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A STUDY OF IMAGE QUALITY, AUTHENTICITY, AND METADATA CHARACTERISTICS OF PHOTOGRAMMETRIC THREE-DIMENSIONAL DATA IN CULTURAL HERITAGE DOMAIN

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ABSTRACT

This study aims to provide a deeper understanding of digital image quality, authenticity, and metadata issues of photogrammetry as a three-dimensional (3D) digitization technique in the cultural heritage domain. Photogrammetric image data characteristics are introduced for information professionals by analyzing features leading to the high-quality, accurate and well-defined three-dimensional data.

Qualitative methodology was employed based on an interpretivist approach. Both synchronous and asynchronous semi-structured interviews with open-ended questions were carried out with seven professionals in the field of photogrammetry, using chat and email as data collection techniques.

The findings of this study suggest that photogrammetry seems to be effective in reconstruction, preservation and visualization of cultural heritage objects because it can acquire the accurate 3D models in a cost effective way. It is shown that photogrammetry is an effective way to present a photo-realistic view for 3D architectures and artifacts.

Moreover, metadata usage in the cultural heritage photogrammetric data is beginning to emerge. In photogrammetry process, image metadata can preserve the original data which is used in the process of camera calibration and consequently building the 3D model.

Keywords: photogrammetry, cultural heritage, digital image, quality, authenticity, metadata

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DECLARATION

“I certify that all material in this dissertation which is not my own work has been identified and that no material is included for which a degree has previously been conferred upon me”

.... (signature of candidate)

Mehrnoosh Vahdat (submitted electronically)

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List of Abbreviations

2D = Two-Dimensional

3D = Three-Dimensional

ASPRS = American Society for Photogrammetry and Remote Sensing

CCD = Charge Coupled Devices

CAD = Computer-Aided Design

CAAD = Computer-Aided Architectural Design

DSLR = Digital Single Lens Reflex

EXIF = Exchangeable Image File Format (“Guidelines for handling”, 2009)

GIS = geographic information systems

GPS = Global Positioning System

IFD = Image File Directory

IP = Internet Protocol

IPTC = International Press Telecommunications Council – creator and maintainer of metadata standards (“Guidelines for handling”, 2009)

IPTC-IIM = Information Interchange Model – IPTC multimedia metadata standard (“Guidelines for handling”, 2009)

PSIR = Photoshop Image Resources

RMS = Root Mean Square

SLR = Single Lens Reflex

TIFF = Tagged Image File Format (“Guidelines for handling”, 2009)

XMP = Extensible Metadata Platform

Chapter 1: INTRODUCTION

1.1 Motivations

This research aims to address the image quality, authenticity, and metadata issues in photogrammetry as a three-dimensional (3D) digitization technique in the cultural heritage domain. Nowadays, 3D documents play an important role in digitization, documentation and simulation of cultural heritage objects because this type of data can represent very comprehensive information about an object. Although, unfortunately information professionals who deal with cultural heritage preservation in museums, libraries and cultural institutions are not fully aware of the significance of the 3D data and the role it can play in the user interaction with digital collections.

I often wonder how the information society will be in a few years when I see the 3D data being produced and used are increasing hugely. With the advancement of new technologies, 3D production has got easily accessible. In addition, by the initiation of social networks; building, interacting and manipulating a 3D world is not far from the imagination. It can be a challenge for information professionals to face massive 3D data-sets when "library users are probably more familiar and comfortable with interacting in 2D and 3D than librarians are" (Eden, 2005, p. 67), since 3D technological environment opens new avenues and enhancements for information organizations to present and manipulate information into new environments (Eden, 2005). For instance, Google Earth has started building a 3D map of the whole world by use of social network. It means that every user from any location can participate in 3D building of their city or hometown by employing user-friendly 3D modeling applications.

This introductory chapter provides an overview of photogrammetry and its role in cultural heritage and why it was chosen to be the object of study for this thesis. Subsequently, the chapter contains of the statement of the problem, research questions and a discussion of the methodology. Finally, this chapter ends with a brief overview of the limitations of this research.

The second chapter comprises the literature that has examined photogrammetry in cultural heritage as well as principles of this technique, image attributes and quality issues of photogrammetry. This section starts by explaining about information visualization and importance of 3D data in the information society as justification for photogrammetry and ends with an overview of research that has been conducted on metadata related to this field.

The third chapter is about the methodology has been applied for this research, data collection techniques, identifying the population, sampling and methods of data analysis that have been employed during the research. Full explanation of why these techniques and methods were chosen is discussed throughout the chapter.

Chapter four contains the results from the study. Themes related to the research questions are explored and discussed in the discussion. Finally, in the fifth chapter, research questions are answered, conclusions are drawn; implications of the study and topics for future research are suggested.

1.2 Photogrammetry Concept

The objectives of my research are to introduce photogrammetry as a 3D digitization technique (For further details see section 2.3: Photogrammetry) which can be effective in documentation and digitization of the cultural heritage theme and try to understand what the image requirements are in data quality and authenticity and what role metadata plays in this method.

Two major aspects are studied in this research. Firstly, photogrammetric image attributes and characteristics in a sense of quality authenticity and secondly, the metadata issue in photogrammetric images. In view of the fact that 3D data are growing in popularity in the field of digital collections by employing photogrammetry as a fundamental data collection technique, it is crucial for both professionals in photogrammetry and information professionals to know how metadata is effective in photogrammetric data usability.

1.2.1 Rational for Studying Photogrammetry in Cultural Heritage

Cultural heritage as a demonstration of past human custom and culture includes a wide variety of artifacts, monuments, historic buildings and archaeological sites. Unfortunately, cultural heritage sites around the world have gone through a lot of wars and natural disasters;

therefore, digitization and documentation of historic objects is important in this respect, as well there is an increasing movement to preserve and document our legacy in both national and international ways. In the approach put forward here, three-dimensional models and virtual content play a dominant role in the user interaction with digital collections, e-learning and even conservation or re-construction (Patias, 2006).

To take an example, the statue of the Great Buddha of Bamiyan in Afghanestan which was ruined by Taleban government military was reconstructed in 3D from images found on internet taken by tourists. Photogrammetric method was used for the computer reconstruction and used for a physical miniature replica (Grün, Remondino, & Zhang, 2004). Digital photogrammetry is a three-dimensional modeling method which uses images as a base to build the object. In contrast to the popularity of 3D laser scanners which are used for digitization of small museums artifacts, there have been just a few efforts in acquisition of full-size monuments and historic buildings. In particular, I will focus on the application of digital photogrammetry in cultural heritage domain since it has the capability of providing accurate and detailed 3D data in a cost-effective way.

1.2.2 Photogrammetric Image Data Quality

One of the issues has been tried to explore in this study is image quality by investigation of image characteristics and attributes which are used in photogrammetry. The issue of image quality is tightly correlated with truth or authenticity in visual evidence which is critical in cultural heritage domain. The current information environment is affected by inaccurate representations due to the availability of tools to manipulate digital images easily ranging from brightening colors, to retouching, inserting or deleting information that was never in the original image. In addition, it is very difficult or almost impossible in most cases to know from a digital image whether or not the content has been changed. Also there are challenges regarding the creation of digital images with a satisfactory quality from various tools (Terras, 2008).

In the photogrammetry concept, image data quality is associated with issues of display and measurement (For discussion of 'Quality authenticity' see sections 2.4.1 and 2.4.2). It can be more probable to gain the high precision, reliability and automation of the system when photographs are of the highest quality (“Basics of photogrammetry”, 2006). Various factors that play a dominant role in the level of images quality and authenticity are explored in this research.

1.2.3 Photogrammetric Metadata

Documentation and plans are critical ways in which the characteristics of cultural heritage sites can be reflected. Although, nowadays difficulties to obtain full documentation leads to irreversible damage and inappropriate restoration in the historic environments. An effective catalogue of properties along with associated metadata can make it possible to ascertain the possible existence of certain information and actions between the responsible organizations (Arayici, 2008). Cultural heritage domain is characterized by a large amount of 3D digital content and increased 3D digitization efforts because 3D models and virtual spaces have huge potential for improving the way people interact with museum collections and e-learning environments. With all the effort has been done, the technology of capturing and managing 3D content still entails lots of research effort in comparison to text- or image-oriented technology (Pitikakis et al., 2009).

In order to derive the metadata for cultural heritage 3D objects, semantic interpretation of the object regarding the history, structure and 3D geometry of the monument must be gained directly from an efficient 3D modeling procedure. Such a metadata standard can be particularly influential for monitoring, preservation and improving identification principles in digital documentation of cultural heritage sites (Styliadis et al., 2009). Image metadata in photogrammetry should cover the sufficient data that is employed in this technique. Since image metadata is interacting with its use, geographic data must be also covered in addition to other common metadata for images. For the reasons mentioned above, this research has attempted to examine the metadata issues that are critical in photogrammetry field.

1.3 Statement of the Problem

In a study of the foundation of 3D digital libraries, it is argued that the next major technological revolution will be affected by massive 3D data sets which will be produced with low-priced new technologies like 3D scanning and photogrammetry (Bustos et al., 2007). Production and dissemination of huge amounts of data without quality control and documentation policies can result in serious problems or damages for information management. Nowadays, 3D information is gaining more popularity among various kinds of users. For that reason, this study aims to provide a deeper understanding of some 3D data characteristics for information professionals by analyzing features leading to the high-quality, accurate and well-defined 3D data.

1.4 Research Questions

The following research questions are the focus points for the study:

1. How can photogrammetry be used in the cultural heritage domain?

2. How are quality and authenticity assessed in photogrammetric digital images?

3. What is the role of image metadata in photogrammetry?

The rationale behind the first question is to find out how photogrammetry can be helpful for cultural heritage objects' documentation, preservation, reconstruction and so on. Second question seeks about image characteristics in a sense of image quality and image data accuracy since the value of photogrammetry result relies on the pictures taken for 3D modeling. The third questions question tries to examine the metadata usability and features in photogrammetry.

1.5 Methodology

In brief, this study employs qualitative methodology based on an interpretivist approach. Both synchronous and asynchronous semi-structured interviews with open-ended questions were carried out, using chat and email as data collection techniques. Seven people were interviewed in total, three of them were interviewed via chat clients like Skype and Gtalk, in addition to four who requested to have discussion take place by emails. The process of identifying the population, sampling and interviewing with more thorough discussion of the methodology is explained in Chapter 3: Methodology. This chapter also covers an overview of data analysis approach.

1.6 Limitations

There are some limitations in the way of this study which should be considered as the factors influencing the scope of research. Firstly, the results from this study are explored in the field of photogrammetry in cultural heritage thus, may not applicable in other disciplines. Since the philosophical approach of this study is interpretive, the findings are not easily generalisable to other applications of photogrammetry.

Secondly, finding professionals to use as samples of this study was very difficult as is fully described in section 3.2: Sampling Strategy and Techniques, therefore due to the time constraints, only seven people from various professional backgrounds were interviewed and their opinions were analyzed and interpreted. It must be considered that having different samples for the study could change the results of the research.

Thirdly, Photogrammetry is a very technical 3D modeling technique which has been explored more from theoretical and general perspective of information management, thus there was the limitation of describing technical concepts in full account. These concepts tried to be explained in a way understandable for information professionals rather than other disciplines like geosciences or computer science.

Lastly, due to the time constraints, the intention of this study is to be a starting point for information professionals to consider the photogrammetric data in particular the concepts of image quality, authenticity, and metadata; that is why the concepts are in broad overview in this field. For instance, the study aims to cover the general idea of metadata issues of photogrammetry in the cultural heritage domain, but does not explore detailed metadata elements and standards form the technical perspective.

1.7 Chapter summary

This chapter has presented the foundation for this study. Initially, the motivations for this study were described; and then the rationale for studying photogrammetry in the cultural heritage domain in particular, issues of image quality and metadata were outlined. Next, the statement of the problem, research questions, and methodology were described. Finally, an overview of limitations of the study was described.

Chapter 2: LITERATURE REVIEW

This literature review presents a brief overview of significant issues regarding photogrammetry in the cultural heritage domain from the perspectives of image data quality and metadata. In order to place this research in the context of information management, the final structure follows a logical sequence from issues starting with a justification of information visualization and significance of three-dimensional data then moving on to the purpose of photogrammetry in information documentation particularly, in cultural heritage context. Subsequently, issues relevant to principles of photogrammetry including photography and geometry as well as quality and authenticity issues are explored. Finally, to narrow the focus of this study in the concept of information documentation, photogrammetric metadata issues along with the relevant existing literature are discussed.

In order to adequately examine the existing literature regarding photogrammetry in cultural heritage domain, I have elaborated a multi-pronged search strategy to investigate diverse sources of information:

The keywords: photogrammetry *OR* photogrammetric *OR* 3D imaging *OR* three dimensional *OR* spatial *OR* modeling *AND* cultural heritage *OR* architectural *OR* historic buildings *AND* digital image *OR* photo *OR* imagery *AND* quality *OR* attribute *OR* accuracy *OR* authenticity OR photo realistic *AND* metadata were used. I also searched for information visualization *OR* display *AND* 3D documentation *AND* GEO *OR* GIS *AND* 3D *OR* virtual museum. Some concepts and definitions were searched after interviews conducted which required proper explanation in the literature review to give an insight to the data analysis. My straightforward rationale for finding these concepts was on photogrammetry for instance: “camera calibration in photogrammetry”. The major attempt was to find the literature from books, full-text journal or conference articles published between 1995 and 2010. The year 1995 was used as a limiting date because photogrammetry emerged to the digital form in 1990s and considered for digital documentation mainly in the past decade by emerging of digital cameras and explosion of digital images on the Web.

The most relevant articles were found through databases *SpringerLink, Emerald, ScienceDirect, EBSCO, ACM Portal* and *Citeseer* were used. However, I did not find any better or relevant articles in *Proquest, ISI* or *JSTOR*. I also applied the same searching criteria to searches in Google Scholar and the E-LIS repository which Google Scholar provided several links to relevant case studies and conference proceedings from various websites. The review is not intended as a comprehensive survey of the existing literature due to the time limit of the study in contrast, intended to build up a well-explained relevant background for the research. The sources mainly derive from the Tallinn University electronic databases in addition to the World Wide Web. Since the research topic is new and challenging for professionals of the field, a lot of useful resources could be found through websites and blogs containing current experiences of the field. Additionally, to provide explanations and definitions of particular concepts, online dictionaries and glossaries mostly from photography and photogrammetry websites were used. I also looked through Google books, Tallinn Technical University Library sources and Ebrary that is a multidisciplinary e-book database of Tallinn University to and could use several useful books in the area of information visualization and photogrammetry.

After searches in the above-mentioned databases were completed, analytical approach was used while studying them to be able to obtain general concepts of the theme. I tried to discover common views and points of all in the respect of photogrammetric image issues to generate a well-defined structure for the literature review. Looking through each and every paper abstract, references and keywords in the beginning was effective to reach a comprehensive insight of pertinent topics. Next step was contributing article summaries, which were then sorted into various categories and placed under appropriate subheadings within the comprehensive final document. In the end, APA standard was applied for the citation.

2.1 Information Visualization

According to Chen (2002) information visualization can be defined as "A computer-aided process that aims to reveal insights into an abstract phenomenon by transforming abstract data into visual spatial forms" (p. 1). Information visualization tries to make use of human visual perception effectively in relation to various phenomena in order to construct a virtual, collaborative environment which people can interrelate with visualized information. Initially, the visual environments were just text-based but nowadays by emergence of spatial-visual interface including two and three-dimensional data, the virtual environment has gained more visual character (Chen, 2002).

Since information visualization is a multidisciplinary concept including different areas like scientific visualization, information retrieval, and geographic information systems (Chen, 2002) there is a need for a wide range of applications to support navigating and manipulating complex information spaces. Presenting 3D data requires a much richer visualization than 2D representation and the process of navigation for users is harder because in usual, the 3D data is heavier and more dense. Virtual reality provides a space for users to navigate through 3D data, explore and understand them in addition to control the behavior of visible objects and their behavior (Card, Mackinlay, & Shneiderman, 1999).

Chen (2004) argues that users retrieve the information more efficiently through the visual-spatial interfaces by their perceptual abilities than the traditional ones. Graphical displays of information by the use of psychological issues and human aspects of virtual interaction can make complex information more accessible and legible for people than textual or tabular data. But designing visualization systems which can provide composite information is not very easy. Like any other kinds of data, information design and organization can be difficult especially when it comes to visual display which needs to handle the important regions of the display and avoid cluttering (Chalmers, Ingram, & Pfranger, 1996).

2.1.1 Significance of Three-dimensional Data

Eden (2005) states that many information professionals are aware that the next generation web (the so-called semantic web) will include both visual and semantic data. 3D data mining, 3D visualization on the web, virtual reality navigation and using various techniques to handle 3D information spaces are some attributes of novel information environments that must be taken into consideration by librarians. Chen (2004) claims that people comprehend some sort of 3D information like graphs in 3D much better than their 2D display. In a study has done on 2D and 3D information user behavior on graphs showed that 3D performance was superior since the 3D condition let users move and rotate the graph thus more effective user interaction was obtained.

Three-dimensional data contains more comprehensive data about an object and can provide valuable information for users who intend to study an object in further details. The 3D data carries the shape, size and geometry of the object in addition to the visual appearance. Texture is an important feature of visual appearance for the 3D models (For further discussion of 'Texture' see section 2.3.2). Texture is defined as an image applied to a polygon in the 3D model to create the realistic appearance of a surface. Almost all the 3D modeling applications have an ability to texture the model; it can be done either by the use of the software features and available textures or by taking high quality pictures and applying them for texturing ("Texture", n.d.). Polygon is a two-sided, flat surface bound by at least three lines. Each 3D model constructed from combination of polygons as principles of an object shape. The object being low poly or high poly affects on the size of file contains the object since the more polygons the object has the denser the model is. Low poly means by means of a minimal number of edges and faces to limit file size and enlarge computer performance ("Modeling a city", n.d.).

