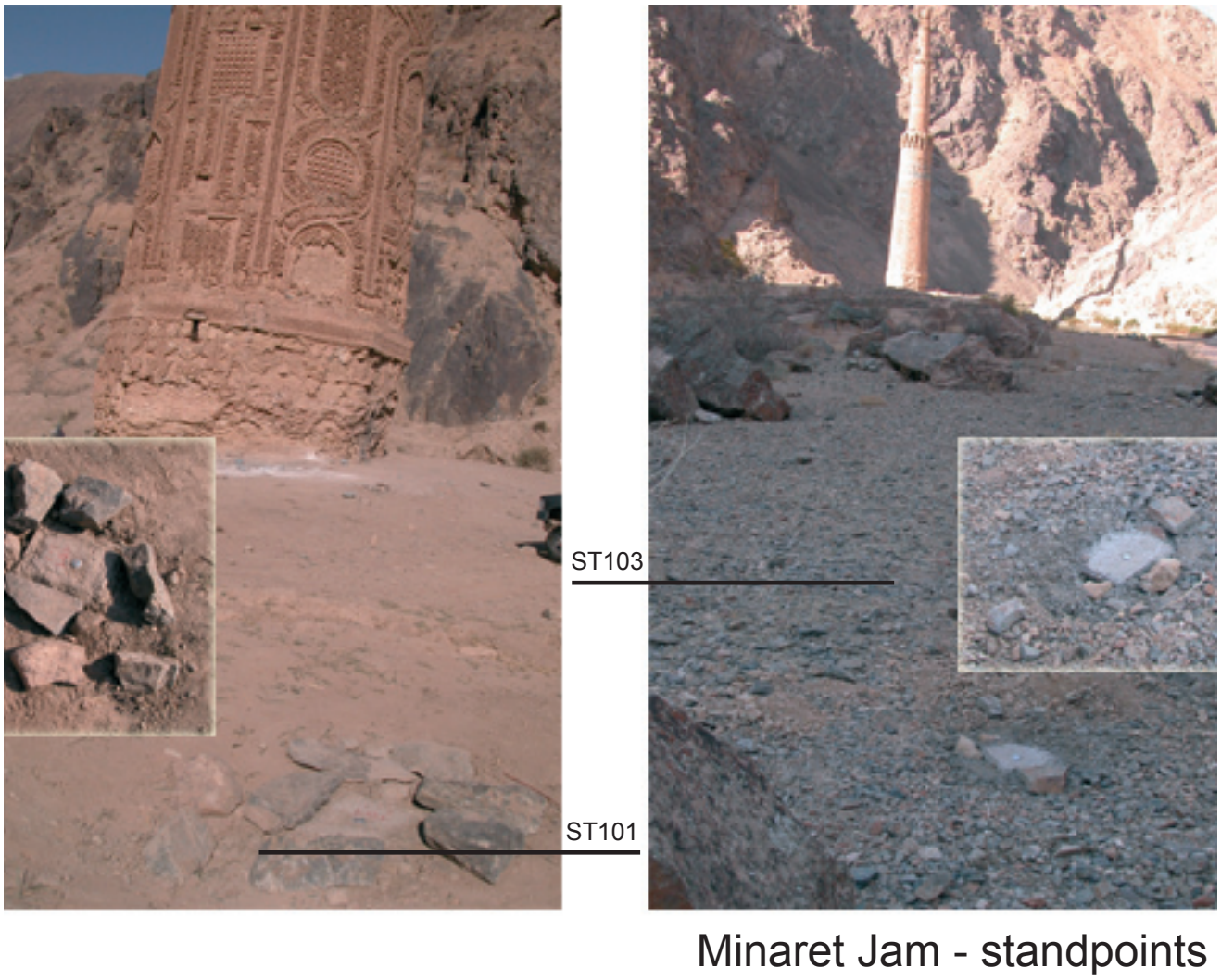


Figure 84: standpoint fixed in the minaret Jam. Author.



Figure 85: views of minaret no.5 - Mussalah complex in Herat. Author.

of the topography of the site using three-dimensional contour lines and surfaces.

Subsequently, the features of the monument fabric are constructed using the commands included in the Computer-Aided Drafting tool (CADR). On conclusion of the survey, the working up and editing of the data required five weeks. The resulting plans showed the topography and archaeological remains in a single three-dimensional representation. The CADR application enabled the drawings to appear in different formats for study or publication.

Measurement of the Minarets using the REDM Total Station

For the measurement of the minarets, an adapted methodology was developed. It consisted in measuring a number of horizontal sections, starting from the bottom to the top, with a number of intervals depending on the different heights corresponding to the stages of the structure.

Moreover, these sections were drawn in the CADR application providing a irregular curved shape that served to draw more regular circles to find the different circumfere's centres. These centres definition were aimed to define the different axes of inclination at each stage.

Subsequently, a graphic average of these inclinations help calculating a general risk axe that was extracted from the CADR drawing and defined in the site with the help of the Total Station programme called 'Set out'.

These standpoints defining the axe in the terrain were use to measure the vertical cross section that could yield the most risky scenario of the current inclination of the structure.

The procedure to set up these positions in the terrain was perform with an instrument (TCR307) application called '*Setting Out', which 'computes setting-out elements for the polar, Cartesian, or orthogonal setting out points using either coordinates or manually entered angles, horizontal distance and height. In the Setting out program three different displays are available showing setting out values corresponding to the relevant method*' (Leica Geosystems AG, 1999, p. 44)[11].

The combination of the vertical section and horizontal sections provided information to define particular inclination angles per stage and a general risk angle of inclination of the minarets.

Finally, for improving the stability study of the structure, the measured sections of the minaret with the aim of the REDM Total Station were combined with hand-survey measurements of the interior; the resulting drawing provides a specific state of conservation of the structure that can be of assistance to study the structural behavior of the monument.

REDM Total Station measurement of natural targets and digital photography for close-range photogrammetric restitution

Natural targets

A number of measurements were collected of Jam Minaret and Minaret No.5 in Herat for a future stage in photogrammetric restitution. These called natural targets are related to architectural features, which are particular aspect to be recognize immediately in most of the photographs taken, these points will provide the information to calculate the external orientation required in photogrammetry (review Chapter V in Part I for more information about this method), meaning scale, position and orientation of the features digitized from the images. The natural targets were measured using the Laser EDM.