Stuerzlinger (1999) claims that not many applications have attempted to store accurate data about surface appearance such as colors and textures. 3D visualization via presentation of CAD (computer aided design) data can describe the geometry of the object precisely but providing accurate data about surface appearance (such as color or texture) is challenging. Consequently, visualization of the object would contain geometric structure which does not match the visual appearance. A common way of texture building is to take photos of the object in a way that can capture all visible surfaces of the object that requires finding good viewpoints for this task.

2.1.2 Three-dimensional Modeling Techniques

There are various ways of 3D data acquisitions depending on the data usability. In cultural heritage sites regarding the architectures and buildings, 3D data can be attained using terrestrial and non terrestrial techniques. Meng and Forberg (2005) describe a wide variety of techniques are applied in the field such as, aerial photogrammetry, aerial laser scanning, terrestrial measurement, close range photogrammetry, terrestrial laser scanning and official cadastral information. Since the professionals who deal with photogrammetry are usually aware of other techniques and might acquire the 3D model by combining different methods, having an explanation of various terms plays an important role in understanding the photogrammetry context and further analysis. These techniques are therefore defined below:

2.1.2.1 Aerial photogrammetry

Aerial photogrammetry is a cost-effective technique to take aerial photos from roof landscapes and ground texture of a large district. Resolution of these photos is limited thus cannot detect detailed visual data like small roof elements or elements that are not clear from the air (Meng & Forberg, 2005).

2.1.2.2 Aerial laser scanning

According to Ding (2000) this technique is based on LIDAR (LIght Detection And Ranging) technology which is more expensive than photogrammetric methods, acquire the 3D model straightly from a point cloud for uncomplicated data processing (quoted. in Meng & Forberg, 2005). The process of detection and identification of an object to generate the image data (e.g. aerial photography and satellite imagery) is called remote as the object and sensor are not connected directly (“Remote sensing”, n.d.).

2.1.2.3 Terrestrial measurement

To acquire more detailed data for 3D models; terrestrial measurement is used as a complementary method when specific points cannot be captured from the air. This technique usually provides precise information but needs a lot of input since terrestrial details are usually chosen and measured on site (Meng & Forberg, 2005).

2.1.2.4 Close range photogrammetry

According to Meng and Forberg (2005), close range photogrammetry is an economic method to obtain geometric information, like size, position, and shape of any object and texture of facade. To achieve the 3D result, it defines edges and points on building surfaces in various images together with all the available measurements.

2.1.2.5 Terrestrial laser scanning

Terrestrial laser scanning or ground-based LIDAR technology is quite expensive and the process takes a large capacity since it contains many measurement points. This technique usually captures complex and irregular sort of objects and does not attain as high a precision as close range photogrammetry or terrestrial measurement (Meng & Forberg, 2005).

Sensor orientation modeling: as a requirement for the georeferencing of satellite images or 3D object reconstruction from satellite stereo pairs includes the Rigorous Sensor Model (RSM) which is able to define the imaging geometry between the image space and object space (Chen, Teo, & Liu, 2006). Meng and Forberg (2005) argue that this method provides the most precise geometrical processing of satellite images.

In summary, all of the techniques described above can be combined to create photorealistic 3D building models or be used individually and construct a model which is based on the object attributes and user needs of data accuracy.

2.2 Cultural Heritage

Digitizing cultural heritage can face a lot of challenges since there are a lot of sites which have been evolved over time and virtual heritage aims to reconstruct them. To reach this goal, the object in its current situation can be digitized in 3D using digital cameras or laser scanners and therefore the parts which do not exist anymore or have changed must be obtained from available resources like old paintings or photos or any record including information about it then, modeled by an appropriate application. If the data obtained are sufficiently accurate, the models can be assembled together with the ones representing the current shape to create the site as it initially was and at different periods in its history (El-Hakim et al., 2006). Cultural heritage digitization and documentation seems to be more challenging than other photogrammetric applications because of the different quality and resolution requirements for the various kinds of objects having different sizes, from building a virtual vase museum to modeling the historic part of a town.

2.2.1 Photogrammetry in Cultural Heritage

There have been increasing efforts in the employment of photogrammetry as a tool for documentation of cultural heritage objects and sites. Due to the fact that cultural heritage documentation requires providing information from various resources and accurate analysis, there are various literatures in the cultural heritage domain which look at 3D digitization techniques including photogrammetry and try to compare them to understand the usability of these methods in the means of cultural heritage objects requirements. Some examples of these literatures therefore are explored here:

Lerma et al. (2010) conducted a case study on combining 3D measuring techniques in order to yield a high-resolution photo-realistic 3D model of Cave of Parpalló engravings. In this attempt, photogrammetry has been used as a mature technique for the extraction of 3D information from images to provide photo-realistic outputs. Yastikli (2007) argues that "precise documentation of cultural heritage status is essential for its protection and scientific studies carried out during the restoration and renovation process. The close range photogrammetry has been used successfully for documentation of cultural heritage" (p.423). An example of modeling cultural heritage architecture by employing the close range photogrammetry technique is presented in (Fig. 1).

With recent developments in computer and information technologies, digital photogrammetry offers new opportunities like direct data acquisition, quality control, high potential for automation, and measurement characteristics by use of Charge Coupled Devices (CCD cameras) or scanned images. Dorffner et al. (2000) conducted a study of the new possibilities for documentation and investigations of historic buildings utilizing the digital applications in photogrammetry. A 3D photo-model of Hagia Sophia dome in Istanbul was generated and stored with the help of photogrammetric methods and Hagia-Sophia Information System created by collecting all information about the building. Furthermore, the potential of photogrammetric vision techniques in building accurate 3D models of small objects in museums have been studied in some case studies. For instance, a set of Greek vases in the Perseus digital library were digitized in 3D from the 2D photographs and were displayed in a virtual space. A comparison between the 3D digital library to the conventional interface showed that a 3D environment can offer better context to the users since they could carry out the tasks 33% better and almost three times faster (Shiaw, Jacob, & Crane, 2004).

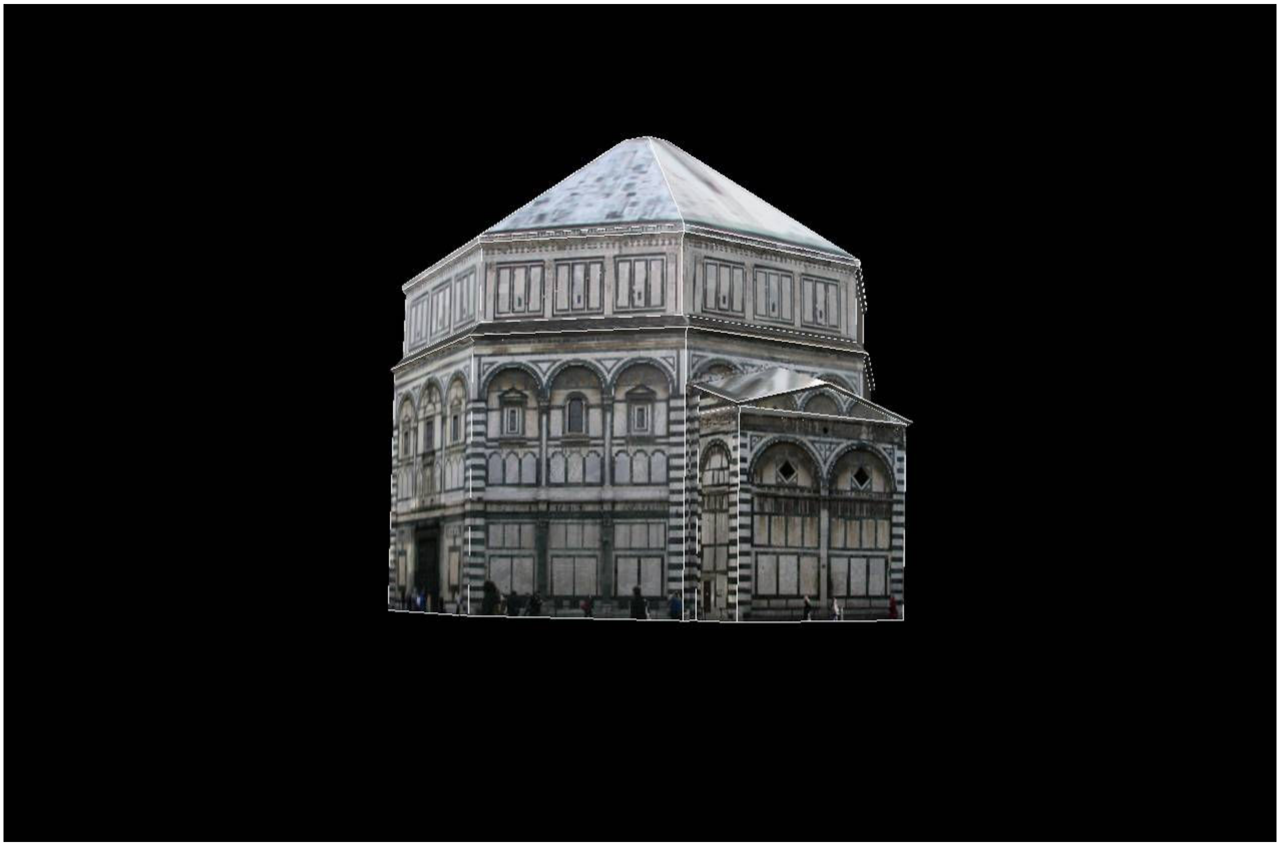

Figure 1: A screenshot of 3D model of Battistero di San Giovanni building in Florence, Italy modeled by researcher using PhotoModeler – example of a photogrammetric 3D model in cultural heritage domain

2.2.2 Architectural Photogrammetry

Architectural photogrammetry initially was established for the documentation of buildings by the German architect A. Meydenbauer in 1858. The first archaeological site recorded photogrammetrically was the ancient ruins of Persepolis located in Iran the city of Shiraz (Patias, 2006). Koutsoudis, Arnaoutoglou, & Chamzas (2007) describe a project on 3D reconstruction of a small part of old city of Xanthi in Greece and explore the 3D virtual reconstruction of historic buildings for preservation and entertainment purposes. In this domain, the study declares that "Interactive 3D representations consist of an important alternative medium for promoting cultural heritage. It is also a fact that 3D reconstructions offer a more data efficient approach than photographs and video sequences" (p. 30).

Photogrammetry includes two different methods when it comes to architectural, archaeological and other historical sites: Aerial photogrammetry and close-range photogrammetry. The methodology of architectural or terrestrial photogrammetry has changed considerably by improvement of photographic acquisitions_(Henke & Grussenmayer, 2002). Styliadis (2007) presents the processing steps for architectural photogrammetry 3D modeling in (Fig. 2).

"New technologies and techniques for data acquisition (CCD cameras, Photo-CD, photoscanners), data processing (computer vision), structuring and representation (CAD, simulation, animation, visualization) and archiving, retrieval and analysis (spatial information systems) are leading to novel systems, processing methods and results" (Henke & Grussenmayer, 2002, P .1). Improvement of these methods plays an important role in preserving and monitoring of cultural heritage object or sites. Development of CCD sensors which are used mainly in photogrammetric applications is strongly connected to the progress of digital image acquisition and consequently its advantages affects on photogrammetric applications. Some of the advantages are: potential of online processing and automation, high geometric features, direct quality control of images, and low-cost technology. Today having access to the high-resolution digital cameras in photogrammetry has led to the fast and easy image acquisition. Such cameras can be explained as a mixture of a traditional SLR (Single Lens Reflex) camera with a high resolution CCD sensor replacing the film and digital image can be stored directly in the camera memory, be transferred immediately to a computer, and processed for a desired quality (Henke & Grussenmayer, 2002). "DSLR stands for Digital Single Lens Reflex. This is the digital equivalent of a SLR camera. The difference between this and a traditional SLR is that a DSLR doesn't need film. The photograph is recorded on a digital image sensor and saved onto a memory card" ("Glossary of digital photography", n.d.). In addition, DSLRs feature allows accurate preview of depth of field and using a variety of interchangeable lenses; that is why DSLRs are often ideal for professional photographers ("NSL photography's glossary", 2008).

Karras et al. (2001) in a study of architectural photogrammetry in the visualization of two large ancient towers in Greece, stress that accuracy comes first indeed in this context. For that reason, acquiring precise 3D models and geometry can be as critical as visual quality and needs to produce accurate mappings under strict qualifications along with the photo-textured 3D models in architecture and archaeology. The exceptional point of such a research can be identified for its accuracy assessment.

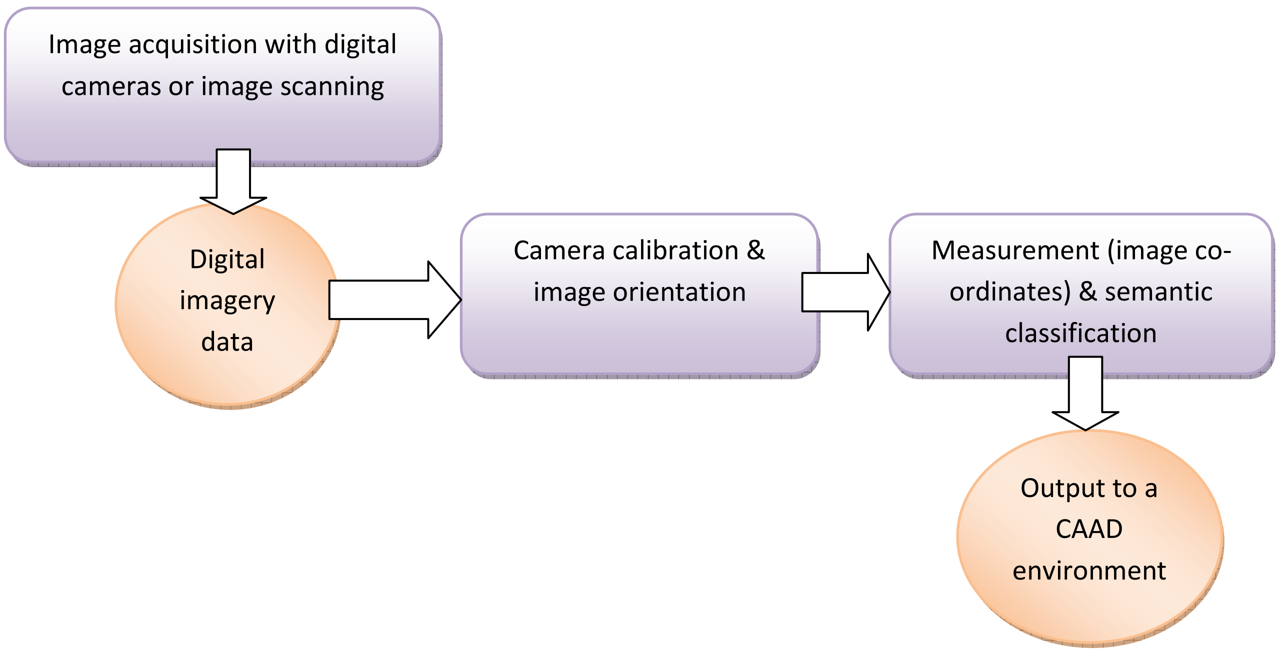

Figure 2: The processing steps for 3D modeling using the digital architectural photogrammetry technique (Styliadis, 2007).

2.3 Photogrammetry

Photogrammetry is defined as a branch of remote sensing that is the process of gathering information about an object without any direct physical contact with the object. Seen this way, photogrammetry is a 3-dimensional coordinate measuring technique that performs the processes of recording, measuring, and interpreting photographic images as the fundamental medium for measurement. Primarily, photogrammetric methods and technologies assisted the production of maps and geographic databases from aerial photographs or by use of photographic film. It can also represent the principal means of generating data for GIS which utilizes both interpretive and mensuration methods ("Guidelines for procurement", 2008).

Photogrammetry technique employs triangulation as a principle of mensuration. By taking photographs from at least two different locations, it can formulate an automatic individual point which is alike or homologous in the two (or several) images. Digital photogrammetry tries to determine the intersected lines of sight generated from points on the object to produce the three-dimensional coordinates of the points of interest (Paparoditis, & Dissard, 2002). To simplify it, this process requires at least two photos from one facade of an object with different angles to be able to determine the similar points of the object in both photographs and produce analogous lines out of them. By performing automatic algorithm, images are oriented and 3D result will be merged out.

2.3.1 Traditional Photogrammetry

The invention of Photogrammetry and photography go back to the same period of time and Aimé Laussedat (1819-1907) is well-known for the 'father of photogrammetry'. At the start of using this method, photogrammetric instruments and techniques were mainly expensive thus just specialists in the area and photogrammetrists (For definition of 'Photogrammetrist' see Appendix 3.) working in the national cartographic institutions were the main group who has been using it for about 150 years. By emergence of cheaper technologies and better computer facilities, the situation has changed hastily in the early 1990s (Burtch, 2004).

2.3.2 Digital Photogrammetry

Photogrammetry has undergone a notable development in recent years with its transformation into 'digital photogrammetry'. Some major features of digital photogrammetry are as follows:

- Automation

Digital tools and technologies were comprehensively beneficial for photogrammetric workstations since they could improve the automation of the processes and can be compatible with classic instruments in terms of quality and fidelity. Using digital automatic methods like real-time image management, digital color cameras and different kinds of scanners cut costs considerably and decreased processing time in a way that it can provide final products under the firm time requirements (Kasser & Egels, 2001).

- Versatility

Using new methods and computer technologies were much more user-friendly than traditional techniques; as a result it has been possible to carry out photogrammetric work without being dependant on photogrammetrists because automatic competences of software can help users to provide a good result even though the person is not expert enough in the field (Kasser & Egels, 2001). Compared to the other techniques, photogrammetry consists of some outstanding points like provision of large amount of data from various scales and resolutions which can contain whole areas or single objects, and can be based on photogrammetric measurements or on combinations with other types of measurements (Patias, 2006).

- Accuracy

Photogrammetry has always been a technique that provides accurate, detailed, 3D data in a cost-effective way. The data provided by photogrammetry can be very accurate since the procedure is regularly monitored and checked to reach the desirable accuracy and precision (Patias, 2006).