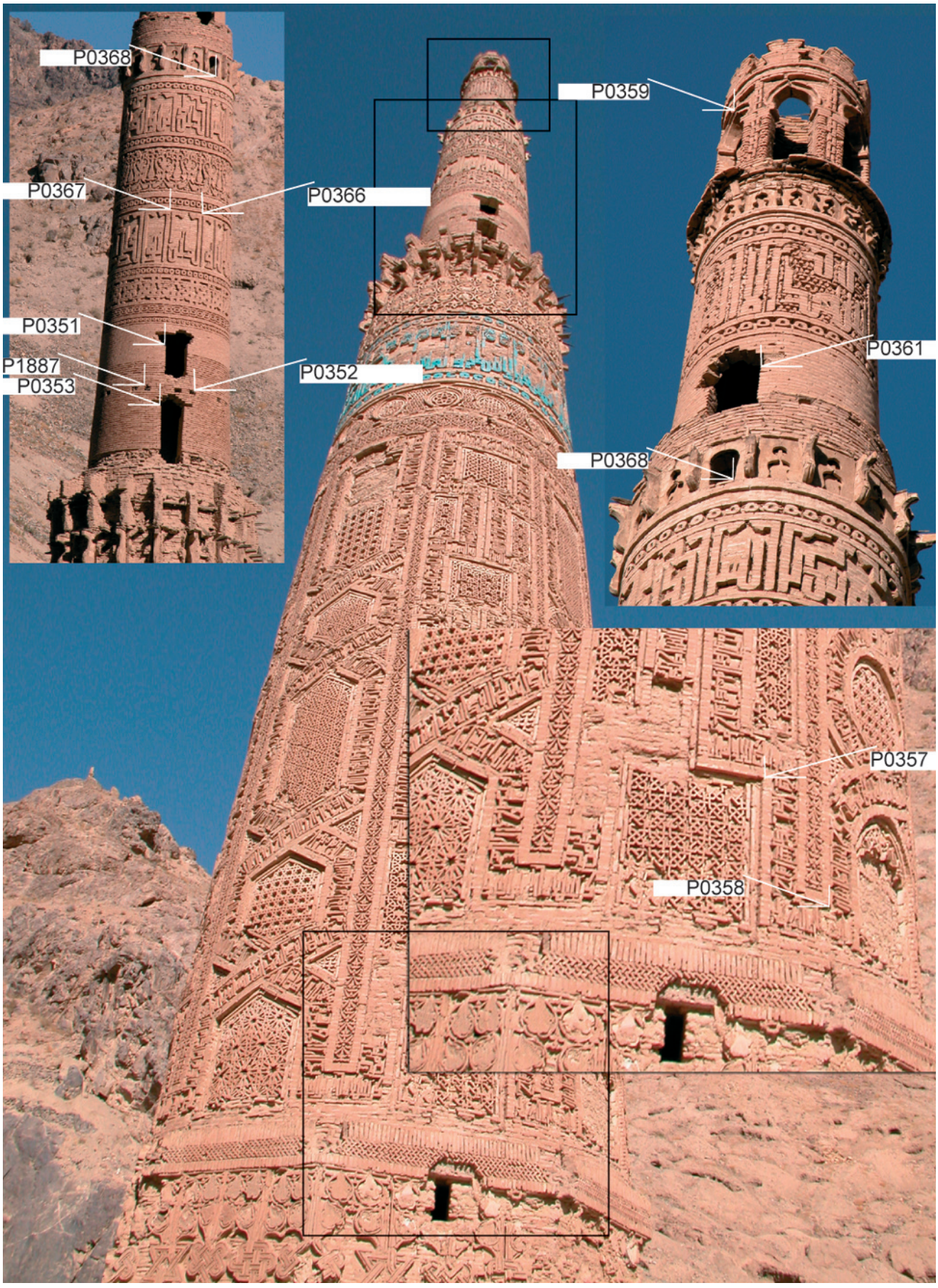


Figure 86: example of natural targets measured with the REDM total station for photogrammetric restitution in minaret Jam. Author.

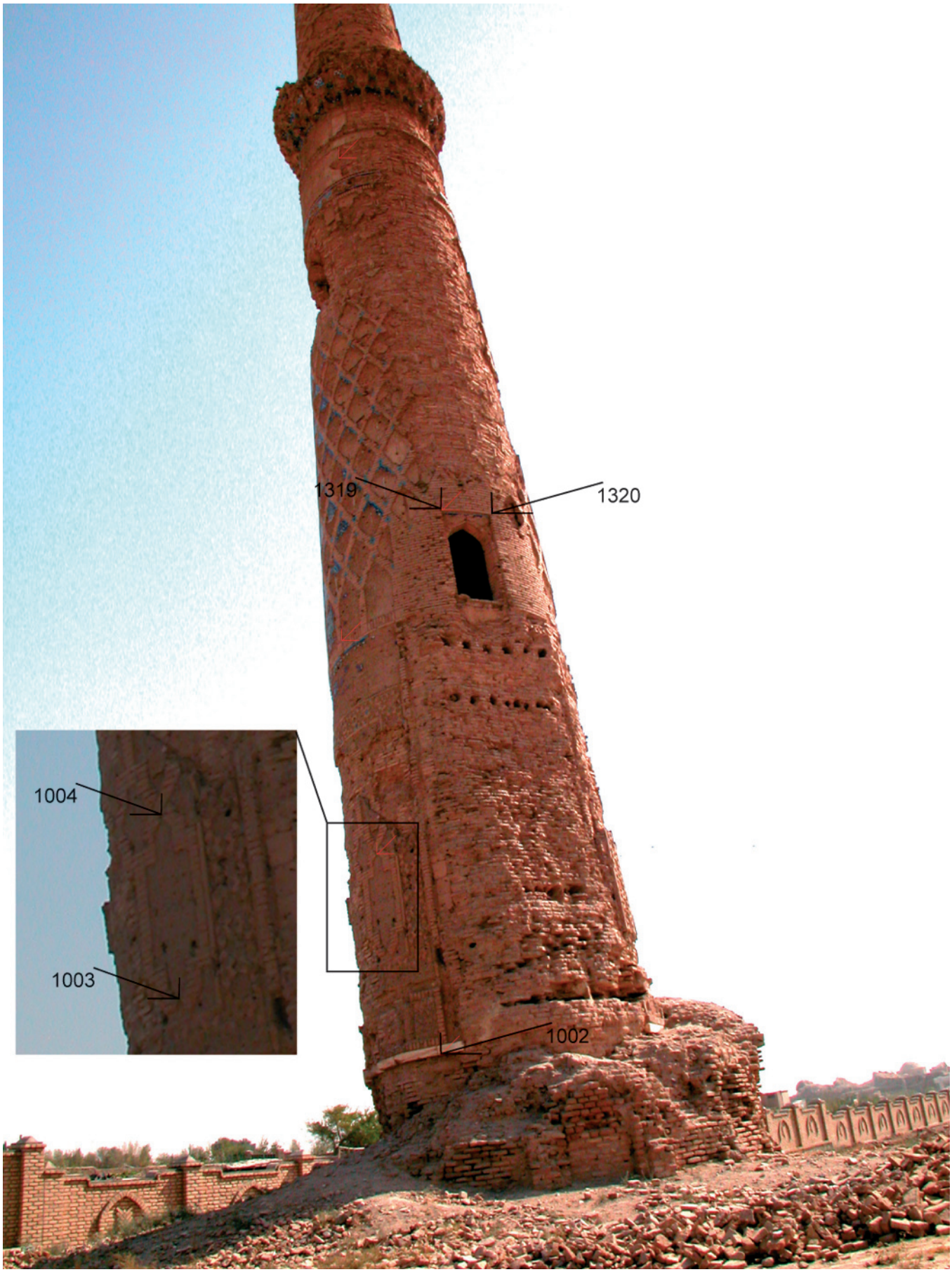
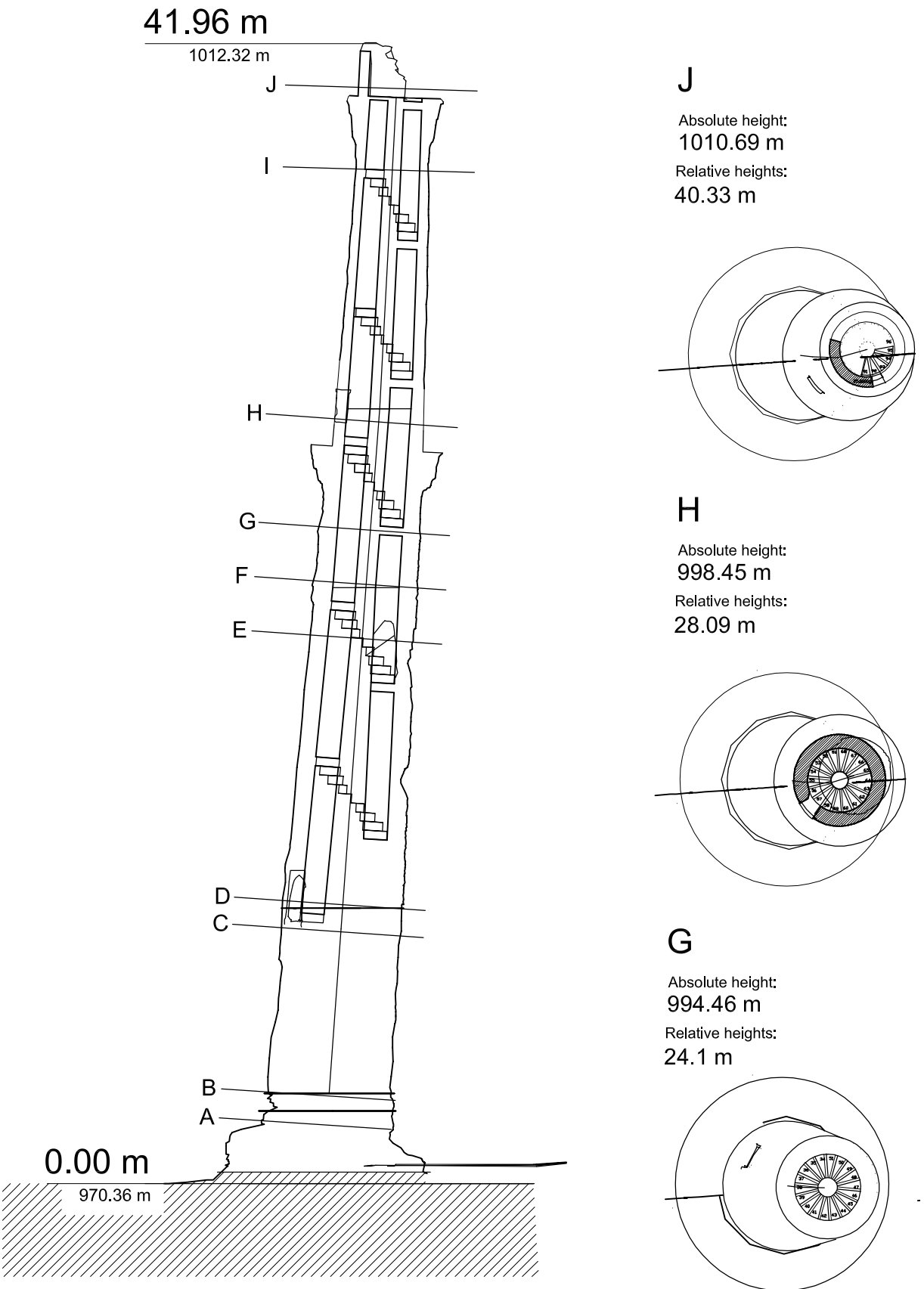


Figure 87: example of natural targets measured with the REDM total station for photogrammetric restitutuion in minaret no.5 (Mussalah complex Herat). Author.

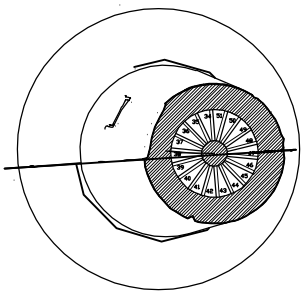


Drawing by: T. Stevens - Complementary CADR: Author

Figure 88: views horizontal and vertical cross section through the minaret no.5, generated with the combination of the readings from the REDM total station and hand-survey measurements.

F

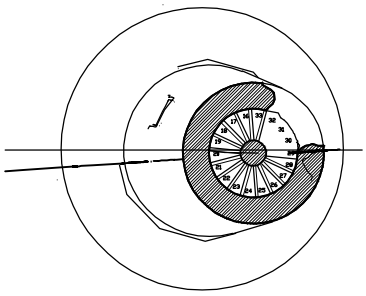
Absolute height:
992.46 m
Relative heights:
22.1 m





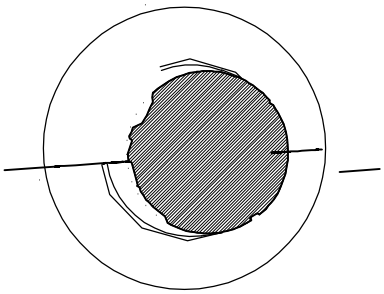
E

Absolute height:
990.46 m
Relative heights:
20.1 m



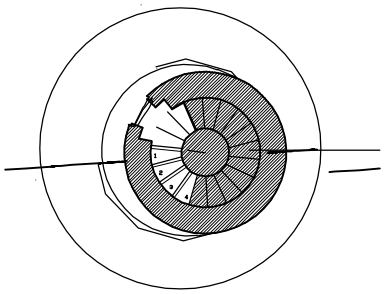
C

Absolute height:
979.66 m
Relative heights:
9.3 m



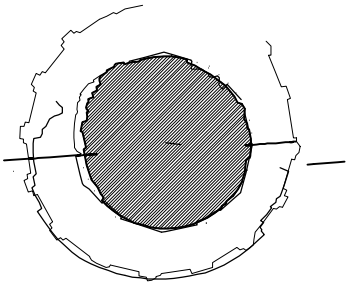
D

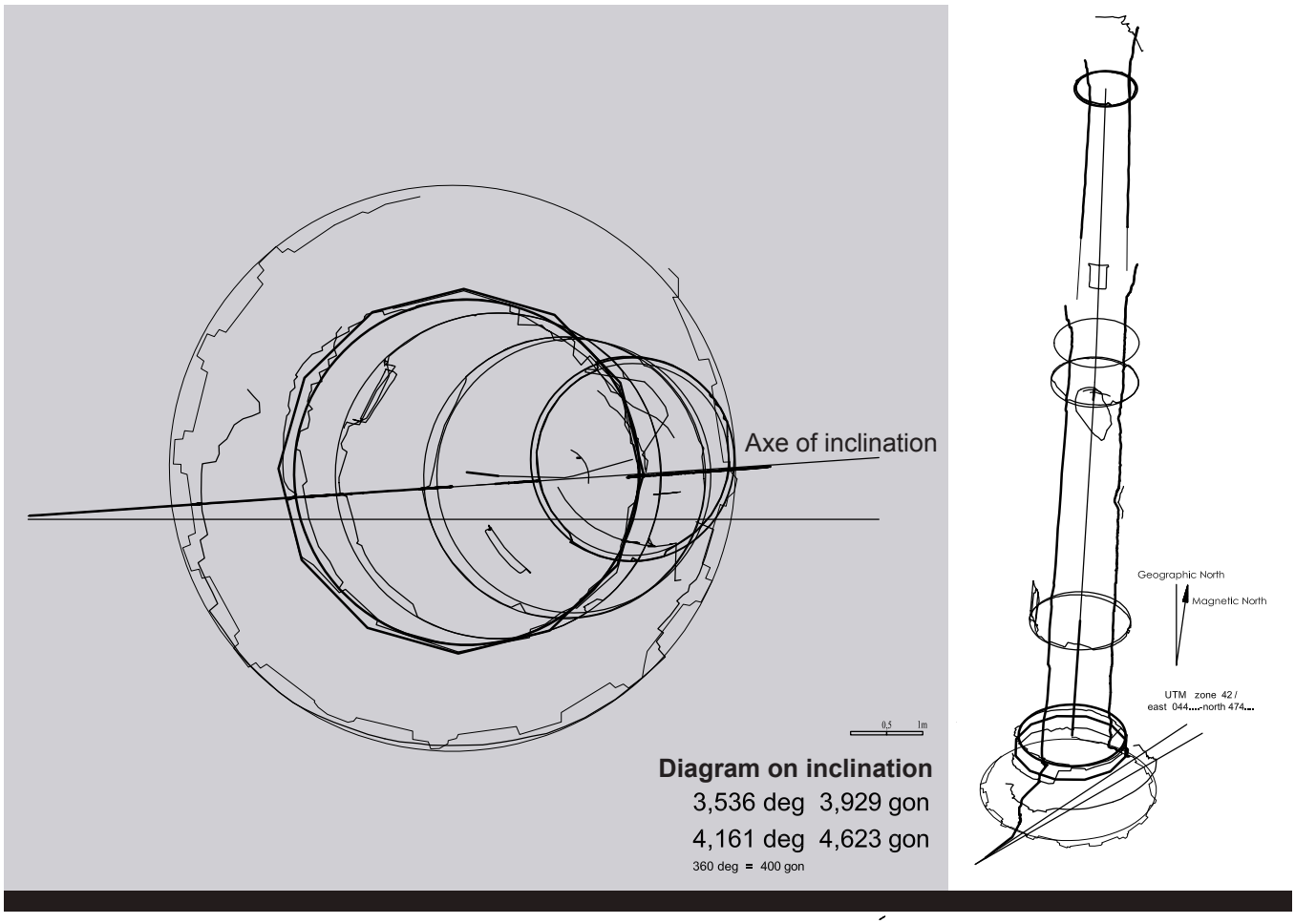
Absolute height:
980.66 m
Relative heights:
10.3 m