- Texture

This method can acquire textured 3D data and reconstructs the 3D surface of a whole area, city, or small archaeological artifact in a detailed and accurate way with a very natural look since texture data is based upon images of the objects. Texture carries geometry, high resolution and detailed data which are processed by increasingly effective automatic procedures (Patias, 2006) (For further discussion of 'Texture' see section 2.1.1.)

- Geo-referencing Capabilities

Photogrammetry can provide geo-referenced data since the metric characteristics of the data refer to real-world geometry and facilitate the ability to extract indirect measurements any time after collecting data and leaving the object (Patias, 2006). Geo-reference is an activity in relation to imagery, feature data and information with a location in physical space which determines and establishes the association of geographical features to map projections or coordinate systems (“Guidelines for procurement”, 2008).

Natural Resources Canada (2001) describes a system that provides reliable location information and accurate geodetic data for any point or object on the Earth that is called Global Positioning System (GPS). It is a surveying method that makes use of a set of twenty four satellites in a high geostationary position above the Earth. They can measure the distance from the point on Earth to three or more orbiting satellites and determine it through the geometric calculations of triangulation (quoted. in “Photogrammetric terms”, 2006)

- Stereo-viewing Capabilities

Another feature of photogrammetry is provision of stereo-viewing capabilities of the 3D data. This technique uses stereoscopic images as a unique characteristic of photogrammetric data (Patias, 2006). 3D photography or stereoscopic imaging is used in photogrammetry and can be explained as a technique to create a 3D illusion of depth from two-dimensional data like photograph or movie. The method provides two diverse images, representing two perspectives of the similar object, with a slight deviation similar to the perspectives that both eyes naturally receive in binocular vision and depth perception can be created (“3D photography”, n.d.).

- Metadata

The last but not least feature of photogrammetry is the ability to provide Metadata. “Metadata, refers to information about the data. Metadata is valuable, since they can be used for tracing down original sources, acquisition times, qualities, metrics, and even ownership” (Patias, 2006, p. 2). This feature will be explained further in section 2.5.

2.3.3 Principles of Photogrammetry

Photography and metrology are the basics of photogrammetry. Photography explains the photographic principles in photogrammetry, whereas Metrology describes the techniques involved in producing three-dimensional coordinates from images. Since the photogrammetric process is mainly independent of the image type, the common physical features of the data acquisition in digital photogrammetry has been taken into consideration (“Basics of photogrammetry”, 2006)

2.4 Quality Authenticity

Image characteristics and attributes are certainly crucial in photogrammetry quality and authenticity; because digital images are the basis of the photogrammetric result. Image quality accuracy in this domain needs to be explored from two major views. Firstly, from visual appearance point of view since photos are like texture in the resulting 3D model thus, it covers the discussion about photography issues to acquire the high-quality images. Secondly, from measurement point of view which means photographs must be taken in a proper way with accurate camera calibration and orientation.

2.4.1 Quality Authenticity in Photography

In the sense of image quality for visual appearance, the digital images produded should have constantly the best possible quality. Further research is needed to be carried out on measuring and perceiving digital image quality. “Quality can be defined as a sense of fitness for purpose. In the case of images, quality can be assessed by considering how effective the image is in communicating its intended purpose or message to the viewer. An image of poor quality may degrade the effectiveness of communication, but what message that image was to portray can only be decided by the creator and deciphered by the user” (Terras, 2008, p. 191). According to MacDonald and Jacobsen (2006), quality can be assessed by how precisely the image reflects the original object and the correlation between the surrogate and the original. Issues such as lighting and viewing geometry; the device that the image is showed on (includes the issues of resolution and color representation); attributes of image like sharpness, noise and meaningful content are effective on the visual presentation observed in its environment (quoted. in Terras, 2008).

There are several factors which play a dominant role in the images efficiency level as of the principals of photogrammetry:

2.4.1.1 Field of View

The camera's field of view determines how much of the area in front of it can be covered by the camera lens. It is correlated with the focal length of the lens and the size of digital sensor. In general, there is a kind of transaction between the field of view of a lens and accuracy. There is also a discussion about wider-angle lenses which are less accurate due to the distortion they create on images (“Basics of photogrammetry”, 2006). Lens distortion is one of the important issues in taking photos which is caused by the instability of the camera lens at the time of data capture. The positional accuracy of the image points is less reliable when lens distortion happens (“Photogrammetric terms”, 2006). Focal length is defined as the distance calculated when the lens is focused at infinity, between the film plane and the focal point (optical centre of the lens). The right focal point can be determined as the position of best focus for infinity (“The photographic glossary”, n.d.).

2.4.1.2 Focusing

Sharpness of a picture is dependent on the depth of focus and this functionality relies on many factors including: the focal length of the lens, the format size, the distance between the camera and the object, the object size, and the f-number of lens (“Basics of photogrammetry”, 2006). F-number or focal ratio measures the camera lens speed and describes the relative size of the lens aperture (Lynch-Johnt, & Perkins, 2008).

2.4.1.3 Exposure

According to Lynch-Johnt and Perkins (2008), exposure is the total amount of light that strikes the surface of photographic medium (photographic film or image sensor) during the process of taking a photograph. For photogrammetry purposes, it is better to set the targets bright and the background dim. For the target exposure, using flash power can be useful although, it depends on the object location being indoor or outdoor while the background exposure is determined by the ambient illumination. To remove the background exposure which leads to measure the target easier, controlling the shutter time and distance between the camera and object are critical (“Basics of photogrammetry”, 2006). When the image is over exposed or under exposed, it can be fixed through different applications.

2.4.1.4 Lighting

Controlling the lighting conditions play an important role in reconstructing the appearance properties of an object from photographs although the kind of lighting technique can differ from one photo to another based on the requirements of image use. For example, a light source where all light is emitted from a single point casts very hard shadows whereas constant and diffuse lighting is ideal to capture the color of an object and give the image a flat looking view since it omits the presence of shadows. The lighting situation is also affected by the surrounding of an object. If the object has a reflecting surface it affects on the light and color viewed on the picture thus, to prevent this problem the object can be set with a dark surrounding to absorb the redundant light and get a diffuse lighting (Lensch et al., 2001). "Diffuse lighting is lighting that is low or moderate in contrast; an overcast day is a good example" ("The photographic glossary" n.d.)

2.4.1.5 Color

Another concern in image data representation is the issue of color accuracy in reproductions. The discussion of color presentation is very complex and cannot be studied here in full account but color management must be taken seriously since color often imparts important information in cultural heritage objects and that is why color precision is central to the usefulness of images in photogrammetric models. for example, due to the difficulties with capturing color and lighting data, it is challenging to reproduce colors on different systems and devices to obtain the similar colors on camera, monitor screen, scanner and so on (Terras, 2008). "One of the most common ISO colour management standards (although most people don't realize it is actually an official standard) is known as IT8, which covers a set of standards produced from 1993 onwards that controls colour specifications and aids in calibration"(Terras, 2008, p. 189).

To sum up, Image quality includes the issues of fidelity, usefulness and the perceived quality and authenticity of the image data which should be double-checked with the original object due to eliminate the technical errors, color disparity and optimization for different viewing environments.

2.4.2 Quality Authenticity in Metrology

Accuracy has been argued regarding the both principals of photogrammetry. The previous section discussed the truthfulness of images in the context of image quality based on image characteristics itself. To continue this issue in further details, accuracy of 3D model which is emerged from 2D images in photogrammetry should be taken into consideration.

From the photogrammetry viewpoint, accuracy can be defined as "The degree of conformity of a measured or calculated value compared to the actual value. Accuracy relates to the quality of a result and is distinguished from precision, which relates to the quality of the operation by which the result is obtained" ("Guidelines for procurement", 2008, p. 1363). To gain the desirable accuracy in addition to the quality of images the camera position and measurement is critical to be capable of acquiring the 3D model with exact size and angles.

As mentioned earlier metrology is another principle of photogrammetry which reconstructs the 3D object by means of measuring two or several images. This feature applies triangulation for this aim thus; it needs two positions for camera to take two distinct views of the object. As a result, the location of a coordinate point can be computed and 3D coordinate intersection of views can be found. By triangulation of a set of points and determining their precise location in space, camera position and aiming angles can be concluded which is called the 'orientation' (Beraldin, 2004). "Orientation is the position of the camera or satellite as it captured the image. Usually represented by six coordinates: X, Y, Z, Omega, Phi, and Kappa" ("Photogrammetric terms", 2006). Camera calibration is necessary to minimize 3D coordinates uncertainties by establishing the ultimate position and aiming (orientation) of the camera when a photograph is taken (Beraldin, 2004).

2.4.2.1 Camera Calibration

A very significant task in capturing accurate images and consequently to get appropriate result in photogrammetry is camera calibration. In order to use a setup for measurement and capture features of an object correctly, various aspects must be calibrated and the properties of the camera transformation which explains how an object is projected onto image plane of the camera can be recovered. For instance, a photometrical calibration is efficient to record accurate color information since pixel values in an image are not usually proportional to the amount of light hitting the camera sensor therefore, more accurate color can be captured by a proper device calibration which configures the camera and light source characteristics and generates a link to color management system (Lensch et al., 2001). Camera calibration also includes the process of finding some other true parameters of the camera like focal length, format size and principal point ("PhotoModeler", n.d.).

Remondino and Fraser (2006) claim that in the photogrammetric measurement, camera calibration is a crucial element for the extraction of precise and reliable 3D metric information from images. Precise camera calibration and orientation procedures help to identify the principal distance, major point offset and lens distortion parameters to get a consistent result. Another reason for camera calibration is to recover distortions which occur from a transformation between object space and image space which is supplied by image plane and lens in the camera (Clarke & Fryer, 1998). Image plane is defined as “the plane in which the image lies or is formed. It is perpendicular to the axis of the lens. A real image formed by a converging lens would be visible upon a screen placed in this plane” (“Glossary”, n.d.). The better the model’s parameters can be estimated in the process of lens calibration, the more closely the model would be conventional to reality since lenses are used to make exact measurements (Clarke & Fryer, 1998).

The displacements of points caused by tilt or perspective during the process of photogrammetry result in a type of image called orthophotograph . An orthophoto is georeferenced (For explanation of ‘Geo-reference’ see section 2.3.2.) and geometrically corrected to obtain a uniform scale and lack of distortion. Thus, it can be applied for accurate distance and location measurement (for aerial photography). When the orthophoto reaches the level of accuracy geometrically is called "orthorectified" (Rau, Chen, & Chen, 2002). An ortho-rectification method by using multi-view images can compensate for concealed areas and shadow effects in built-up areas and eliminates various error factors. Additionally, the generation of orthophotos from mathematical models of photogrammetry images is important and has applications to estimate the geometric distortions. Rectified imagery or photography is a more general term used to apply to imagery that has been corrected or adjusted by transformation and projection on to a common coordinate system (“Guidelines for procurement”, 2008). “By its very nature it provides a detailed photographic record of the subject at a point in time. Areas of surface requiring repair or conservation can easily be measured and calculated from the images” (Brennan, 2008).

2.5 Metadata

Every day, lots of data are produced and archived in many different formats thus, users face data interoperability and usability problems due to the variety of formats. Various organizations have produced different systems to handle the datasets leading to complicated locating and retrieving processes for the relevant datasets. That is why there is a vital need of an efficient system to discover the required information (Xu, Xinyan, & Daosheng, 2008). A study on cultural heritage digital documentation claims that "for the case of the incoherent metadata required in the enriched data based 3D modeling procedures, a new metadata structure must be introduced and thereafter documented as a metadata standard, since – according to the available literature – there is not a 3D modeling-based metadata standard available so far" (Styliadis et al., 2009, p. 297).

Pitikakis et al. (2009) explore the employment of semantics in 3D content modeling and processing in the Focus K3D project. The study claims that more and more cultural institutions need to be involved in this technological progress. A major challenge of these institutions to handle large 3D repositories would be providing effective content-based and semantic-based organization and searching of the repository. Content-based feature by giving structure helps the user navigate the collection and retrieve content of interest. For this purpose, features of the data must be defined and a general ontology of 3D attributes needs to be configured, which will allow a meaningful description of 3D content. To classify the 3D objects augmenting descriptive metadata by use of Semantic Web technologies would be beneficial for the content search and retrieval. This study discusses that creating an effective library of 3D content needs a lot of requirements and there are still many challenges toward research and technological development (Pitikakis et al., 2009).

Collection, study and preservation of cultural heritage digital images require the integration of large amount of data which can guarantee the integrity, identification, and persistence of the digital resource. In this regard, effective data and metadata standards for incorporating data-sets are important. The Walters Art Museum has addressed metadata development for Archimedes Palimpsest collection including spectral imaging of cultural objects. Exploring this study is rewarding, since the museum had an attempt to develop metadata to capture object identification, scientific, and geospatial information needed for long-term access and use of the objects. In the same way, photogrammetric digital image metadata in cultural heritage domain must include the common metadata of digital images in the area in addition to geospatial information (Emery, Toth, & Noel, 2009).

An overview of the current literature shows that there are metadata standards regarding to geographic data which is usually called GIS (geographic information systems) metadata that more or less is used for mapping data and Geosciences' purposes. In addition, there are metadata standards with extensions to cover the digital images field like Dublin Core (For definition of 'Dublin Core' see Appendix 3.), but there is not much effort on generating metadata standards on 3D modeling based on digital images which contains also geographic data. This metadata should contain any available metric and non-metric information recorded in the studied object (Styliadis et al., 2009).

Martynenko (2001) argues about the role of standardization in the area of creating the electronic geoinformation resources, which common metadata must reflect the most common characteristics of photogrammetric information. For instance, beside a comprehensive array of measurement data, common metadata must include the quality information like attributive and positional accuracy, data completeness, criteria of data generalization and lineage. According to Strynatka (2009), data interoperability is one of the major challenges in the world of photogrammetry and "a practical standard for photogrammetric metadata is inhibiting the adoption of stereo imagery as a data product" (Strynatka, 2009). There are a lot of efforts underway toward image georeferencing metadata (IGM) which is a set of schemas that define geopositioning metadata. He argues that the desirable service for any organization that deal with photogrammetric metadata, can include the initial IGM (initial metadata such as sensor name, image names, etc), triangulate the imagery (e.g. provide server-side georeferencing) and then return updated IGM results.

A study on geographic metadata states that the ISO19115 standard is inclusive of the geographic metadata and focuses on identification information, data quality information, spatial representation information, content, acquisition, requirements and extent information; in addition to citation and responsible party information. Data quality information is important because the quality control process needs the documented production information to carry out the general assessment of quality of the end products. As mentioned before, geospatial metadata norm is produced to facilitate data sharing for geospatial information such as ISO 19115 or CSDGM (content standard for digital geospatial metadata).There are geometric data involved in the process which its metadata of measuring process and the properties of the measuring equipment needs to be maintained with the raw data to support the production process (Xu, Xinyan, & Daosheng, 2008). "Raw files are the actual data taken directly from a digital camera's image sensor. They have not been processed by the camera at all. This means they are the purest image file possible in digital photography. Often, quite correctly, the terminology "digital negative" is used to describe them." In contrast to JPEG images, RAW files need specific software to be observed ("Glossary of digital", n.d.).

A survey on metadata standards requirements for Walters Art Museum collection shows that in addition to the core standardized metadata elements; the project needed the metadata with the flexibility to include a standard that describes spatial, scientific and content information. Thus the decision was made to employ the Dublin Core Metadata Element Set (DCMES) with extensions to Content Standard for Digital Geospatial Metadata (FGCD 1998) to incorporate the scientific description of image creation and spatial information. The standards define six type of information: "Identification information; Spatial data reference information; Imaging and spectral data reference information; Data type information; Data content information; and Metadata reference information" (Emery, Toth, & Noel, 2009, p. 344)

"Today, there are just a few approaches on metadata based heritage data modeling of excavation sites, historical monuments or artefacts. The most important of these approaches, which are based on XML, are the Object ID and Core Data Standard (by Getty Institute) and some extensions of Midas (for monument inventories)" (Styliadis et al., 2009, p. 298). In Styliadis' (2007) study on the digital documentation of historical Basilica, it is discussed about the metadata concept by identification of a hierarchy of modeling records to acquire the accessible metric information for truthful 3D modeling applications. In this regards, primary records identification contains both quantitative and qualitative data about the historic buildings and primary records maintenance includes the primary records in an archive to be developed.

2.6 Chapter Summary

The focus of this chapter is on introducing the concept of photogrammetry and its principles, the role it plays in cultural heritage documentation, in addition to image quality, authenticity and metadata applicable in photogrammetry context. These topics were discussed in order to provide the literature necessary to answer the research questions. As can be seen from the literature, there are various issues on the way of quality authenticity and metadata. Since photogrammetry is a multidisciplinary topic, it is hard to find a general agreement in the existing literature therefore this literature review tried to present a comprehensive context to explain the topics. Finally, metadata issues were explored which as the examples were mentioned in section 2.5 demonstrate, the research around this area is still in the early stage

Chapter 3: METHODOLOGY

This chapter presents a brief overview of significant issues regarding methodology applied in this study and justifications for the decisions made. Details of sampling techniques and sources of the population for research are described along with the procedures of conducting semi-structured interviews. A discussion of some advantages and disadvantages of applying text-based synchronous and asynchronous interviews as data collection technique are explored. Interview procedure and questions, ethical issues and finally, the techniques which are used to analyze the data are explained.

3.1 Methodology

This study employs qualitative method since it offers a deeper, more subjective approach to produce descriptive data such as people's lives, their stories, and behavior rather than results that are not obtained by statistical procedures. It can also be used to examine organizations, relationships, and social movements (Bouma & Atkinson, 1995). Qualitative method is appropriate for this study as, according to Pickard (2007), "When applying qualitative analysis the purpose is to generate a hypothesis based on the data gathered and interpretation of that data. It is applied in any study that focuses on emerging theory, using the inductive analysis process to arrive at an understanding of the phenomenon under investigation" (p. 239).