B

Absolute height:
973.645 m
Relative heights:
3.285 m





Drawing by: T. Stevens - Measurements: Author - T.Stevens

Figure 89: calculations about the inclination of the minaret no.5 using the most leading axe. Drawing by T. Stevens and measurements by T. Stevens and author.

Specification in Minaret Jam: due to the lack of a printer to plot the photographs and indicate the natural targets, a number system was introduce to identify the different faces of the Minaret from 1 to 8 clockwise and according to the octagonal bases of the monument, number 1 corresponds to the point facing ST101 and having a gap in the octagonal layer (see figure 87).

Subsequently, a sketch was prepared by M. Schadl of each numbered face and the targets were indicated. Further the targets were transferred to actual photographs (see figure 87).

Specifications in Minaret no. 5 in Herat: all the natural targets were indicated in plotted photographs of the Minaret. These papers were later digitized (see figure 88).

Digital photography using different lenses

Photogrammetric images for Minaret Jam: a series of oblique and overlapping photographs covering homologues features and taken from different positions of the Minaret were taken. Each photograph is identified by the lens and zooms used to take the shot. This permits to process the internal orientation for photogrammetry along with the natural targets measured to generate the external orientation parameters (see figure 88).

However, due to the lack of scaffolding, the middle part of the first stage of the Minaret was not adequately photographed;

photographs with more detail should be taken in a later stage.

Photogrammetric images for Minaret No.5 in Herat: a number of oblique and overlapping photographs with homologous features were taken covering the entire Minaret. The photographs were made with different lenses and zoom, each photograph is identified with the lens used for achieving internal orientation in the photogrammetric package (see figure 88).

Due to the sun direct light, the north front of the Minaret was not sufficiently photographs, this should be executed in a later stage using more adequate equipment.

Photographs for Minaret No.1, 2, 3, 4 and 6: a sequence of photographs from bottom to top was taken from different angles of each minaret. The angle and orientation of each photograph along with the lens used were included in the name file. The orientation was measured with a hand held electronic compass.

General recommendations for photogrammetric restitution

The photographs taken along with the already known parameters of the camera used can serve to prepare a preliminary photogrammetric restitution that can be improved during future mission aimed at preparing a full set of measured representation of the site.

5.3.3 CAPACITY BUILDING: TRAINING OF LOCAL EXPERTS

The main aim of this activity is not only promote the understanding of recording every stage of work during the works of conservation, but also to donated a set of equipments and knowledge to organize a government cell that is capable of recording and monitor the state of conservation of a larger number of afghan sites during the years to come.

The training consisted in the combination of a theoretical and a practical framework. The contents of these two areas were limited by the:

- A short time available to teach the afghan experts in the use of the instruments. Time available: 7 days (3 days in Jam and 4 days in Herat, this last four days were possible due to the support of Mr. Wahid from the Herat authority in preservation of architectural heritage, which provided lodging and local facilities to the trainees of the Ministry of Information and Culture from Kabul).
- Their restricted knowledge in the use of electronic equipment and computers.

To make use of all the time available, the theoretical aspects were integrated into the actual survey work.

Trainees:

Ministry of Information and Culture, Department of conservation and restoration of historical monuments: engineer Abdul Ahad Abacy and engineer Ahmad Fahim Fayeq.

Coordination Afghan Humanitarian (CHA – NGO): Engineer Masood Temory from Herat.

In addition, the section of heritage at UNESCO has proposed to prepare a full



Figure 90: example of capacity building of afghan experts in the use of the instruments and an explaination of the training framework. Author.

scale training course next year to improve the capacities of the trainees in the use of these tools.

This programme for capacity building of local afghan experts in the use of these tools consists:

- A broader perceptive of the techniques and instruments available in the market.
- Concepts and principals in recording built heritage.
- An appropriate balance among the quality of the records to be prepared, budget available for the survey, and variables of the recording techniques available

Furthermore, at the end of the course a set of guidelines for preparing an adequate set of measured plans of the site, including three-dimensional topographic models and orthographic representations, rectified photography of standing and buried structures, and other relevant measured representations will be produced, taking into consideration local aspects and available sources.

This course will be structured in the already known international experience in the field of capacity building of experts in developing countries in the use of REDM total station, CADR-DTM applications and digital photography achieved by the University of Technology Aachen RWTH, which in the past has promoted and participated in the organization of training workshop.

The equipment donated consisted of:

Hardware:

- TCR307 Leica Total Station: capable of measuring without reflector to a range of 80 m and with a set of four batteries to operate for 3-4 days.
- Sony Vaio model PCG-GRX316MP notebook with a Pentium IV processor, 30 GB Hard disk, 16x CD-Writer, and a screen of 16" for AutoCAD and other graphic software. An external floppy disk unit.
- Nikon Coolpix 5500 Digital Camera with 5 MP resolution and two memory cards (128MB and 32 MB), along with an adapter to read the memory cards in the computer directly.
- HP Deskjet printer 1220, capable of printing up to A3+ size.
- UPS electricity regulator: to avoid damage of the instrument from electricity fluctuation currently happening in Afghanistan.

Software:

- AutoCAD Land development desktop r3 for CADR processing and Digital Terrain Modeling generation to create representations of the topography and architecture of the measurements collected with the total station.
- AutoCAD Raster Design: a plug-in to AutoCAD that enables the user to rectified plan parallel and aerial photographs directly into the CADR drawing.
- Adobe Photoshop 7, a program for processing of digital images produced by the camera and other raster images work.
- MS Office for word processing, spread-sheet and other features to produce reports.