The philosophical stance for this study is an interpretive approach, since qualitative research is endlessly creative and interpretive. In such studies, the researcher does not just leave the field within mountains of empirical materials and then easily include his or her conclusions (Denzin & Lincoln, 2000). Willis, Jost and Nilakanta (2007) state that context is an essential aspect of understanding your data in interpretivism approach. Furthermore, the objectives of interpretivism looks for understanding of a particular context which is critical to the interpretation of the data gathered in any form of research. The question of interpreting data in context highlights the concern interpretivists have about the situatedness of knowledge; thus, the goal of interpretive research is an understanding of a particular situation or context much more than the discovery of universal laws or rules (Pp. 98-112).

Additionally, interpretivists believe that realities are multiple, constructed and holistic. There is no single reality; instead there are only complex, multiple realities of the individual. Reality is seen as individual and embedded in context, rather than universal in this point of view (Flick, 2002). Seen this way, this study is going to interpret individual experiences in the context of photogrammetry. Each and every participant are professionals interacting with this area from different aspects since they were selected from various backgrounds and work areas and their perceptions are different toward the image characteristics and metadata features in the photogrammetry technique.

3.2 Sampling Strategy and Techniques

The sampling of this study is purposive which has taken two approaches: "priori sampling, which establishes a sample framework before sampling begins; and snowball sampling, which takes an inductive approach to growing the sample as the research progresses" (Pickard, 2007, p. 64). The priori criteria was to find professionals and experienced people in the field, having in mind that the person is using photogrammetry along with the cultural heritage area. To reach this goal, sampling was done through searching various forums related to photogrammetry and 3D imaging, individual blogs, company websites and several social networks to find the most relevant people working in this area. Due to the time constraint of the research, authors of relevant articles were not contacted since it was preferable to use the articles' content in the literature review and discover different ideas by finding interviewees from other populations.

Alongside the purposive sampling, snowball sampling was applied as it was difficult to find the appropriate people in the field, so when a person is interviewed he can have a good understanding about who might be knowledgeable for this study among colleagues or community and might be interested in being interviewed. For instance, from the first interview who I found in the Google 3D warehouse (For explanation of '3D warehouse' see Table 2.), he suggested another person from the same community who is experienced in making architectural models as well.

As mentioned previously, the only criteria for sampling was any kind of experience with photogrammetry. Age, gender and nationality were not major concerns in the process of sampling since these limitations would not add any related data to this study. Furthermore, finding people with appropriate background was very challenging. More than thirty emails, forum comments and messages within the communities were sent to skilled people. Initially, the level of skill and their work area were studied out of comments, profiles, blogs and website pages then samples were selected quite confidently after studying them. With all the effort, it was very challenging to get responses from people who were willing to devote some time for an interview. The interview invitations were sent to each and every email considering the ethical issues (See an invitation sample attached in appendix 1).

To be able to find appropriate people for this study, I tried to read about their viewpoints in the case of blog or companies websites, considering their works, exploring the 3D models they had there and trying to observe the pictures and texture conditions. For example, Google Earth (For explanation of 'Google Earth' see Table 2.) website has a section named 3D Warehouse which contains architectural 3D models modeled by users, by looking closely in the 3D models by Google Earth application (Fig. 3.) which is downloadable from the website, I tried to find more cultural heritage sites models and zoom in to the maximum point and see the quality of pictures, for those pictures with natural and better quality, I started to read the explanation about each model, and see if there is any profile, website or more information about the producer background and profession . For example in (Fig. 4.), on the right and top of the screen shot, some information of 3D modeler like full profile and email address can be found. Carrying out the sampling in this way took a lot of time, although having such information about individuals was a help to seize the person interest since emails and messages were specifically oriented. For instance, I mentioned that I observed the modeler's work in a website and interested to know more about his activities.

3.2.1 Identifying the Population

Since in the interpretive approach participants influence the meaning and understanding developed by the research, using multiple sources of data are very important. Willis (2007) argues that "different participants have different views of what really happened thus, writeups of qualitative research often present more than one perspective" (p. 203). To find different sources for sampling, major groups were used as follows which was found initially by searching the general keywords of research like: photogrammetry OR 3D imaging OR

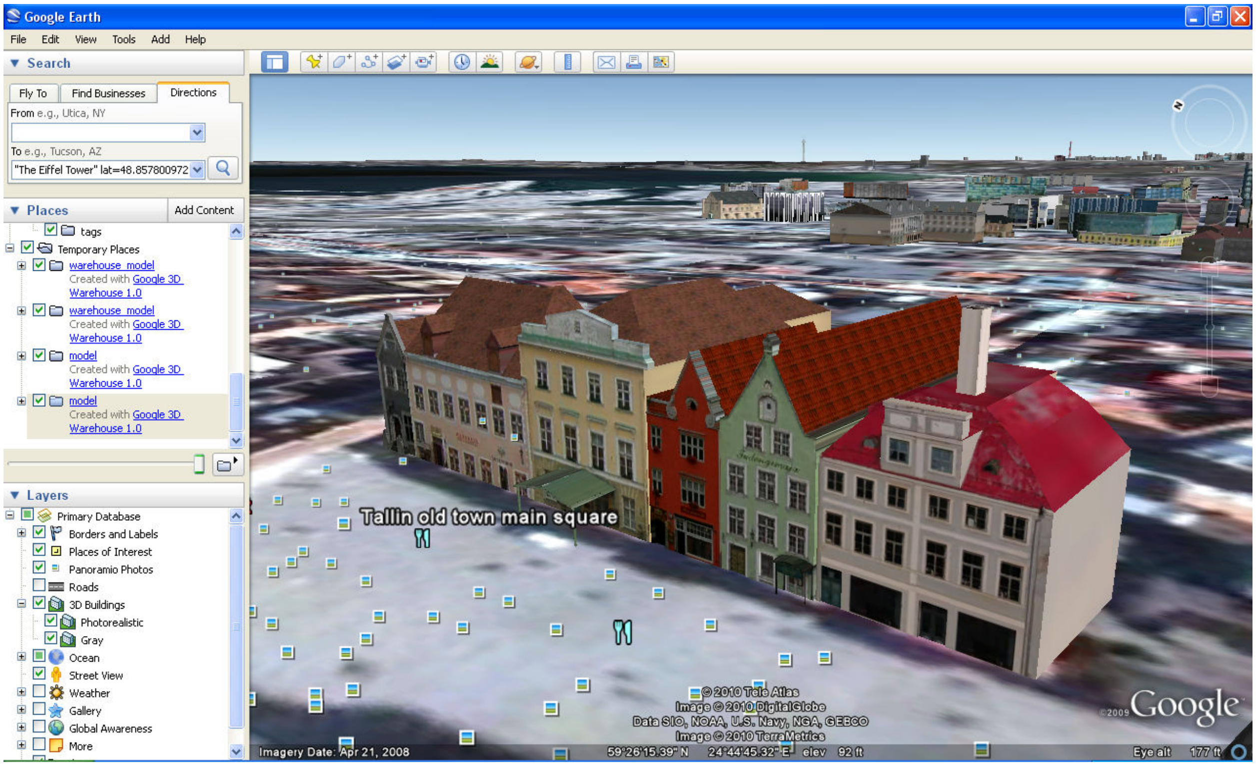

Figure 3: A screenshot of Google Earth from Tallinn Town hall square - example of photo-realistic 3D models

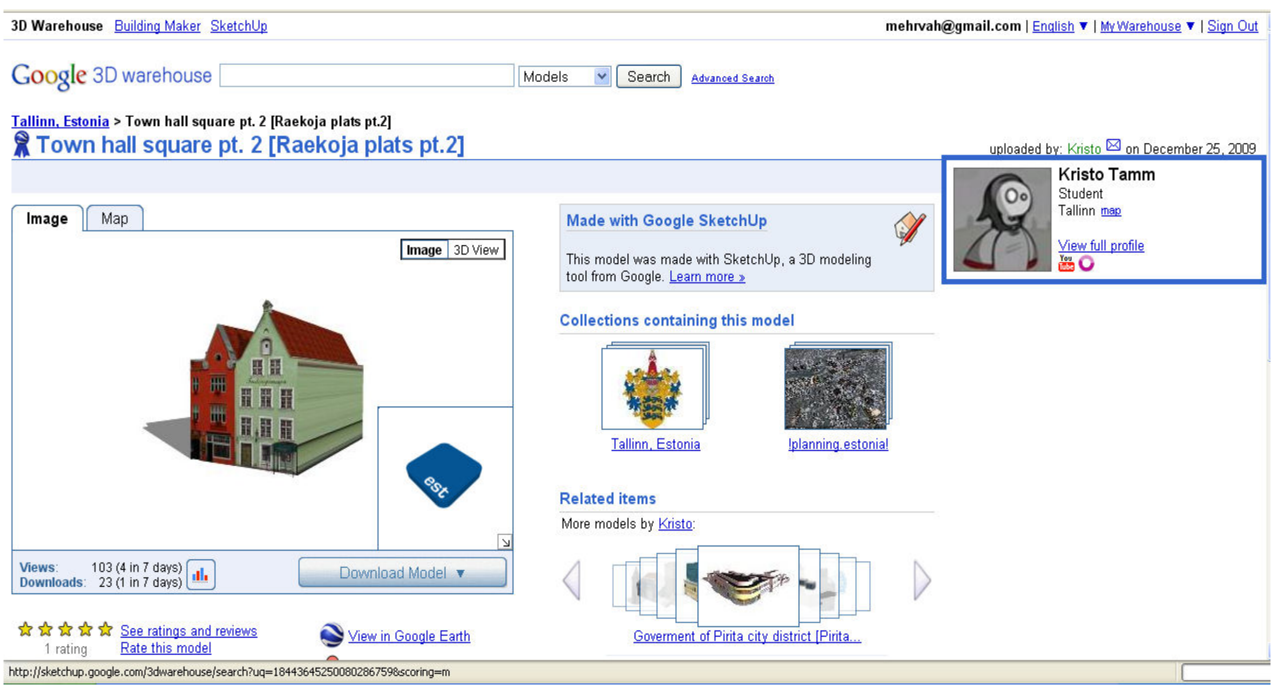

Figure 4: A screenshot of Google 3D warehouse from - example of user 3D profile (http://sketchup.google.com/3dwarehouse/)

terrestrial photogrammetry AND blog OR forum OR company, then from each one, I could find more relevant sources.

3.2.1.1 Forums

The forums have been used as sources of sampling are as follows:

-Google Earth community:

This forum includes a lot of discussion rooms for the users of Google Earth around any subject related to the Google Earth (“Google Earth Community”, n.d.). By searching the keyword “Photogrammetry”, discussions and users interested in this topic could be obtained.

- Photogrammetry forum:

Photogrammy.de is the website for PhotoModeler discussion forums, maintained by the PhotoModeler user community. The forums contain methods and tips for PhotoModeler and photogrammetry (“Photogrammy”, n.d.).

-The GIS forum:

The GIS Forum goal is to give GIS users a place to teach, learn, and explore the geospatial community in an interactive and social atmosphere (“The GIS Forum”, n.d.).

In each of these forums by going through more related forum discussions and read the comments, looking at the commenter’s profile if existed and observing the models they shared in the community, I sent the interview invitation either by using the forum private messaging system or emails to individuals. Finally, by registering in the forum, an invitation was sent as a separate topic named “Photogrammetry research” asking for participation in this research.

3.2.1.2 Photogrammetry Blogs

Blogs are good sources of finding the population because usually people are active in blogs, show interest in learning and research, and they are more willing to participate and help. I tried to navigate through two groups of blogs, individuals’ blogs which were retrieved by searching through Google blogs, Blogger or Blogspot and Wordpress; in addition to some applications and companies blogs like Google Sketchup Blog (For more information about 'Sketchup' see table 2).

3.2.1.3 Companies and Applications Websites

Companies which carry out photogrammetry projects or provide software and applications in this area are usually very useful because they are familiar with up to date information. Also, people who are working are professionals dealing with the new technology in the area. The newest projects and researches can be found along with the employers and researchers names and contacts.

3.2.1.4 Social Networks

-Flickr (www.flickr.com) is an online photo management and sharing application. By searching the word "photogrammetry" I could find some people having experiences in this area and sharing their photogrammic photos there.

-Linkedin (www.linkedin.com) is a business-oriented social networking site; by searching the same keyword, I could find some professionals resume and see if they are experienced in the area. Finding their contact information was done through searching their names on Google and finding their profiles in other sites; since Linkedin does not provide any contact information or messaging system for free users.

-The Google 3D Warehouse (http://sketchup.google.com/3dwarehouse) is a free, online repository where people can find, share, store, and collaborate on 3D models. This social network tool was a great help for the sampling since a lot of professionals share their 3D architectural models there. They can use either Sketchup or other application to build the 3D model and if their models get accepted, will share on the website. There are a lot of 3D models of cultural heritage sites can be obtained through this application. Most of them contain information about the model and contact information of producers in addition to their profiles or blogs (Fig. 4). Thus, can be used as a good starting place to find skilled modelers and select them based on cultural heritage models with high quality pictures.

3.3 Method of Data Collection

Due to the time constraints of this study, 6-8 people considered as a manageable number to do the interviews and analyze them. Among 7 number of respondents back from sent emails, three of them accepted to have chat interview and four did not have time for that but suggested to reply to the interview questions and continue the discussion via email. As the number of respondents was very limited, I took the advantage of the opportunity to discuss around the topic by exchanging emails.

Several various ways of data collection were considered as possible ways to suit the study purposes and objectives. Online semi-structured interviews, online synchronous and asynchronous interviews and discussion via exchanging emails were considered. Initially, online semi structured interview by using voice applications was selected; but after more investigation around the topic, semi structured chat interviews with open ended questions sounded better and more appropriate for this study. Denzin and Lincoln (2000) argue that: "The latest trends in interviewing have come some distance from structured questions; we have reached the point of interview as negotiated text. Ethnographers have realized for quite some time that researchers are not visible, neutral entities; rather, they are part of the interactions they seek to study and influence those interactions" (p. 663).

To name a critical reason for this decision, the people I would deal with are professionals and the field is very technical; having in mind that they name various frameworks, standards and guidelines, it could be very difficult to understand their statements from voice over IP (Internet protocol) interviews. In addition, since interviewees are from different countries with different accents and some names they might say, can be new and unfamiliar to me, chat interviews would match best for this kind of research because it can eliminate transcription error. "It is now possible to engage in "virtual interviewing" in which internet connections are used synchronously or asynchronously to obtain information. The advantages include low cost, as the result of no telephone or interviewer charges, and speed of return. Of course, face-to-face interaction is eliminated, as is the possibility, for both the interviewer and respondent, of reading nonverbal behavior or of curing from gender, race, age, class and other personal characteristics" (Denzin & Lincoln, 2000, p. 666).

In addition to previously mentioned advantages of this technique, there is no need to transcribe the interviews so it is an advantage for this study which has time constraint. However, the interviews take more time than voice over IP interviews. As mentioned before, the answers contains lots of technical information, in the way of chat interview respondents could share websites, pictures and files to help their statements become more clear. Another fact is that geography and interviewee location are not limiting in this method and anyone around the world can attend the interview.

The difficulty of this method is the lack of visual and vocal cues. When you write the question, the participant's reaction cannot be observed, for instance, if the person wants to take more time to answer the question with provision of more sentences, it is kind of challenging to be aware of it and wait for him rather than asking the next question. Another challenge is that, the interview itself takes more time than voice over IP interview. The whole interview was supposed to be done maximum half an hour, although the first one took almost an hour, but tried to organize the rest in 30 minutes as I had promised in the invitation. There is also a possibility of misunderstanding the text-based questions; to eliminate this problem, definitions and examples were provided in case the respondents ask for it. With all the drawbacks were mentioned while using this method, the advantages are critical since it would be obliging to gain thorough and accurate technical information during the interviews.

As mentioned before, some respondents were asked for doing the interview in a way that they can answer the questions by email and argue about different aspects by exchanging emails. Since the aim is to obtain in-depth qualitative data with a possibility of getting clarified information and asking follow-up questions if needed, email interviews was selected as a possible method. Additionally, due to the lack of time and contributors, this method was used to collect more data to this study. Regarding the email interviews, the advantage would be that respondents have more time to think about their experiences and answer the questions thoroughly. The disadvantage is that the discussion takes longer because exchanging emails are more time consuming than instant messages.

3.4 Interview Procedure

Over thirty emails and messages were sent to the potential respondents to invite them for the interview. Every invitation was different from one another considering the individual interests, background and skills; however had ethical issues in common. Most of emails had statements and comments about their skills and models if observed on the internet to affect their feeling of contribution to the study. The invitation email had an explanation of study goal besides the aspects of photogrammetry that research aims to look for: "I am currently conducting research on Photogrammetry as a 3D modeling technique for cultural heritage sites. I would like to study the metadata features, standards and effectiveness of pictures taken for photogrammetry and how they are associated with the image qualifications" (see Appendix 1)

In this procedure, pilot interview was not adopted since the number of responsive professionals was very limited and it was very hard to find a fair amount of interviewees, thus it preferred to use up all the potential interviews as the source of data for the study. For those who replied and were interested, an email to arrange the date and time of interview accompanying the ethical considerations of the research was sent back to them. Some of the respondents asked for the meaning of Metadata and image qualifications which were explained in a follow-up email. Some were not sure if their knowledge can be useful in this kind of research which I tried to assure them by some clarification: "The core concept of my research is around the general idea of photogrammetry, image qualifications in this technique, quality authenticity, and image metadata in photogrammetry. My research is not very technical, so your opinions toward each of these can be very helpful for my study. If you do not know about any of the questions you can ignore them or maybe explain why it is not important in your work area."

The interviews were carried out via Skype or Gtalk and for those who were willing to answer the questions via email, Gmail and forum private messaging system were used. The interviews conducted between April 21 and May 14, 2010; and for each took between 30 minutes and 1 hour. In the chat interviews, open-ended questions were asked based on the participants replies and knowledge of specific photogrammetric aspects; in the email interviews after getting the replies, more questions were asked to clarify the fuzzy features and get more information about some remarkable views. After getting responses and interview ended, each participant was asked to pass any contact of people they know working in the same area and can be helpful in my study. In addition, they were informed about the possibility of receiving an electronic copy of the entire thesis by the end of June 2010 if they are interested in greater detail.

3.4.1 Interview Questions

The interview questions primarily consist of a list of 16 questions (For the list of 'Interview Questions' see Appendix 2). Since the approach of interview is to apply the open-ended questions, the interview guide can be taken just as a principle. The flow of conversation did not firmly follow the order of questions which can be observed in the guideline and was dependant on the respondent. The number of questions decreased or increased based on the answers and the interviewee's knowledge around the area. Supplementary questions were asked to make the viewpoints more clear and some queries were omitted when were not applicable according to the person's reflection. For instance, some of the questions about Metadata and its standards were ignored in the interviews that participants stated they do not interact with Metadata issues in their experiences.

The questions attempted to answer the research questions outlined in Chapter 1: Introduction, which include:

1. How can photogrammetry be used in the cultural heritage domain?

2. How are quality and authenticity assessed in photogrammetric digital images?

3. What is the role of image metadata in photogrammetry?

The interview questions start with asking about the participant background. The first four questions attempts to learn about the professionals' skills and relation of their jobs or background to photogrammetry and how long they worked in this area. The fifth one asks about applicant perception of photogrammetry which can be critical in data analysis since photogrammetry has been used in multidisciplinary fields. Thus their viewpoints about it can explain the answers for the rest of questions. It also looks for their opinions in cultural heritage domain. The following two questions are about image characteristics and image data accuracy in this technique. By having "image qualifications" in the question, it means the attributes of a picture which can make the image qualified to be used in the photogrammetry and acquire the 3D model. For instance, if participants are aware of any criteria of image features or consider any at work, could name the guidelines, standards or their viewpoints. These can be any features like resolution, color, file format or any geographic data depending on their work area. Quality authenticity seeks the attributes of an image which leads to a more accurate 3D result.

The next eight questions are all about Metadata issues to learn if participants know about any metadata standards, or it can play an important role in photogrammetry and if yes, which metadata features they consider more in their work in the case of either data provision or retrieval. If a participant asked for its definition, metadata would define as: "Metadata, refers to information about the data. Metadata is valuable, since they can be used for tracing down original sources, acquisition times, qualities, metrics, and even ownership. Within image file formats, metadata can be stored within a variety of common metadata container formats such as Exif/TIFF IFDs, Adobe XMP, Photoshop Image Resources (PSIR) and IPTC-IIM" (Patias, 2006; "Guidelines for handling", 2009) (For definition of abbreviations see List of Abbreviations). Ultimately, the last question is a request for further opinions and comments.

3.5 Ethical Considerations

Ethical issues were considered to inform participants via email. The role of participants was notified in the invitation letter and they were fully informed about the research objectives. Their agreement to participate in this research (via email or forum messaging system) was notified as their informed consent. Confidentiality was declared in a follow-up email to respondents in order to assure them that no individual and institutional recognition will be published in the result. Besides, an agreement to set a date and time for the interview was requested. All the information respected to be anonymous, thus personal identifications were taken away in the process of data analysis. Furthermore, the respondents were informed that the whole research can be made available to them at the end of June, 2010.

3.6 Data Analysis

This study tried to analyze the data using the Miles and Huberman's data analysis model which define analysis as consisting of three flows of activity: data reduction, data display, and conclusion drawing/verification (Miles & Huberman, 1994)

After the data collection was done, for organizing the data, data reduction which is "the processing of selecting, focusing, simplifying, abstracting and transforming the data that appear in written-up field notes or transcriptions were carried out" (Miles & Huberman, 1994, p .10). During the data reduction it was decided which data chunks need to be coded or provided with memos or explanations and which to pull out. For those interviews which were done by chat, there were lots of data needed to be thrown away, some of the replies were repeating in various places that were organized using Microsoft Excel. For every interview a sheet was applied including two columns for questions and answers (see Fig. 5). The same task was done for the replies received by emails which data was more organized to begin with.

After each interview was structured in an Excel sheet, comments and notes were added to the answer's column by the use of commenting feature. Since almost all of the replies include lots of technical information and guidelines, supplementary remarks were necessary to convert raw notes into a coherent account. The additional information which drawn from various related online glossaries, websites, and articles in addition to explanatory remarks were added to each interview. Organizing data, commenting and coding by Excel in such a way applied which the final conclusions can be drawn and verified. A screenshot of the commenting process with the use of Excel is shown in the next page (Fig. 5).

Several numbers of concepts were highlighted in red as major codes that most of them are summarize of interview questions. Extra codes were added in red following the interview questions. A range of colors were used to differentiate the different types of answers based on their codes and themes. The same color was applied to indicate codes that belong to the similar themes (e.g. all codes that are about Metadata are blue). As mentioned earlier, the codes are meaningful names and keywords which address the interview questions and try to indicate the concepts and themes of this study. Appropriate labels were chosen for code topics associated with the answers' text. New codes were created for the text that did not fit into the

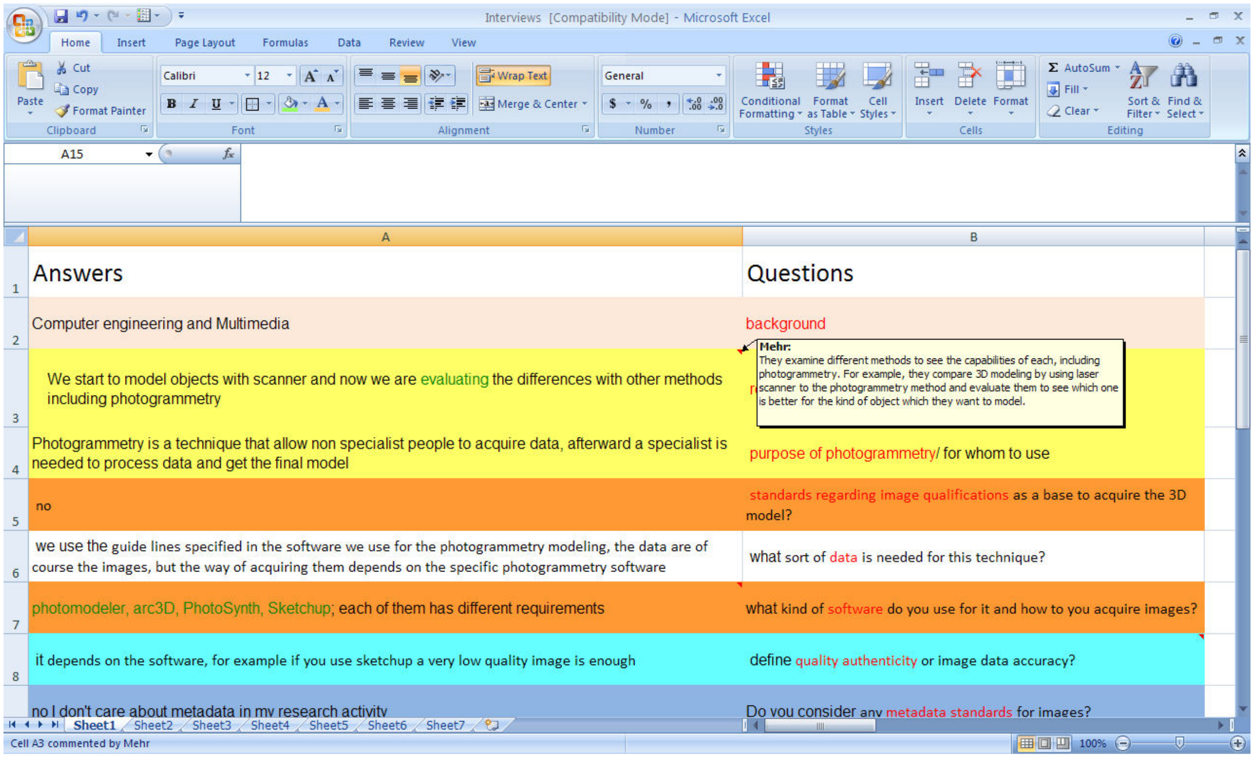

Figure 5: A screenshot of Microsoft Excel sheet – An example of commenting and coding the interviews

existing codes within the questions, then all the codes were categorized under four general themes which derived from research questions and identified by a color in the Excel file. These major themes are as follows:

1. Photogrammetry (Yellow): This theme includes all the codes regarding purpose of photogrammetry, users of photogrammetry, any related respondents' judgments toward photogrammetry, and the role it has in cultural heritage documentation.

2. Image quality characteristics (Orange): Standards regarding image characteristics and attributes in photogrammetry, the software they use (each software has own requirements and standards) and related techniques.

3. Quality authenticity (Green): Image data accuracy and quality assessment.

4. Metadata (blue): Metadata standards, contribution of image metadata into image quality, metadata usability, effect of metadata on the photogrammetry result, metadata for users.

Supplementary codes are assigned to include the background information of respondents which can play an important role in the data analysis whereas they do not address any research question directly. After codes and comments were assigned in this way, quotes with same color were gathered in a similar sheet of another Excel file considering a number for each respondent (Fig. 6.) to be able to reference the quotes after organizing them. When the statements with similar topic collected in the same place, comparing them and reaching a general overview on the theme got possible. For instance, (Fig. 6.) shows that the same themes about metadata that had been coded before in blue are collected in a sheet for further analysis.

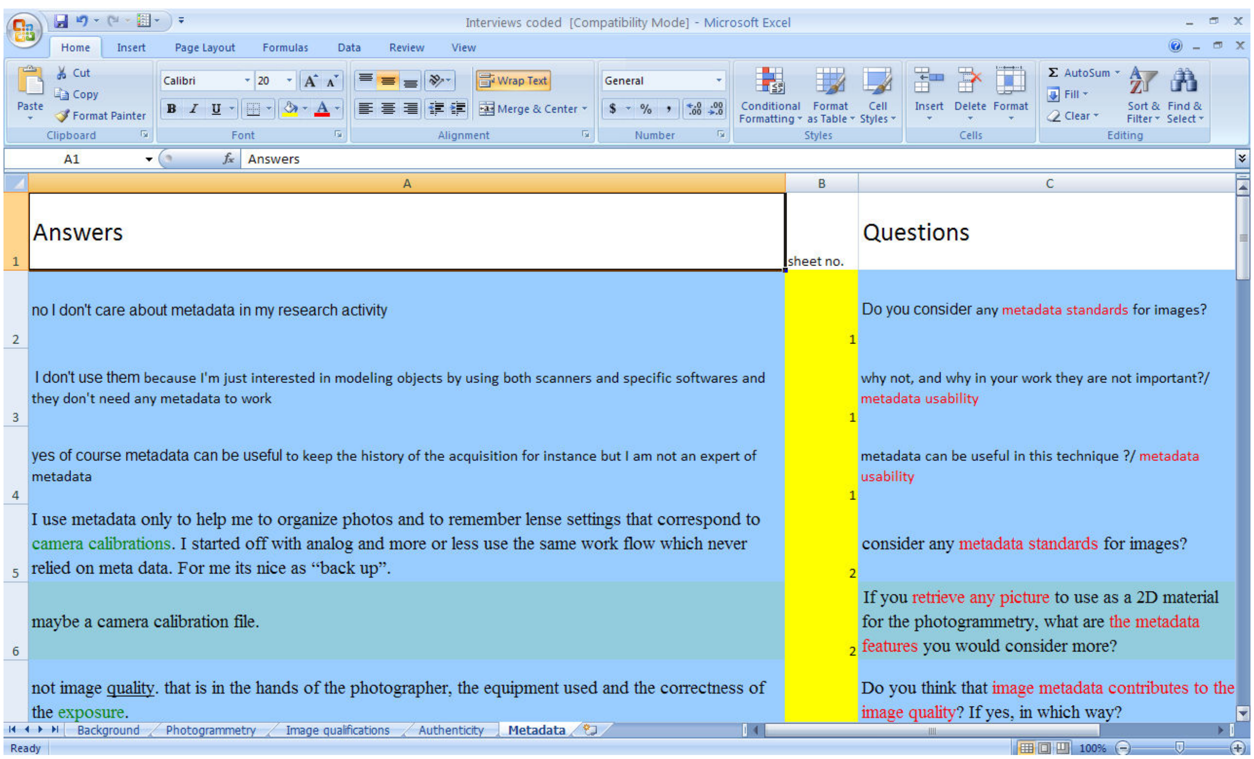

Figure 6: A screenshot of Microsoft Excel sheet – An example of data analysis by gathering similar themes

After completing the Excel files, analysis was performed by reading each file several times, highlighting the main points and trying to verifying the general and major statements. All the statements converted into a Microsoft Word file under relevant subjects, explanations about quotes were provided if needed, and conclusions were drowned which are clarified in the following chapter: Data Analysis.

3.7 Chapter Summary

The objective of this chapter is to describe and justify the research design and methodology of this research. The chapter begins with full account of methodology and philosophical stance was chosen to study this research topic. Qualitative method with an interpretive approach could suit best to answer the research questions. Subsequently, text-based semi-structured interviews were adopted as the data collection technique which is described in this chapter. In addition, the sources for identifying the population, interview procedure, interview questions, and ethical issues are discussed. Finally, data analysis procedure and techniques are depicted. The research result and findings are presented in the following chapter.

Chapter 4: DATA ANALYSIS AND DISCUSSION

This chapter presents the analysis of the data collected from interviews and discusses themes in response to the main research questions. As mentioned in Chapter 3: Data Analysis, four major topics are extracted from the interviews which describe photogrammetry in cultural heritage, image characteristics of this method, quality authenticity and metadata issues related to photogrammetry. Before exploring the major themes, this chapter begins with a brief overview on demographics of samples and their background information along with their experiences related to photogrammetry technique; since it is critical to analyze their responses from view point of their experiences toward this technique and why respondents utilize it. The subsequent sections explain the information collected from interviews by applying the literature from Chapter 2: Literature Review. Lastly, the Discussion explores the concepts from the major statements realized from answers and concludes the findings of data analysis.

Statements from respondents are extensively quoted in order to support the main themes. Extracts from interviews are quoted verbatim; only misspellings are specified with [sic] or where needed, terms were explained or referred to other sections in order to understand responses.

4.1 Background Information of Respondents

All the respondents are from various areas of engineering disciplines. Referring to the table 1, it can be seen that two people out of seven interviewees have the same background but different specializations and other five people are from various backgrounds. The point worth noting is that photogrammetry can be used in multidisciplinary areas and can be seen from a variety of viewpoints. Respondents were familiar with photogrammetry in different levels; some of them were newly experienced and some had worked in this area from two to eighteen years. The table below shows background areas of interviewees along with the abbreviations which are used as references for their quotes in this chapter.

Table 1: Respondents' professional background

Discipline	Respondent
Computer engineering and multimedia	COM1
Architecture	ARC1
Geodetic engineering/ Geomatics	GEO1
Mathematical background, 3D simulation/re-construction experience	MAT1
Civil engineering	CIV1
Mechanical engineering	MEC1
Computer Engineering, image processing and geometry processing (watermarking of 3D objects) and visual perception (for quality assessment of impaired 3D models)	COM2

4.1.1 Respondents' Background in Relation to Photogrammetry

As demonstrated in Table 1 on the previous section, respondents are from various educational and professional backgrounds therefore, they were asked to explain about the relation of their experiences to photogrammetry subjects and their opinions toward the role of photogrammetry in the cultural heritage documentation. It is important to explain the data chunks by referring to each and every professional's background to be able to understand the relation and usage of photogrammetry in the related disciplines. Here are examples of the reasons for using photogrammetry:

> "We start to model objects with scanner and now we are evaluating the differences with other methods including photogrammetry" (COM1).

To further discuss, companies that need to acquire 3D data usually need to evaluate different techniques to see which technique fits their needs and examine different methods to see the capabilities of each, including photogrammetry. For example, they compare 3D modeling by using laser scanner to the photogrammetry method and evaluate them to see which one is better for the kind of object they want to model.

> “the portion of my work involving photogrammetry is centered on a service provided architects & property owners with measured drawings and rectified photography that documents existing structures as a first step in preservation work.” (ARC1) (For discussion of ‘Rectified photography’ see section 2.4.2.1).

GEO1 declared that he is new in geo-modeling, he knew more about remote but less knowledge about photogrammetry. And MAT1 does research on remote sensing/GIS techniques (For explanation of ‘Remote sensing’ see section 2.1.2.2.) for practical applications in agriculture, forestry, biodiversity, pollution, change detection and so on. CIV1 uses photogrammetry in the field of visualization and documentation of buildings, excavations and archeological objects.

> “The majority of our research requires alternate methods of measurement, mostly non-contact displacement measurement. We use photogrammetry to generate a 3D model of surfaces in order to compare the results with experimental sensing methods.” (MEC1).

MAT1 does research in the field of 3D laser scanning (For discussion of ‘3D laser scanning’ see sections 2.1.2.2 and 2.1.2.5.) applied to Cultural Heritage applications:

> “My work consists of development of tools for geometry processing, in particular processing operations to improve the quality of geometry acquired through laser scanning technologies, Research and development concerning visualization of large scale 3D models (e.g. cities) and or very dense sampled 3D objects (millions of vertices)” (MAT1).

From the statements above along with the explanations in section 2.1.2: Three-dimensional Modeling Techniques, it can be seen that photogrammetry has been used as a supplementary method for all of respondents. In addition, from wide variety of backgrounds; it can be realized that photogrammetry can be helpful in different areas and professions where 3D modeling or measurement is needed.