5.4 RECOMMENDATIONS: PLANS FOR THE FUTURE

Metric survey in the Mussalah complex Herat

A full scale image-based and geometric measured dataset should be prepared of the site including:

- Ortho-graphic projections of the six minarets: vectored maps or ortho-photographs (as suggested by Archidata).
- Detailed survey of minaret no. 5 and establishment of a monitoring system to record structural behavior of the monument.
- The preparation of a topographic map of the site, especially of the site of the four minarets and Madrassah Hussein Baiqara by means of a digital terrain model. Including the immediate urban context surrounding the site and the type of vegetation present. This map should also identify the position of illegal excavations around the site.
- 3D dimensional model of the site and Minaret no. 5 and site

Probably photogrammetry will be the most suitable technique to achieve these goals, because is a portable and highly effective technique.

This project should take into consideration the possibility of further training afghan experts in the use of these techniques and the setting up of advanced monitoring system.

Metric survey in minaret Jam

A full scale image-based and geometric measured dataset should be prepared of the minaret including:

- Ortho-graphic projections of the façade: vectored maps or ortho-photographs (as suggested by Olivier Feihl).
- A digital terrain model to represent the topography of the site with a higher density of points that the one presented in this report. Including a hydrographic documentation of the rivers and the type of vegetation present. This map should also identify the position of illegal excavations around the site.
- 3D dimensional model of the minaret and site

Probably photogrammetry will be the most suitable technique to achieve these goals, because is a portable and highly effective technique. However, 3D long-range mapping devices should be taken into account for a quick documentation of the topography and geometry of the monument.

This project should take into consideration the possibility of training afghan experts and set up a monitoring system that could yield results on the structural behavior of the site.

Capacity building of the Afghan Ministry of Information and Culture in the use of Metric Survey tools, follow-up plan

Main goal: creation of a government cell capable of providing services on the documentation of afghan heritage in different fields of action:

Basic objectives:

(1) Creation and implementation of a methodology for a national record system for inventorying and monitoring the actual state of conservation of historical sites across the country, this point can be done in cooperation with the already created database of monuments in Afghanistan by the University of Aachen RWTH in Germany. Training should be concentrated in the use of basic

CAPACITY BUILDING: PROPOSAL

SPRING WORKSHOP

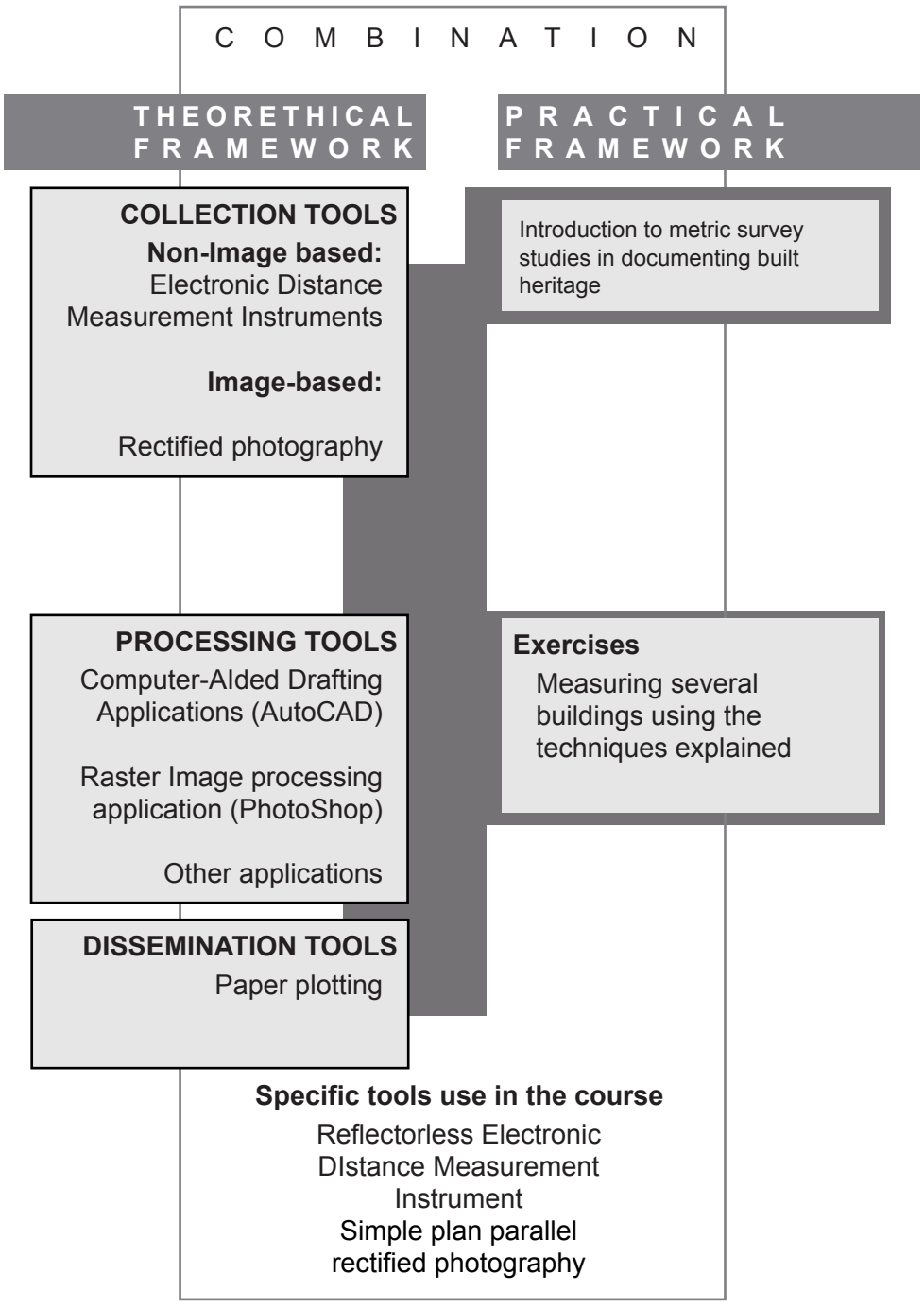
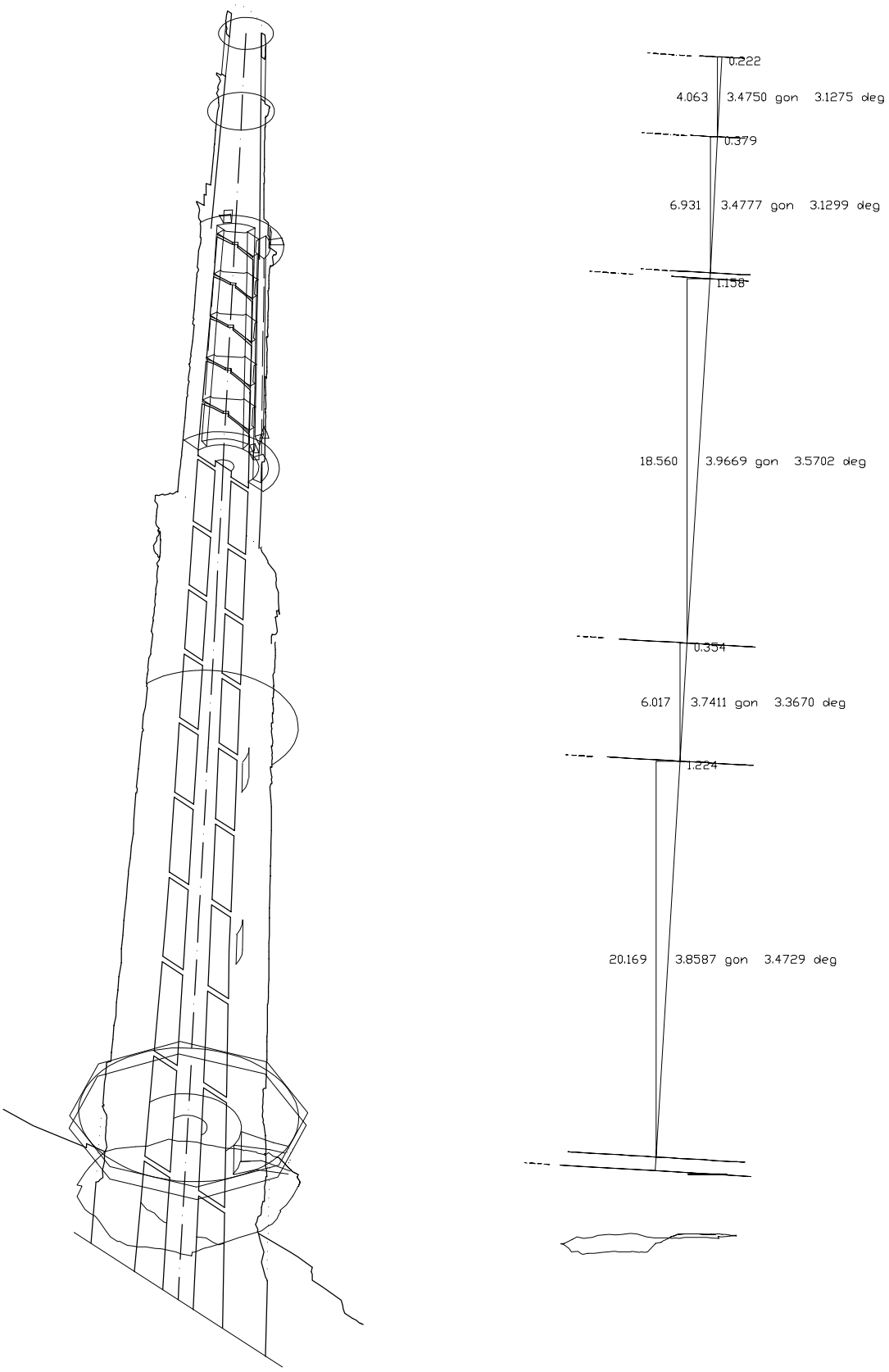