4.2 Purpose of Photogrammetry and Its Role in Cultural Heritage Documentation

All of the participants agreed that photogrammetry can play an important role in the cultural heritage domain. Here are the examples of answers regarding their opinions toward this technique:

> "One of the aims of Photogrammetry is the image-based acquisition of 3D models at an high level of accuracy. In the last years Computer Vision researchers have put a lot of effort in the development of automatic tool for image-based reconstruction of 3D objects. The main differences are the level of accuracy of the reconstruction reached by the Computer Vision techniques that is lower with respect to what required/reached in photogrammetry. The general purpose of Photogrammetry is to make reliable and accurate geometric measures starting from photographs, nowadays from digital images. The 3D reconstruction of buildings and archeological sites starting from a set of images is one of the main activities of photogrammetry. Often, Cultural Heritage experts need a 3D representation of the site or building or statue or artifacts of interest for documentation, preservation and planning purposes. For these reasons photogrammetry and also modern Computer Vision technologies play an important role in Cultural Heritage applications, documentation in particular" (COM2).

A very important point stated by COM2 is that photogrammetry can acquire reliable and accurate data; therefore it has been taken into account for cultural heritage purposes. Similarly, another respondent highlighted the emergence of new technologies as an important factor for cultural heritage documentation:

"I think making a 3D snapshot of the actual state of cultural heritage is very important for cultural heritage documentation. The object can be studied better, serve for replication/reconstruction. The technique will advance in my opinion rapidly in the near future with 3D DSLR/3D-Camcorders so the role will be even more important when the technique gets easier" (CIV1) (For explanation of 'DSLR' see section 2.2.2; for definition of 'Camcorder' see Appendix 3.)

Another respondent brings up the usability feature of photogrammetry. As digital photogrammetry was described in section 2.3.2, building a 3D model by use of photographs gives a user-friendly feature to this technique:

> “The benefit of photogrammetry is that is so versatile. As an engineer, I use photogrammetry to make non-contact measurements of test specimens. However that is only one case of it's use. Photogrammetry can easily be used to create a 3D model of anything, large or small. Whether someone wants a computer model for decorative, or artistic value purpose or to document a historical monument, all that is required is a few pictures of another object” (MEC1) (For discussion of ‘Remote sensing’ see section 2.1.2.2.)

Likewise, this feature has made some parts of photogrammetry process very simple to apply:

> “Photogrammetry is a technique that allow non specialist people to acquire data, afterward a specialist is needed to process data and get the final model” (COM1)

Reconstruction is one of the major functions of photogrammetry. Examples in sections 1.2.1 and 2.2.2 about the projects have done on reconstruction of monuments show that modeling the cultural heritage sites which were demolished fully or partly by usage of existing images, can be a great help for reconstruction purposes:

> “of course photogram[metry] is so important not only for cultural heritage but also for others, in fact cultural heritage reconstruction by photogram[metry] has just been exploited for a couples of years, many applications of photogram. for cultural things are about reconstruction” (MAT1)

Similarly, some other usability features of photogrammetry were stated by MAT1:

> “still an important thing is data acquisition and data presentation, i'm talking about how to get the image for photogrammetric work and how to present the results. architectures need photogrammetry for visualisation, demonstration, virtual reality, simulation, reconstruction…” (MAT1)

Finally, the crucial advantages of photogrammetry in cultural heritage were identified as follows:

> "Obviously I think it can play an important role as a vital tool to quickly and accurately - and cost effectively - gather field data that can be transformed into precise documentation" (ARC1)

As can be seen from the statements above, there is an agreement among all the participants that photogrammetry has an effect on documentation of cultural heritage objects. The most important factors they mentioned which are important in this field are that this technique is cost effective and can acquire accurate data. High level of accuracy that is important in documentation of cultural heritage domain can be gained by photogrammetry modeling. Six respondents mentioned that photogrammetry is crucial in documentation of cultural heritage objects; three of them discussed about the role it has in the reconstruction of monuments. Other advantages from this technique in cultural heritage from the above statements are: data acquisition, preservation and planning, visualization, simulation of the objects. One of the participants stated that photogrammetry is flexible toward 3D modeling of objects with various sizes; Furthermore, two participants mentioned that it can obtain accurate results which this issue will be discussed further in the following section by asking more detailed questions about the authenticity issues.

4.3 Image Quality

This section analyzes the answers regarding image quality standards, image characteristics and attributes in photogrammetry; in addition, software or applications which were mentioned by respondents are discussed.

4.3.1 Image Quality Standards

From the answers in this part, some of participants use guidelines for image acquisition but from very various perspectives which mean that based on the software requirements and its use, they need to follow rules for image acquisition. Two interviewees stated that they do not use any standards and they perform based on their knowledge. While, others pursue the guidelines and standards of applications or software they use for modeling and follow the guidelines in PhotoModeler or Google Earth. Just one of the participants named the ISO standard which can be used in photogrammetry which meant to be a standard explaining about the image quality standards in the field of Geosciences and mapping purposes. Three of interviewees declared that they follow the quality requirements of the photogrammetry applications they use which some of them are overviewed in the next section: Photogrammetry Applications.

Here are the responses regarding this issue:

> "we use the guide lines specified in the software we use for the photogrammetry modeling, the data are of course the images, but the way of acquiring them depends on the specific photogrammetry software" (COM1)

> "For photogrammetry software, I use Photomodeler which uses it's own algorithms to determine how suitable an image is. I do not use any set standard in order to determine if an image is suitable or not, rather I use my judgement [judgment] based on the softwares calculated residuals, and the end performance to decide if a different photo is needed, or more photographs are required" (MEC1) (For definition of 'Residuals' see Appendix 3.)

From the section 4.1.1, as COM1 mentioned that they compare different applications of 3D modeling based on their needs, they follow the guidelines of each and every application to acquire the images. Likewise, MEC1 uses the guidelines in PhotoModeler (For explanation of 'PhotoModeler' see Table 2.) in addition to his knowledge which helps him decide based on the provided information by application; whereas, ARC1 claims that there is no standards among professionals:

> "I have my own standards but am not aware of anything industry wide. there is no standard among professional in this field because, I gather, it is still so small and fragmented" (ARC1)

Another respondent answers in detail about the way of acquiring photographs:

> "If possible I use fixed lenses and try to get a diffuse lighting for taking the fotos [photos]. I am always taking raw photos" (CIV1) (For explanation of 'Diffuse lighting' see section 2.4.1.4; for discussion of 'Raw data' see section 2.5.)

Similarly, MEC1 brings up the issue of camera position and orientation and its role in taking accurate images (For explanation of 'Orientation' see section 2.4.2.):

> "More important than the quality of the image, is the position and orientation of the camera. So long as the parameters of the camera are well known, and the image is in focus, not much else can improve the quality of the image. You are left with what you are taking a picture of. Significantly more work goes into improving the scene than the image" (MEC1)

As COM2 says below, having knowledge of 3D reconstruction and being experienced in this field is important to reach satisfactory results:

> "Sometimes, our group did photographic acquisition of statue/buildings for the creation of a 3D representation used by Cultural Heritage experts for several purposes. These image-based acquisitions do not follow any coded standards, but we take into account the limitations of the algorithms employed to obtain the final 3D reconstruction. For example, certain ways to take the picture could not give reliable reconstruction at the end. Also the experience and a deep knowledge of the algorithms used for the reconstruction are very important to plan an efficient photographic campaign" (COM2)

Similarly, another interviewee shared his detailed experiences of using Google Earth application (For explanation of 'Google Earth' see Table 2.) and its criteria to acquire the images. He described the limitations and standards by sharing the Google Earth criteria PDF file:

> "there's a standard in taking pictures for modeling (pdf file by Google Earth: http://www.google.com/intl/en/sketchup/3dwh/pdfs/modeling_a_city.pdf), you must use that standard to be able to have your models in Google Earth, there's a criteria to modeling them: the buildings had to represented like what it looks (the link:

http://sketchup.google.com/intl/en/3dwh/acceptance_criteria.html), if you don't match the criteria, your model will rejected by google earth's team" (GEO1)

Google Earth has quality standards in order to accept 3D models from users. It should be mentioned here that Google Earth has its own requirements and quality standards. Since the models are represented online on Google Earth 3D map, accuracy in scale and location is important because the models must fit in the map scale. Models cannot be high-poly because they would get a lot of space as it says in the criteria: "show small, intricate details through photo textures, keep a low polygon count" ("Modeling a city", n.d.) (For explanation of 'Polygon' see section 2.1.1.), it means that displaying details should be through high-quality images not modeling a dense model.

For the applications which use photographs as the main feature of 3D modeling having a lighter model is advantageous while presenting on web. To explain it in a further account, level of detail in 3D objects can be shown in the model itself and also in the texture. "If your model contains too many polygons, its file size will be too large to load into Google Earth. Modeling too many architectural details increases the file size. Only model the details that are defining characteristics of the building. Often by using a good photo texture on a face, there is no need to model all of the details" ("Modeling a city", n.d.)

"for modeling in google earth, better you have a high resolution pictures" (GEO1)

As GEO1 states, the image quality defined by this application: "We suggest using images that are greater than 256 pixels wide but less than 512 pixels. It's possible to use images greater than 1024 pixels and less than 2048 pixels; however, files larger than 10MB won't be accepted into the Google 3D Warehouse" ("Modeling a city", n.d.) (For explanation of '3D Warehouse' see Table 2.)

Since taking good photographs is crucial for Google Earth, it has provided more hints for it: "Models should be completely photo-textured: We recommend using high-quality and properly sized photographs to produce textures; Texture the entire model, including the roof. For faces that can't be photographed, such as the roof, use the imagery in Google Earth; Use one photo for a face to enhance a model's realism. Please make sure that the face is completely covered with the photo, and no sky or ground imagery can be seen" ("Modeling a city", n.d.)

Having the texturing issues in mind, I asked GEO1 if he uses pictures for all the models or some of them are just textures.

> "some of them/ that's why you have to know any kind of buildings, because data from google earth sometimes to [are] low in resolutions, modeling a building for google earth is just like making a miniature, high resolution data is just for texturing" (GEO1)

It means that, he uses both photo and non-photo textures since the satellite imagery on Google Earth is not high-quality, he uses high resolution images for 3D models. In addition, when the images are not clear or there is no image for some parts of a building, by having knowledge of architecture, he uses textures provided by application: (For discussion of 'Texture' see sections 2.1.1 and 2.3.2.)

> "but you have to know about architecture a little bit, you have to know about many kind of buildings because sometimes lacks of data (so you have to figure out by yourself for the measurements), sometimes you miss some sides of a building" (GEO1)

One of the respondents declares that there is an ISO standard to acquire images in various ways. He suggested looking for USGS's standards in the related websites:

> "it's ISO/ check USGS's standards, to take the pictures, there are many ways, from a camera, from a balloon, airplane, helicopter… try asprs.org and usgs.org , they provide lots of information" (MAT1)

> "for the image, it must be ortho-rectified, it means georeferencing work needs to incorporate elevation information" (MAT1) (For discussion of 'Ortho-rectification' see section 2.4.2.1.)

Having explored the standard, American Society for Photogrammetry and Remote Sensing (ASPRS) provided quality standards for photogrammetry aerial imagery; since "The mission of the ASPRS is to advance knowledge and improve understanding of mapping sciences and to promote the responsible applications of photogrammetry, remote sensing, geographic information systems (GIS), and supporting technologies" ("ASPRS Mission Statement", n.d.), ASPRS more or less explored quality issues in the aerial imagery (For explanation of 'Aerial photogrammetry' see section 2.1.2.1.)

The guidelines provided by ASPRS explain the quality issues of air born photography in particular for mapping purposes, which is not intended to be explored in this research context since, it is less applicable in the cultural heritage context. The following section provides some information about the software and applications which respondents utilize.

4.3.2 Photogrammetry Applications

This section provides an overview on the software and applications that respondents mentioned they use for photogrammetry purposes. As you can see in the table below, some of the applications are used more for mapping and in geosciences and some can be applied for the 3D modeling of objects. The table also provides some introductory information about Google Earth as a 3D social network for contribution of 3D models which users can use Google Sketchup or other applications to provide the architectural models and share them.

Table 2: Applications related to photogrammetry were mentioned by respondents

SOCET SET	SOCET SET is a mapping software which is used for precision photogrammetry and geospatial analysis. The software is famous for its depth, performance, and ability to ingest data from numerous image sources ("SOCET set", n.d.).
Virtuozo	Virtuozo is a registered trademark used in the field of digital photogrammetry for recording, manipulating, and mapping Geographic images ("Virtuozo trademark", n.d.)
ERDAS IMAGINE	ERDAS IMAGINE performs remote sensing analysis and spatial modeling to create new information. In addition, it can be used in visualization of results in 2D, 3D, movies, and on cartographic quality map compositions ("ERDAS product", n.d.) (For discussion of 'Remote sensing' see section 2.1.2.2.)

PhotoModeler	PhotoModeler is photogrammetry software that provides image-based modeling, for accurate measurement and 3D models in engineering, architecture, film, forensics, and more. PhotoModeler is used as 2D to 3D converter (“PhotoModeler - Accurate”, n.d.).
Arc3D	Automatic Reconstruction Conduit (ARC) 3D is a free application for generating 3D models from photographs. ARC 3D uses series of overlapping input images taken of some static object and provide depth information for each of the input photographs thus, a 3D model can be computed (Craig, 2010).
PhotoSynth	Photosynth uses a bunch of photos of the same scene or object and automagically stitch them all together into an interactive 3D viewing experience. Using methods from the field of computer vision, Photosynth studies images for similarities to each other and uses that information to approximate the shape of the subject and the point each photo was taken from. With this information, it can restructure the space and use it as a canvas to present and navigate through the photos (“Background – Photosynth”, n.d.).
Google Earth	Google Earth: An online environment which has the ability to perform geo-referenced models of various architectures (Google Earth, n.d.).
3D warehouse	3D warehouse is a layer on Google Earth which anyone can get their 3D models included in after going through an internal review process. To pass through, there is criteria must be considered (3D warehouse, n.d.).
Sketchup	SketchUp is a 3D modeling program planned for architects, game developers, and related professions. It also includes features to facilitate the position of models in Google Earth. It is designed to be easier to use than other 3D CAD programs. A feature of SketchUp is the 3D Warehouse that lets SketchUp users search for models made by

	others and contribute models (“Google SketchUp”, n.d.).

Here are a few examples of answers regarding the applications and techniques utilizing in photogrammetry where described in table 2:

> “a laser scanner is a good option [to acquire the images]” (MAT1) (For discussion of ‘Laser scanning’ see sections 2.1.2.2 and 2.1.2.5.)
>
> “beside, try some other keywords: soccet set, virtuazio[virtuozo]… those softwares are for photogrammetry, their websites provides lots of infor[mation] / ERDAS imagine also has a good module for photogrammetry/ i think photo modeler [PhotoModeler] is more about individual models while photogrammetry is related to mapping” (MAT1)
>
> “photomodeler, arc3D, PhotoSynth, Sketchup; each of them has different requirements” (COM1)
>
> “modeling a model for google earth is quite simple, you just have to trace from a map, directly download from google earth maps, i just use sketchup and photoshop for texturing, photoshop is quite important in texturing in modeling in google earth/ the interesting part of this job is you can do it by remote” (GEO1) (For discussion of ‘Texture’ see sections 2.1.1 and 2.3.2; for explanation of ‘Remote’ see section 2.1.2.2.)

4.4 Quality Authenticity

In this section the data gathered from respondents about their opinions of how they figure out the data accuracy. Besides, some hints about the data authenticity some of them made; two claimed that they make use of the applications’ requirements they use. And they need different criteria based on the object’s need for accuracy. For instance, using the Google Sketchup as COM1says, does not require a very high-quality image and by use of a low quality photo one can make the 3D model. On the contrary, PhotoModeler is a kind of application which requires higher quality images because at first the camera must be calibrated (For discussion of ‘Camera calibration’ see section 2.4.2.1.) and images are oriented (For explanation of

‘Orientation’ see section 2.4.2.) then, the 3D model can be constructed. Here are the examples from respondents:

> “it depends on the software, for example if you use sketchup a very low quality image is enough” (COM1)

Another issue to reach the corresponding accuracy is considering the graphic scale:

> “As an architect I deliver drawings, the drawings are prepared for output at graphic scale. They must respect the corresponding accuracy of the graphic scale” (ARC1)

As mentioned before, different applications have different criteria for data accuracy. GEO1 states that Google Earth requires an approximation of scale for the 3D model:

> “if the model is too big, they will reject it, google earth had a tool to measure a map, not too accurate of course, you don't have to really accurate in modeling them, because they just miniatures, a digital mock up i guess, you just have to represented them by they looks like, so it means that the measures are not based on the real dimensions, sometimes you have to approximate the measurements from a google maps. the challenge is when you found a client with a different standard of measurement (US company using feet and inch but here in my country, i use meters), you have to get use to other standard of measurement. i guess, sketchup had a very useful tool to do that, you can work by different circumstances, by feet or by meters” (GEO1).

Similarly, he describes a challenge toward various linear units of length in different countries which must be taken into account in different applications. Additionally, he stresses the importance of correct measurement to fit the 3D building in scale by sharing an image (Fig. 7.):

> “ you have to figure out if a side of the building covered by other building, you have to find out what it looks like. you can see that one building covered by another, so, you have to find out what kind of textures do you use, and it represented how important the measurement is, because if your measurement is not correct, it can affect other people's model too and it will [be] rejected by google earth's team” (GEO1)

Figure 7: A screenshot of Google Earth 3D buildings – example of correct measurement

From the (Fig. 7.), it can be seen that 3D models of buildings are situated on the 2D map. For that reason, Google Earth criteria requires that 3D model must be the same size as it appears in Google Earth's aerial photography and be correctly aligned with the aerial imagery in Google Earth’s Models. Structure must sit directly on top of its flattened image in Google Earth (“Modeling a city”, n.d.). GEO1 claims that Google Earth has standards about the modeling accuracy which is necessary for the position of the building and if the building is not in the right location or size, it affects other buildings and overlap with them; that is why it would be rejected by Google Earth. As he says, approximation of scales would be enough for the acceptance. From the Google Earth criteria, models should have the correct height which can be obtained by checking the height of a door to approximately determine the height of the building (“Modeling a city”, n.d.).