Chart 54: framework for the training course for capacity building of afghan experts in the use of the instruments. Author.

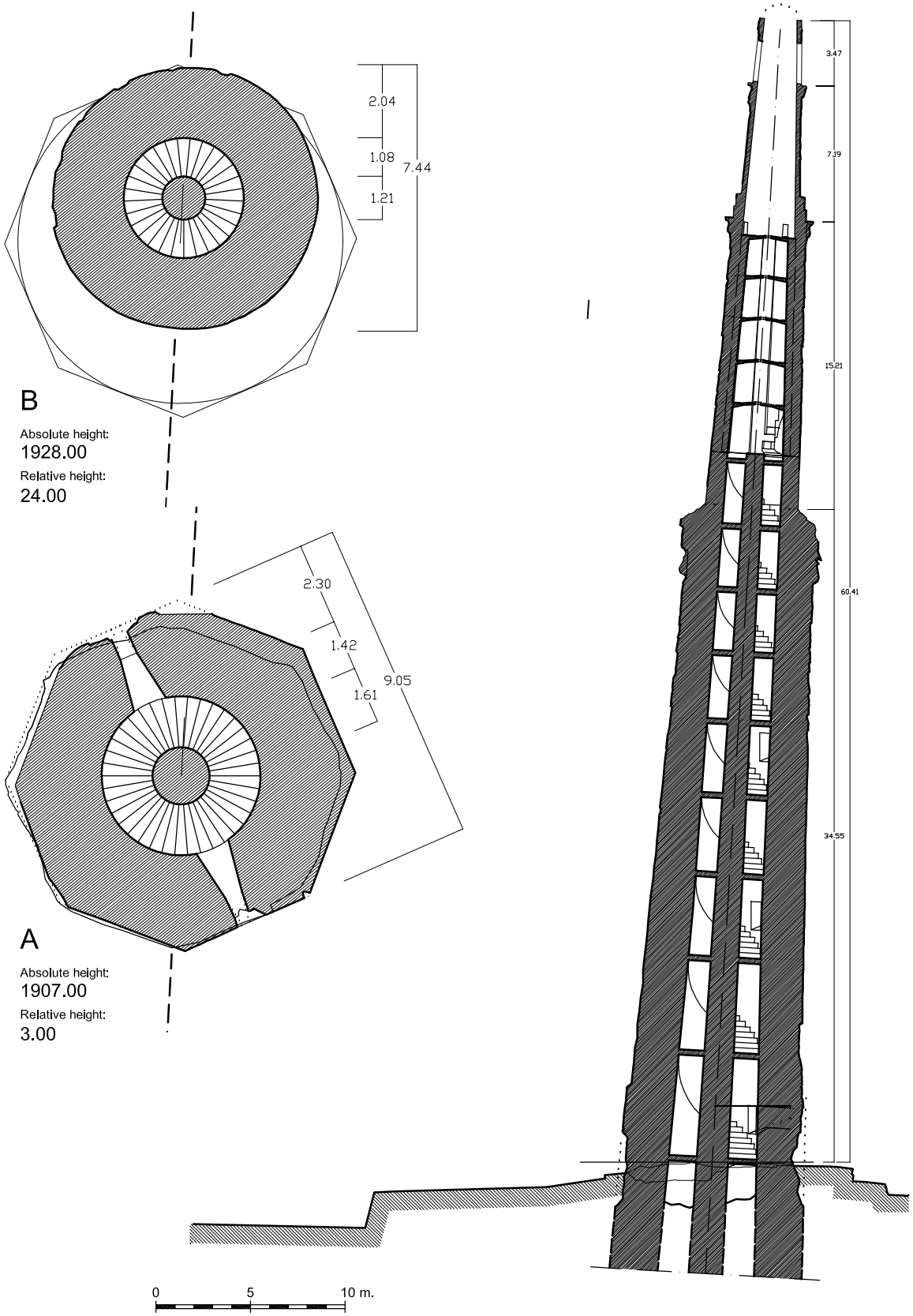
referential tools for recording, such as digital cameras and scanner. Furthermore, the use of Geographic Information System and image databases should be included as an advanced course.

(2) Metric Survey of historic sites, training should be concentrated in the use of electronic distance measurement (EDM) devices (Total station – Laser scanning?), Computer-Aided Drafting application, Digital Terrain Modeler

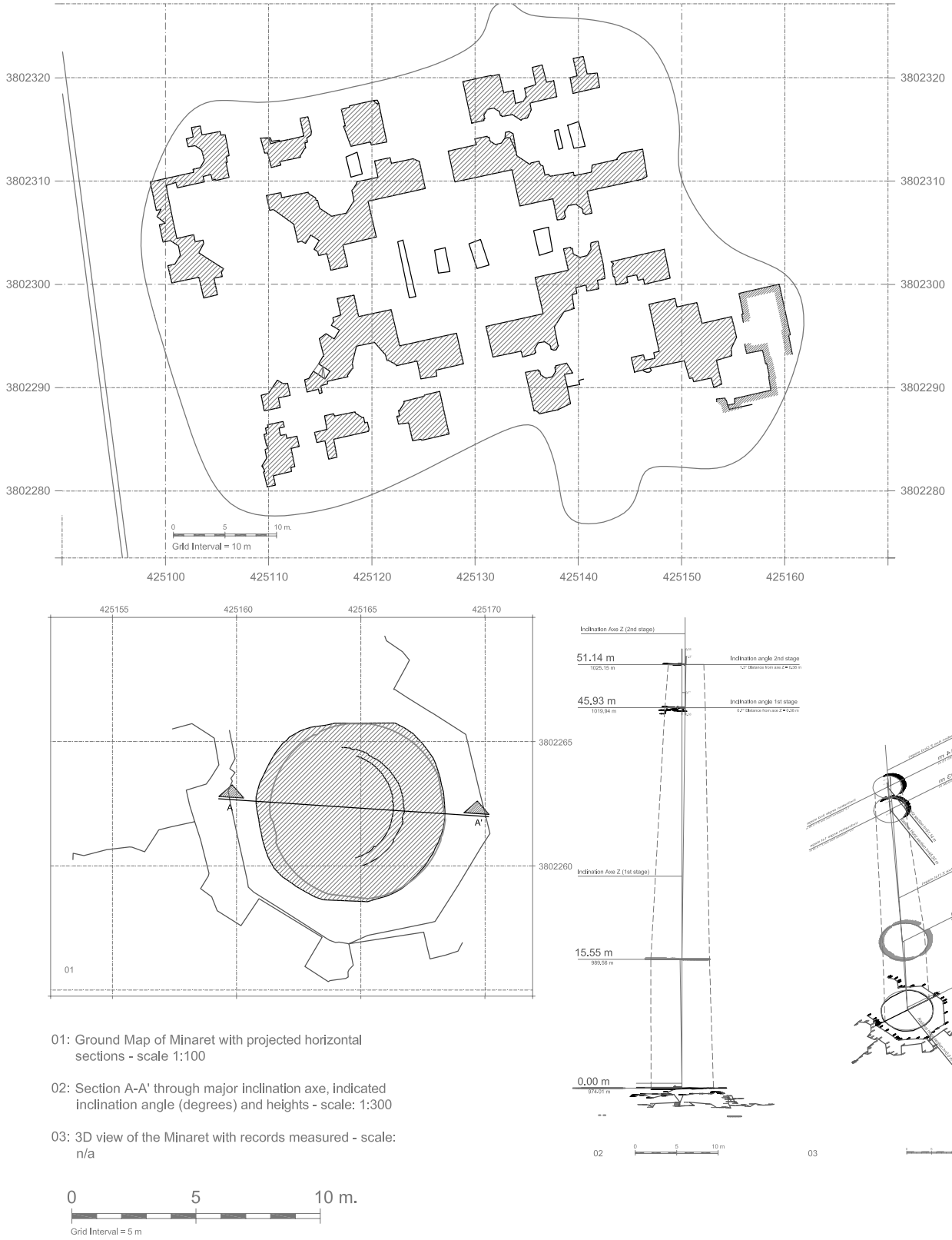


Drawing by: T. Stevens - Complementary CADR: Author

Figure 91: vertical and horizontal cross section through Minaret Jam. Author.


2.04
1.08
7.44
1.21
B
Absolute height:
1928.00
Relative height:
24.00
2.30
1.42
9.05
1.61
A
Absolute height:
1907.00
Relative height:
3.00
3.47
7.19
15.21
60.41
34.55
0
5
10 m.

RUINS - MADDRASSAH HUSSAIN BAIQUARA



01: Ground Map of Minaret with projected horizontal sections - scale 1:100

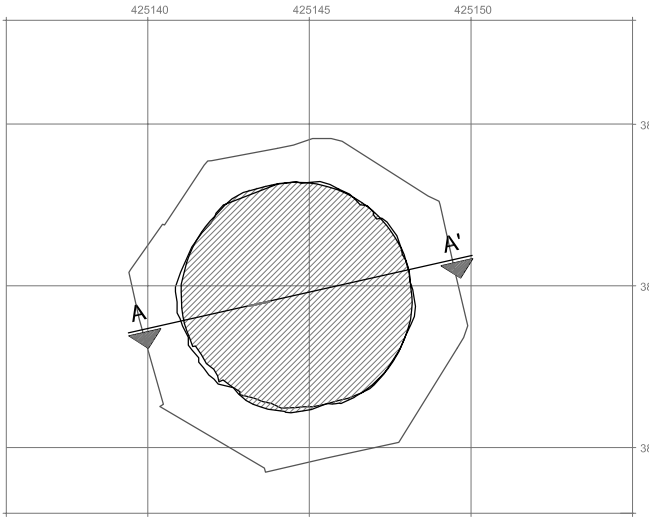
02: Section A-A' through major inclination axe, indicated inclination angle (degrees) and heights - scale: 1:300

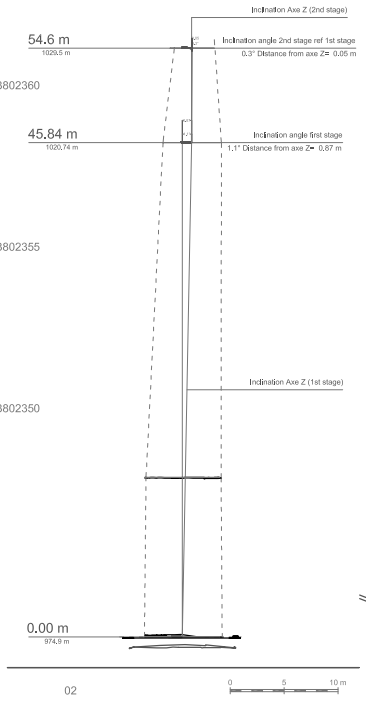
03: 3D view of the Minaret with records measured - scale: n/a

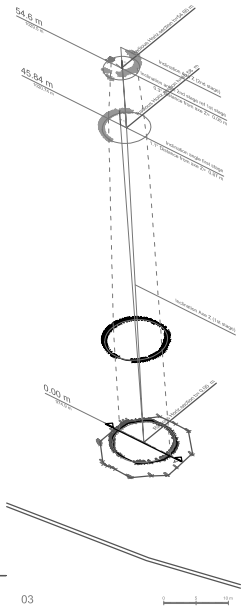
MINARET NO.1

Figure 92: different maps of the Mussalah complex Herat. Author.

MINARET NO.2







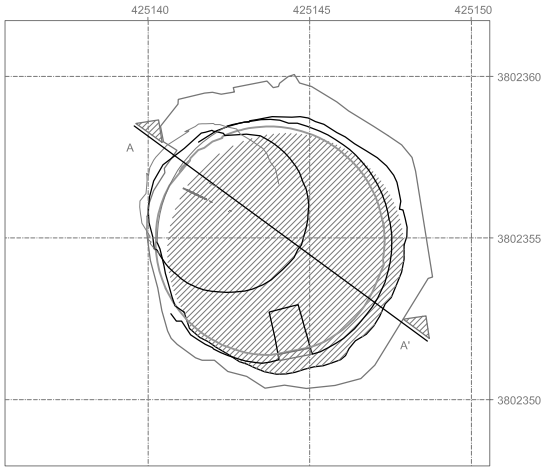
01: Ground Map of Minaret with projected horizontal sections - scale 1:100