> “as the image in photogrammetry is not acquire[d] in a normal way like remote sensing, it can be taken from a balloon, a stand camera, a spot airplane… not fixed position and projection, that's why it needs to be corrected, those information helps correct the image” (MAT1)

To explain further, MAT1 refers to aerial photogrammetry (For explanation of ‘Aerial photogrammetry’ see section 2.1.2.1.) which the pictures are taken from the air and not static location that is why ortho-rectification process must be done afterwards (For discussion of ‘Ortho-rectification’ see section 2.4.2.1.)

> “talking about accuracy, it depends on the scale and the resolution of the image. for image registration, the RMS error should be less than 1 pixel/ for mapping accuracy, it's equal to map scale * 0.5 (mm)” (MAT1)
>
> “Maximum/RSM residuals of calculated points” (CIV1)
>
> “if you can provide enough information, some apps [applications] can do automatic correction, NASA always implement automation in their applications” (MAT1)

As can be seen clearly, two respondents claimed that RMS error or RSM residuals of calculated points determines the level of accuracy. “Residuals are differences between the observed values and the corresponding values that are predicted by the model and thus they represent the variance that is not explained by the model. The better the fit of the model, the smaller the values of residuals” (“Statistics glossary”, n.d.). There are different applications that can calculate the difference value automatically.

RMS error is “Acronym for root mean square error. A measure of the difference between locations that are known and locations that have been interpolated or digitized. RMS error is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points, and then taking the square root of that result” (“Glossary – ArcGIS”, n.d.). These explanations are about the technical points of photogrammetry which usually a person who wants to 3D model an object by use of photogrammetric applications, do not need to calculate these values by himself. Whereas, knowing about these concepts are necessary, since they show how much your model is different from the real value and if the difference is high, the person must go back to the images taken and fix the quality of images or add more pictures to the process. For instance, as MAT1 says “RMS error should be less than 1 pixel” means that if the RMS error calculated by system succeeds this amount, the 3D model of the objects cannot reach the desirable level of accuracy.

Another important factor in authenticity is camera calibration (For discussion of 'Camera calibration' see section 2.4.2.1.) as MEC1 describes:

> "The most important part of a photogrammetry project is the camera calibration. Once the software is confident in the calculation of the cameras parameters such as focal length and lens distortion, any image can be used with confidence. The higher the resolution of the photo, the more accurate a measurement can be made of course. a more accurate 3D result comes from the careful planning of where photos are taken from, and what exactly a camera is taking a picture of. In order to verify the accuracy of our models, we have taken secondary measurements with calipers, and other measurement devices, and verified them to our own individual tolerances" (MEC1) (For definition of 'Tolerance' see Appendix 3.)

To summarize the responses in this section, in the process of photogrammetry to reach the high level of accuracy several factors are crucial. First of all, the quality of the pictures taken is the most important factor which depends on lots of issues (See the discussion in section 2.4.1.) among these factors, resolution of images, graphic scale and lighting conditions of images in addition to correct camera parameters like focal length and lens distortion (For explanation of 'Focal length' and 'Lens distortion' section 2.4.1.1.) were critical for interviewees. Secondly, camera calibration plays an important role in this process; if camera calibration can be done successfully, images can be oriented therefore it shows that picture taken are in a satisfactory condition. After this process, applications can calculate an approximate level of accuracy. As mentioned above, RMS error is one of these values that can be helpful to estimate the authenticity of results.

4.4.1 Quality assessment

Regarding the answers about quality assessment, two interviewees brought up the issue of user study which the quality of results can be evaluated by user needs, judgment and their behavior toward the result. In addition, two respondents mentioned that to examine the quality of result by photogrammetry, the result can be compared with other applications results. Here are a few answers regarding the quality assessment:

> "Image data accuracy could be evaluated when a ground truth is available. The building of a ground truth to evaluated image data accuracy is a complex task. Concerning image-based 3D acquisition in particular, an interesting comparison could be done using the data of the same 3D model acquired through different technologies, for example by laser scanning devices that have an accuracy of 1/3 of mm (typically)" (COM2) (For definition of 'Ground truth' see Appendix 3.)

Similarly, COM1 also suggest comparing the result to the production of another technique like 3D laser scanner:

> "in theory it can be assessed by performing psycho visual test on several users. in the case in which the same real object could be measured also with a scanner, the quality of the one coming from photogrammetry can be evaluated by means of hausdorff distance that is a metric that measure distance between 3D objects" (COM1) (For definition of 'Hausdorff distance' see Appendix 3.)
>
> "assessment comes from the judgement/experience of the user" (ARC1)

Another respondent looks at quality assessment from the perspective of image quality:

> "It is difficult to answer to this question. Quality assessment heavily depends on the definition of quality. For certain kind of applications some properties could be more important than other. In the case of taking geometric measures from images, surely the sharpness and the uniform illumination of a set of photographs is an important factor to evaluate quality. For example, a set of photographs with photos with very different lighting conditions and with some out-of-focus photographs could be completely unuseful to obtain reliable measures. Hence, metadata related to these image properties could be important" (COM2)

In short, technical aspects of quality assessment were mentioned by majority. Five respondents explained the technical ways facilitated by different applications can approximate the level of accuracy. Camera calibration, RMS error, ground truth, and hausdorff distance were mentioned as helpful factors for the quality assessment. Furthermore, metadata is pointed out as a supportive point for quality which will be explained further in the following section.

4.5 Image Metadata

This section aims to explore the issues about metadata from eight questions that were asked in the interviews. In summary, the questions seek to understand if participants use any metadata standards, if they think metadata in general is useful in photogrammetry; if yes, which features in particular, and if they play any role in the quality of images and ultimately the 3D result.

4.5.1 Metadata standards

When the respondents were asked if they use any metadata standards, six respondents claimed that they do not use any standards for metadata. Just one of the respondents mentioned some metadata standards which are used for geospatial data. Table 3 explains about standards providers and two metadata standards. As explained in section 2.5, geospatial metadata elements can be critical in the field of photogrammetry since, beside the common metadata elements, part of the elements should cover geospatial data like the location and measurements.

Three interviewees claimed that they do not use any metadata in their field of work and without considering metadata their projects are fine. On the contrary, three respondents named some metadata elements which they use in their work. And one states that he uses metadata for archival purposes. Here are their answers explaining why or why not they use metadata:

> “no I don't care about metadata in my research activity. I don't use them because I'm just interested in modeling objects by using both scanners and specific softwares and they don't need any metadata to work” (COM1)

> “I use metadata only to help me to organize photos and to remember lense [lens] settings that correspond to camera calibrations. I started off with analog and more or less use the same work flow which never relied on meta data [metadata]. For me its nice as “back up” (ARC1)

From his reply, camera parameters like lens settings can be very important to be kept as metadata elements because it is used in camera calibration process and also can be accessible later on. Another issue comes from this respond is working with analog instead of digital. Although digital cameras are in great use these days, there are professionals who still prefer to use analog especially artists think that the result can have higher quality and also they can influence the result better. In this case, the acquired images is scanned after the production to digital form and metadata features, then must be added manually since camera parameters are not included in the scanned file.

> "not really" (GEO1) [he does not use any metadata standards]

> "Im not sure I understand what you are referring to when you mention image metadata, however I hope I was able to shed some light on what is important and what is less important in a photogrammetry project" (MEC1)

From the statement by MEC1, it can be realized that metadata is not known for him. From his responses in previous sections, it is clear that he uses various data chunks in photogrammetric process but does not define them as metadata. The same situation perceived from most of answers toward metadata. For instance:

> "without metadata, the image is still fine if it's good, but a standard one should have all things. i'm not using but I'm sure that metadata is existing" (MAT1)

> "Sometimes, metadata inside the images like the EXIF data, could be useful for reconstruction purposes. For example, modern digital cameras embed in the images the focal length of the camera that is an important value considering 3D reconstruction of a model" (COM2) (For explanation of 'Focal length' see section 2.4.1.1.)

An example of EXIF metadata sent by GEO1, as can be seen in (Fig. 8.), there is an explanation about EXIF which states: "Almost all new digital cameras save JPEG (jpg) files with EXIF (Exchangeable Image File) data. Camera settings and scene information are recorded by the camera into the image file. Examples of stored information are shutter speed, date and time, focal length, exposure compensation, metering pattern and if a flash was used" ("EXIF information" n.d.); (Fig. 8.) shows part of EXIF metadata included in the file.

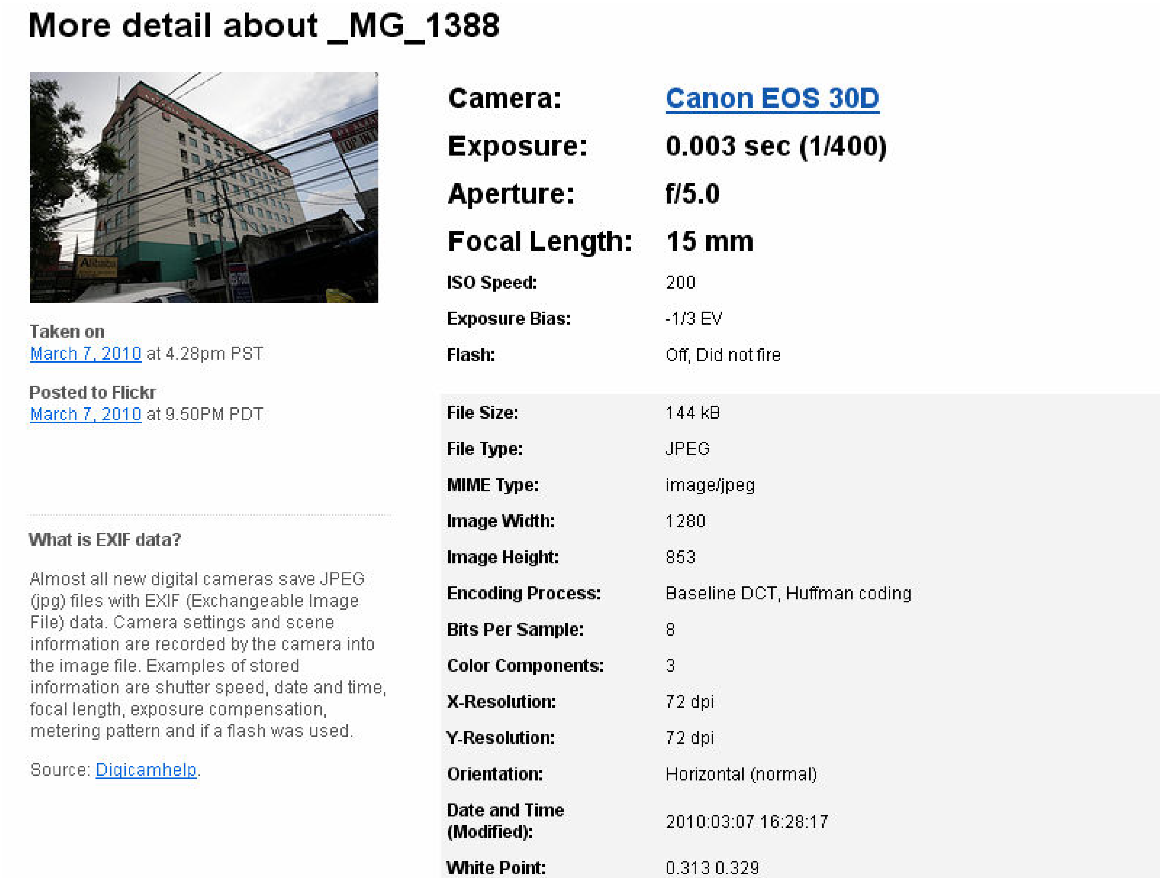

Figure 8: A screenshot of Flickr – example of image metadata ("More detail about", 2010)

> "Focal length, image orientation, date of shot" (CIV1) (For explanation of 'Focal length' see section 2.4.1.1; for discussion of 'Orientation' see section 2.4.2.)

> "Focal length (and camera and length type of course) is crucial in photogrammetry" (CIV1)

> "the metadata for photogram. [metry] is basically similar to remote sensing image, excepts it includes more information like 7 parameters, in remote sensing, we don't care much about interior, exterior, focal length and so on but in photogrammetry, they're important. without those parameters, you can't make orthogonal image (that looks like a map) it's ISO/ check USGS's standards, all of them are there" (MAT1) (For definition of 'Orthogonal image' see Appendix 3.)

As can be seen in the last three answers, they mentioned a few examples of metadata which are associated with the camera parameters. Table below provides descriptions about two metadata standards were mentioned by MAT1 starting with an overview of USGS and FGDC as standards providers.

Table 3: Metadata standards and providers related to photogrammetry were mentioned by respondents

USGS	U.S. Geological Survey (USGS) prepares standards to examine if the products produced under the National Geospatial Program are accurate and consistent in style and content ("National geospatial", n.d.).
FGDC	Federal Geographic Data Committee (FGDC) specifies the content of standards for the Preparation of Digital Geospatial Metadata. The standard provides a common set of terms and definitions for the documentation of geospatial data. For instance, it includes data quality information which provides a general assessment of the quality of the data set ("Standards for the preparation", 1997). "Metadata are data about the content, quality, condition, and other characteristics of the data. This standard specifies the information content of metadata for digital spatial data produced by the U.S. Geological Survey (USGS) National Mapping Division (NMD) and provides common terminology and definitions for NMD metadata" ("Standards for the preparation", 1997, p. ii).
CSDGM	The Content Standard for Digital Geospatial Metadata (CSDGM) is the US Federal Metadata standard and is often referred to as the FGDC Metadata Standard. The Federal Geographic Data Committee originally adopted the CSDGM in 1994 and revised it in 1998 ("Geospatial metadata", n.d.)
ISO metadata standard	The international community, through the International Organization of Standards (ISO), has developed and approved an international metadata standard, ISO 19115. As a member of ISO, US required revising the CSDGM in accord with ISO 19115. Each nation can craft their own profile of ISO 19115 with the requirement that it include the 13 core element

	("Geospatial metadata", n.d.). ISO 19115 Core Metadata Elements includes mandatory and conditional elements as follows: Mandatory Elements: Dataset title, Dataset reference date ,Dataset language, Dataset topic category, Abstract, Metadata point of contact, Metadata date stamp ("Geospatial metadata", n.d.) Conditional Elements: Dataset responsible party, Geographic location by coordinates, Dataset character set, Spatial resolution, Distribution format, Spatial representation type, Reference system, Lineage statement, On-line Resource, Metadata file identifier, Metadata standard name, Metadata standard version, Metadata language, Metadata character set ("Geospatial metadata", n.d.)

4.5.2 Metadata usability

Most of the respondents had an agreement on that metadata is useful but stated various usability. Three respondents declare that metadata is useful in data retrieval, preservation and provide descriptions for users. Two of the interviewees claimed that metadata is not useful at all in the process of photogrammetry. To have a further explanation here, there were different approaches to metadata concept here; some was thinking about the explanations which are added to data in the sense of archival use, some thought that it is related to camera parameters which can be critical in photogrammetry but after the process there is no need to keep them. Here are therefore the answers:

> "yes of course metadata can be useful to keep the history of the acquisition for instance but I am not an expert of metadata" (COM1).
>
> "maybe a camera calibration file" (ARC1)

In this answer ARC1 meant that camera calibration file might be useful when he wants to retrieve the images for photogrammetry. And he continues that none of the metadata parameters are crucial in photogrammetry:

> "none is crucial" (ARC1)

> "i use metadata for the description of the building or maybe taglines so people could found [find] your models in the internets/ it's impact for your reputation as a modeler. google earth is use[d] to be as a GIS so, good information is a must, sometimes google earth not to pay attention for that [sometimes Google Earth does not pay attention to the good information provided by modelers]" (GEO1)

In the Google Earth 3D map there are thousands of pictures attached to the map in addition to the 3D architectural models. People who share data on the map can supplement explanation about the place, for cultural heritage sites most of the explanations are about history of the object. The figure in the next page shows a snapshot of Google Earth with a description provided by the modeler (Fig. 9).

> "It can serve for sorting the pictures in a database, for fast and exact access to the data. Metadata is not useful for users of 3D result. And useful only for quick acces[s] to the right image data if there is a big amount of pictures" (CIV1)

> "for the process of modeling not for the users" (GEO1)

Amongst the respondents, a few mentioned that metadata is not useful for the users of photogrammetric 3D result but it is just useful for the process of photogrammetry. For instance, the following interviewee mentions that after using the data for geo-referencing (For explanation of 'Geo-reference' see section 2.3.2.) they are not useful anymore.

> "the metadata is just for raw image processing, after having it geo-referenced, we don't need metadata or perhaps still need, but it's not so important anymore" (MAT1)

Similarly, CIV1 mentions that metadata parameters are useful for the application to process data:

"I think it is useful for the program that can/could do very much with that information (focal length, gps-location, time of day)" (CIV1) (For explanation of 'GPS' see section 2.3.2.)