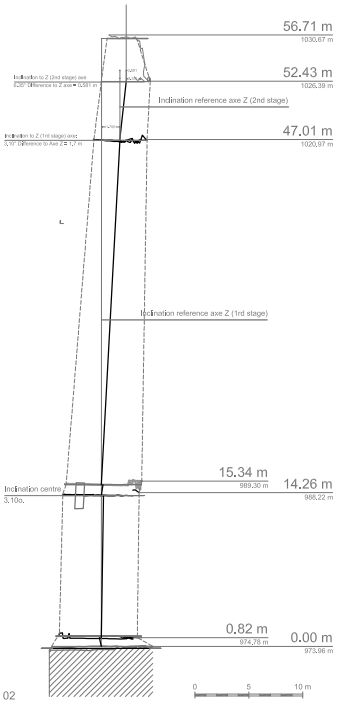
02: Section A-A' through major inclination axe, indicated inclination angle (degrees) and heights - scale: 1:300

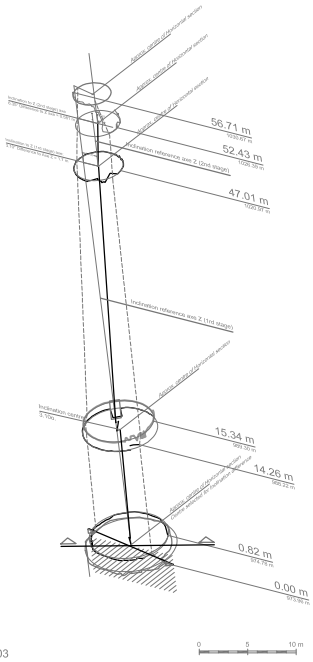
03: 3D view of the Minaret with records measured - scale: n/a

0 5 10 m.

Grid Interval = 5 m







01: Ground Map of Minaret with projected horizontal sections - scale 1:100

02: Section A-A' through major inclination axe, indicated inclination angle (degrees) and heights - scale: 1:300

03: 3D view of the Minaret with records measured - scale: n/a

0 5 10 m.

Grid Interval = 5 m

MINARET NO.3

applications, and photogrammetry.

(3) Training to university and other educational institutions in the country, the documentation cell should be encourage to spread knowledge to other institutions, such as department of geodetic engineering, architecture, archaeology, art history, etc. Perhaps a programme on conservation of heritage should be establish in the university that could offer a course on documentation techniques, ranging from creating inventories to the use of metric survey tools.

Equipment required:

Point (2): a set of instruments and software has been already donated to the Ministry of Information of Culture by UNESCO, however for a second stage, more material should be made available to set up a metric survey cell, including:

Hardware:
PC desktops
A large format Plotter
A server and other items to set up a network.

Software:
Photogrammetric software

Action plan:

The members of this cell have been already selected by UNESCO in cooperation with the Ministry, these persons should have a fluent English capability and sufficient technical knowledge to operate the equipment, therefore the following action plan is proposed:

Before spring (March or April 2003):

- Intensive English course, available locally.
- Computer basic use course, showing the main features of a computer, such as word-processing, spread sheet, and general operation, available locally

Workshop March or April 2003: Theoretical and practical framework in the use of electronic distance measurement devices and image-based application in preparing a measured dataset of built heritage sites:

- Intensive course on the use of metric survey tools, including EDM devices and simple image-based tools: tentative contents:

  Theoretical framework:
  Introduction to metric survey studies in documenting built heritage
  Use of a REDM Total Station, working with the already donated TCR307 Leica, explaining all the procedures for recording measurements and transferring them to the computer.
  Computer-Aided Drafting and Digital Terrain Modeling processing of measurements course, working with the already donated version of a AutoCAD land desktop v3.
  Simple rectification of plan parallel photography, using a mechanic technique and automatic applications, working with the already donated software of Adobe PhotoShop and Raster Design. As well as, the digital camera.
  Preparing Monitoring forms for a historic site: conclusion combining all the documentation tools explained in the course.
  Practical framework:
  The explanation of each of the contents will be introduce by directly working with case-studies.
- Intensive course of the use of image-based techniques, making emphasis in photogrammetry. This part of the

course can be introduce to the trainees in the spring workshop and further developed in a second stage. However if it is relevant, it can be already be integrated in the course.

This workshop can be organize by the University of Aachen in Germany and in conjunction with Aga Khan Trust for Culture, which has plans of acquiring the same type of equipments and give training to their staff. This is aimed at having two instruments for give training.

Moreover, the University of Aachen in Germany and the R. Lemaire International Centre for Conservation (University of Leuven) in Belgium could offer short term internships to some of the trainees to experience the use of these techniques in a different environment.

5.5 CLOSING REMARKS

This case study demonstrates that the adapted used of sustainable tools of for urgent work in recording historic buildings, with specific variables dealing with the expected quality and precision requirements of the measured representations adjusted to the specific needs of a problem and the desired dissemination product.

Comparative studies using the metric survey representation prepared can yield results to evaluate:

- The structural stability in relation with the inclination of the minarets.
- Evaluating the surveys carried out by previous missions.
- Prepare a permanent document showing the different problems and the initial work needed to measure in more detail the monuments.
- Evaluate the development of the works, speed and constraints

Furthermore, it proposes a model for capacity building of local experts including the development of local structure that is capable of documenting and caring the heritage of the country. This cell should have strong links to academic institutions, providing further training to experts in this area.

Notes:

[1] Knobloch, E. 'The Archaeology and Architecture of Afghanistan, Tempus Publishing Inc., Gloucestershire 2002, p. 127

[2] Society for the Preservation of Afghanistan's Cultural Heritage (SPACH) 'Jam Minaret', SPACH newsletter, Issue 6, May 2000, Islamabad, p. 2.

[3] Ibid 1.

[4] SPACH: Society for the Preservation of Afghanistan's Cultural Heritage – HAFO: Helping Afghan farmers organization, NGOs working on conservation of monuments in Afghanistan.

[5] Jawed, S. 'The Rehabilitation of the Musallah Complex in Herat Begins' Society for the Preservation of Afghanistan's Cultural Heritage (SPACH) newsletter, Issue 7, Jul. 2001, Islamabad, p. 12-13.

[6] Ibid 1. P. 132.

[7] Van Eenhooge, D. 'Preliminary Report on the Archaeological Excavations at the Qala-I Ikhtiaruddin and the Madrassah of Sultan Hussein Baiqara, in Herat' UNESCO – UNDP 'Restoration of Monuments in Herat: Strengthening Government's capability for the preservation of Historical Monuments' Technical report, Paris 1981. Pp. 25-26.

[8] Ibid 4, p.26.

[9] See Appendix for the explanation about UTM.

[10] Leica Geosystems AG 'TPS Basic Series: User Manual TCR307', Leica, Heerbrugg 1999. p. 51.

[11] Ibid 4. p. 44.

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CURRICULUM VITAE

Mario Santana Quintero was born in Caracas (Venezuela) on June 13, 1970. He completed studies of architecture in 1994 at the Universidad Central de Venezuela. In 1997 he obtained the Master in Conservation of Historic Buildings and Tows (Cum Laude) at the R. Lemaire International Centre for Conservation (K.U. Leuven). The same year he was admitted in the doctoral programme at the K.U. Leuven with a four years doctoral research grant awarded by CONICIT-FUNDAYACUCHO (Venezuela). In 2002 a supplementary one year grant was awarded by the R. Lemaire Centre for Conservation (K.U. Leuven) for the completion of his PhD dissertation. Besides his doctoral research, he has been responsible for the Integration of digital documentation Techniques in the module IPW of the Master in conservation of historic buildings and towns (R. Lemaire Centre for Conservation). Furthermore, he has been working since 1999 as built heritage documentation consultant for UNESCO and the University of Aachen RWTH in different international projects in the Sultanate of Oman, Afghanistan, India, Kazakhstan, and Syria.

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