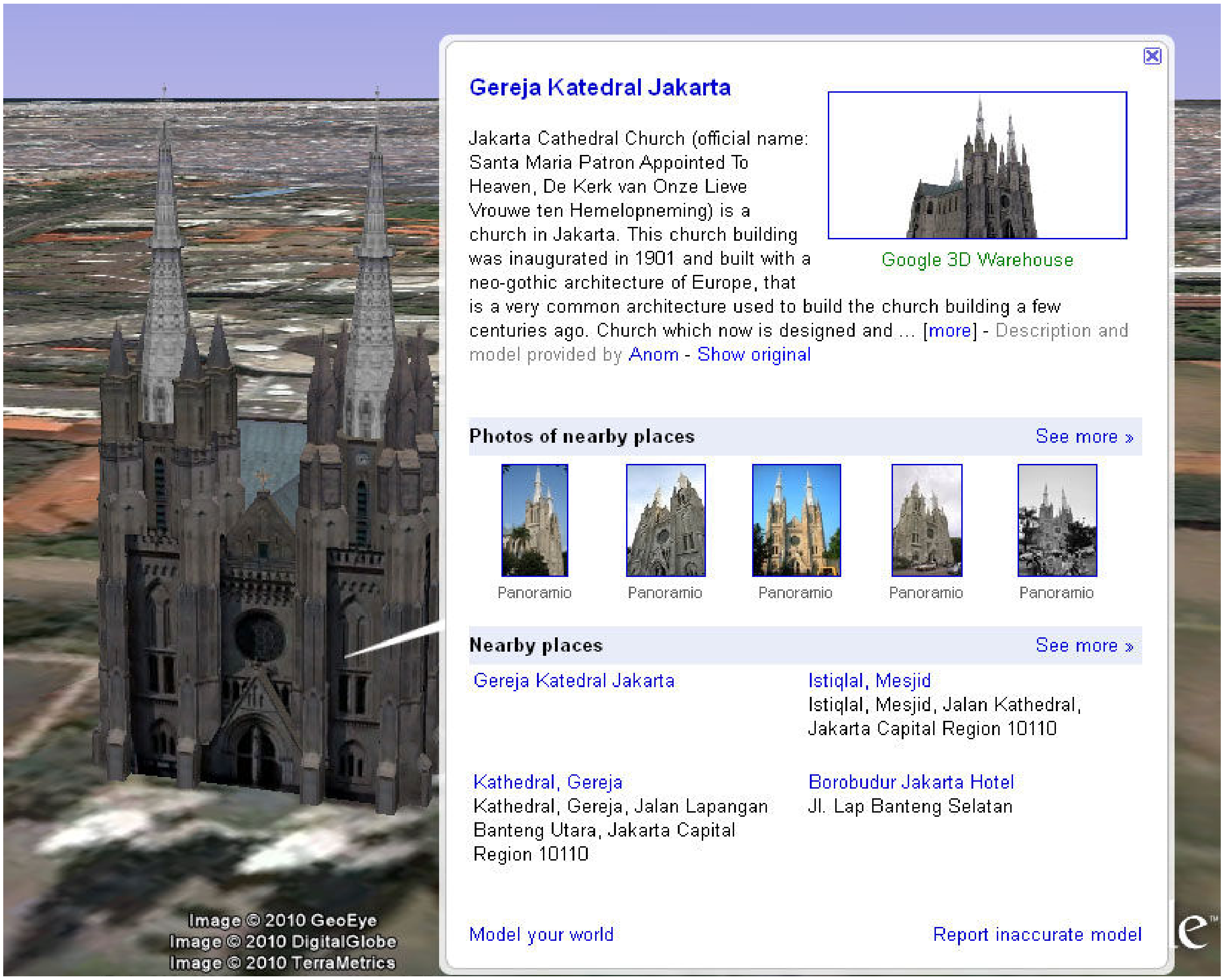

Figure 9: A screenshot of Google Earth – example of metadata provided by a modeler

"The only bit of metadata used, at least in the case of Photomodeler, is to determine what camera took the photo and to automatically determine which calibration file to use. Photogrammetry uses the cameras parameters, and then the x-y coordinates of pixels referenced across multiple photos to geometrically determine the location of points in 3D space. To my knowledge, beyond the identification of the camera used, metadata is not need in a photogrammetry project" (MEC1)

> "In my opinion and following my experiences all optical parameters related to how the photos has been acquired such as focal length, focus range, size of the CCD, optical center of the CCD, optical distortions parameters (if known), geolocalization of the camera, and so on [are crucial in photogrammetry]" (COM2)

From the last answers and the discussion in the previous section: 4.5.1 Metadata standards, metadata features appear to be useful for identification of camera parameters in camera calibration. Also an EXIF file as COM2 mentioned implements optical parameters which are practical in photogrammetry.

4.5.3 Metadata Contribution to the Image Quality

There were different opinions about if metadata contributes to the image quality or not. Since most of respondents stated that they do not use metadata in the process of photogrammetry, I conclude that they do not use it in association with the image quality either, since image is the base of photogrammetry. Just two respondents state that it can be effective since metadata includes the original features of an image for instance, as GEO1 says it serves the measurements and also color tones which can be changed by image editing applications thus, the original data can be vital to reach the level of accuracy and reliability. Here are a few examples of answers regarding this issue:

> "not image quality. that is in the hands of the photographer, the equipment used and the correctness of the exposure" (ARC1) (For explanation of 'Exposure' see section 2.4.1.3.)

Whereas two respondents claim that metadata parameters are effective in the image quality:

> "i use any data for measurement like focal length/ the other is for color tones, so you can figure out the correct color for the buildings, sometimes people touch up their photograph so they'll miss the original color" (GEO1) (For discussion of 'Color' see section 2.4.1.5)

> "Yes, I think so. For example, it could be very useful if the images of a photographic campaign could include data like position (GPS or similar) and shot properties (focal length, focus range and in general any optical parameter). The parameters just

mentioned regards the purpose of obtaining 3D measures/reconstruction of the site/object of interest, other kind of metadata could be useful for other applications in Cultural Heritage" (COM2)

4.5.4 Metadata Influence on 3D Result

From the answers in this section, metadata can be important in the process of photogrammetry, as mentioned before by keeping metadata of optical parameters; metadata can be crucial in the level of accuracy. As MAT1 says, if the image data is not correct, the 3D result would not be either. COM2 mentions an interesting point: he claims that the 3D result does not carry image metadata since this metadata is useful just in the process of photogrammetry; however, if image metadata associate with 3D results, some of them can be used for reproduction purposes and also evaluation of the 3D model. Here are the examples of respondents' statements on if image metadata affects the 3D result or not:

"none that i am aware of" (ARC1)

"Only in accuracy" (CIV1)

It means that image metadata affect the accuracy of 3D result.

"the 3D data is built from 2D data, if the 2D is not correct, so is the 3D" (MAT1)

"That depends on he [the] programs if they make use of it. (focal length, camera tpye [type] etc.)" (CIV1)

It means that if the software uses metadata for building the 3D object or not. So from the statement, if the software use camera parameters like focal length these data contribute to build the 3D result.

"Considering the methodology we use to obtain image-based 3D reconstruction no metadata are used (except as just stated sometime the knowledge of the focal length could be useful in some cases)" (COM2)

> "Usually image metadata are not embedded in the reconstructed 3D model. Concerning their usefulness for the process of building the 3D object itself, the answer is positive, as just stated in previous answers" (COM2)

An important point stated by him is that 3D model does not hold the image metadata. Image metadata is used for the process of building the 3D model, but are not available after the production. The original image metadata should be preserved to be able to analyze the result as he says:

> "In our work usually we do not use 3D metadata. Anyway, it is true that associate some metadata to the 3D model, for example about its creation, it could be useful to guarantee reproducibility and from a better analysis of the obtained results" (COM2)

4.6 Discussion

This section has an overview on the themes discussed in this chapter with relation to Chapter 2: Literature Review in greater detail. Cross referencing is provided to the relevant concepts where applicable.

4.6.1 Role of Photogrammetry in the Cultural Heritage Domain

From the interviewees background in section 4.1.1 along with the explanations in section 2.1.2: Three-dimensional Modeling Techniques, Apparently, photogrammetry has the characteristics for visualization purposes which can be beneficial while using along with other techniques such as 3D laser scanning (For further explanation of '3D laser scanning' see section 2.1.2.5). To further explain why photogrammetry usually is used with other techniques, each three-dimensional digitization technique has its own advantages and drawbacks thus, it is reasonable and probably more beneficial to use each method in need based on the project requirements. For example, Photogrammetry is a good choice in a project when high-quality visual appearance is needed since it can employ high-quality images but if a very dense, high-poly model (For explanation of 'Polygon' see section 2.1.1.) is needed specially for small objects, most likely using 3D laser scanning method is more advantageous.

To have a comparison between the results of section 4.2: Purpose of Photogrammetry and Its Role in Cultural Heritage Documentation, with section 2.3.2: Digital Photogrammetry about the advantages of photogrammetry, it can be seen clearly that all of the points respondents mentioned are backed up in his overview. All of the respondents in this section stated about the role of photogrammetry in cultural heritage documentation since this technique is cost effective and can obtain accurate data. Some other critical features of photogrammetry discussed in the section 4.2 are: Reconstruction of monuments, preservation, visualization, and simulation of the objects. Furthermore, flexibility of photogrammetry toward modeling various objects was mentioned. In my opinion this point is one of the advantages of photogrammetry as in section 2.3.2; Patias (2006) name this feature as 'provision of large amount of data from various scales and resolutions' that is why this technique can be used for different purposes.

4.6.2 Image Quality and Authenticity

Image quality characteristics are explored in literature review section 2.4.1, to have a comparison with responses in both section 4.3 and 4.4: Image Quality and Quality Authenticity, most of the respondents are aware of applications' guidelines they use for photogrammetry purposes. And make use of the software automation for accuracy assessments. Quality of images and level of accuracy for most of interviewees depend on the requirements of the applications they utilize. (Some criteria are explored in section 4.3).

From the responses and the discussion about the section: 2.4: Quality authenticity, apparently there have been a lot of research done in the area of digital image quality issues but not in photogrammetry from cultural heritage point of view; since it has not been a long time that digital photogrammetry in particular, digital terrestrial photogrammetry has been used in the field of cultural heritage and much more has been done on image requirements in photogrammetry in the area of mapping and satellite imagery. In my opinion, professionals who apply photogrammetry method for 3D modeling purposes more or less use their own knowledge and judgment in addition to the software principles they use. Therefore, quality authenticity would be configured through the experience and also the final result if is acceptable or not for the project.

When the respondents were asked how quality can be assessed, three approaches were determined:

- The quality of results can be evaluated through the process of user study to seek the user needs and find out about their behavior toward the 3D results. Since the attempt is to reach the highest accuracy and quality as possible and provide a realistic character for the result for high-quality 3D projects in the cultural heritage domain, these projects attempt to acquire data in the highest quality as possible; although, the authenticity level cannot be 100%. There are various projects under way though considering the budget and capacity limitations, therefore one of the best ways would be having the priority and user needs in mind to see if the result is satisfactory.

- Evaluating the result can be carried out by a comparison between photogrammetric results with other applications results. For instance, the same object can be modeled by use of 3D laser scanner and seen which device can acquire the best result. As discussed in the section 2.1.2: Three-dimensional Modeling Techniques; there are various ways to construct a 3D model. Depends on the project requirements and the size and location of the object one or combination of several techniques can be employed. Sometimes companies must choose one of the methods due to the time and money constraints thus, they examine them on a similar object to be able to decide for their project (See also the responses in section 4.1.1.)

- From the data analysis in section 4.4.1, technical aspects of quality assessment were mentioned by respondents. Technical measuring facilities by different applications (For further explanation see section 2.4.2: Quality Authenticity in Metrology) can approximate the level of accuracy; such as camera calibration and RMS error that were mentioned as supportive factors in quality assessment which are described in section 4.4. Furthermore, image quality features which are important at the start of photogrammetry project are foremost in authenticity (See section 2.4.1: Quality Authenticity in Photography).

4.6.3 Image Metadata

It is important to consider that metadata definition was not well-defined by most of respondents; by the time of interviewing even though metadata definition was provided for the respondents (as explained in section 3.4.1: Interview Questions) I suppose they had different meanings in mind. In addition, I did not want to affect the respondents' judgments by approving or disapproving their opinions, because one of the objectives of this is study is to explore what features of metadata professionals think is important in photogrammetry. When the respondents were asked if they use any metadata, there were two approaches taken by respondents:

Firstly, metadata usability from the perspective of archival purposes was mentioned from some which they stressed that metadata is useful to restore the data and have access to them later on. In this respect, without considering metadata, the photogrammetry process is fine and in their opinion there is no need for metadata in their field of work. These respondents declare that metadata is useful in data retrieval, preservation and providing descriptions about 3D models for users.

Secondly, metadata contribution to technical data parameters was considered by some and stated that image metadata is important in photogrammetry because it restores the camera parameters like camera calibration file, geospatial data and measurements (For discussion of 'GIS metadata' see section 2.5.); that is why it can play an important role in the process of photogrammetry. As described in section 2.4.2.1, camera calibration also includes the process of finding some other true parameters of the camera like focal length, format size and principal point ("PhotoModeler", n.d.). Thus, camera parameters like lens settings can be very important to be served as metadata elements since it is included in the process of camera calibration and also must be accessible in the future. In this approach, since metadata preserve the original image data, it can be crucial for the assessment of the level of accuracy and reliability because image data can be lost or changed during the photogrammetry process thus these data can be used for evaluation purposes

To sum up, metadata appears to be effective in the process of photogrammetry since by including detailed data about the image production and optical parameters; metadata can hold data which determine the level of accuracy. I suppose, if professionals in the field of cultural heritage provide a system to preserve image metadata along with the 3D result it can increase the usability of the 3D model. For example, the user would know if the model is built from different images from different periods of time, which part is built from the real images and which part of the building is the approximation created by the modeler by repeating some images in case some parts of the building were not visible at the time it was photographed (because of lack of lighting or shadows, areas hidden behind the trees, parts that were demolished over time and so on). Providing the model with original information of pictures like dimensions, location, time, color and such would give lots of information to see how realistic the model is in comparison with the current condition of the cultural heritage object.

4.7 Chapter Summary

Main themes and topics that corresponded with the research questions of this study are explored in this chapter. The data collected in this study are analyzed qualitatively and presented in their respective sections of this chapter. Finally, Discussion section concluded the research results by provision of links to the aspects of Chapter 2: Literature Review.

Chapter 5: CONCLUSIONS

The objective of this study was to acquire a deeper understanding of the image quality, authenticity, and metadata issues in photogrammetry as a three-dimensional (3D) digitization technique in the cultural heritage domain. This chapter intends to wrap up the findings of this research associated with research questions and research problems. In addition, Implications of the study and suggestions for areas of research in the future are offered. Photogrammetry was chosen as the studied topic because due to the emergence of new digital technologies, it has come to be used in cultural heritage digitization. The statement of problem was concerned with three research questions of the study outlined in Chapter 1: Introduction; which set out to shed light on the role of photogrammetry in the cultural heritage area, image characteristics from the perspective of quality and authenticity in photogrammetry, and image metadata associated with this technique.

The literature review explored in this study identifies that digital photogrammetry in cultural heritage is beginning to be employed immensely and the issues relating to image quality, data accuracy, and especially metadata are beginning to emerge. There have been a lot of studies on digital image quality characteristics but exploring digital images from the perspective of photogrammetric 3D modeling in cultural heritage needs more attention. Therefore, this study aims to add to the existing literature and provide new ideas for further research which will be described in section 5.3. In the next section, answers to the research questions of this study are presented and general implications of this research are discussed.

5.1 Conclusions to the Research Questions

This section presents an outline of the findings of the three research questions. It should be considered that the findings of this study are not representative of the entire populations and cannot be generalized since this is an interpretive research.

- Research question 1: How can photogrammetry be used in the cultural heritage domain?

The findings of this study seem to indicate that photogrammetry is highly applicable to the documentation of cultural heritage materials. From the results of interviews along with the Literature review discussion about digital photogrammetry in section 2.3.2, photogrammetry can be applied for reconstruction, preservation and visualization of cultural heritage objects because it can acquire the accurate 3D models in a cost effective way. Furthermore, photogrammetry is used in various disciplines since it is versatile toward modeling objects with various scales or locations when different levels of quality are needed. It is also flexible to be utilized in combination of other 3D modeling methods based on the project requirements. Photogrammetry can be applied in a 3D modeling project when high-quality visual appearance is needed since high-quality images is used as the principle of modeling; that is why this technique can play an important role in digitization of cultural heritage monuments and objects with photo-realistic appearance.

- Research question 2: How are quality and authenticity assessed in photogrammetric digital images?

According to the results of this research, different applications of photogrammetry have different requirements for the level of image quality and authenticity. There are some technical aspects are provided by these applications which are helpful for professionals to assess the quality and authenticity of the results along with their own judgment and expertise on the process. One of these technical facilities which support the quality assessment is the camera calibration process. When the photographs are in the satisfactory level of accuracy and quality as discussed in the Literature Review: section 2.4.1, camera is calibrated, images are oriented and RMS error provided by application can show the level of quality of the result. Metadata can be served for evaluation analysis since it preserves the original data of images which will be explained further in the following research question.

Quality and authenticity can be assessed by evaluating the photogrammetric results in comparison to the results of other 3D modeling techniques. The same object can be 3D modeled by a photogrammetric application and non-photogrammetric way to see how high-quality and accurate is the result between the existing potential ways. User study is another possible way of conducting the assessment. Since the time and budget is always limited, to see the user expectations and satisfaction about the result is helpful for the assessment. Due to the fact that this study aimed to explore the technical factors of quality and authenticity, did not investigate the issues from the perspectives of user needs however, the combination of assessment methods is necessary for the evaluation of results.

Research question 3: What is the role of image metadata in photogrammetry?

The findings of this study along with the literature provided in chapter 2; seem to present that metadata usage in the cultural heritage photogrammetric data is beginning to emerge. According to the participants of this study, there was very slight awareness of the need for metadata evidenced in the population. In photogrammetry process, image metadata can preserve the original data which is used in the process of camera calibration and consequently building the 3D model. Camera calibration file, geospatial and measurement data as discussed in section 2.5 about GIS metadata; in addition to the common image metadata that should be preserved, since image data is used in the photogrammetry process and cannot be obtained if changed during the process and 3D metadata does not include the original image metadata. These metadata can be used for further analysis of the result, evaluation of the model and images, and for reproduction purposes.

Additionally, the fact that metadata can include the detailed data of photogrammetric images and optical parameters of camera; it can be crucial for the assessment of the level of accuracy and reliability since analyzing the original image data before they get lost or changed during the photogrammetry process is a base of 3D result assessment after production. Photogrammetric image metadata like any other kinds of metadata can be used for data retrieval and use. Without provision of sufficient metadata, the 3D model can be lost in the excessive data production especially since we are facing explosion of 3D data as well as other kinds because its production is getting simple by emergence of new technologies.

5.2 Implications of Research

It appears that photogrammetry seems to be effective in the cultural heritage digitization and documentation amongst all 3D modeling techniques. It is shown that photogrammetry is an effective way to present a photo-realistic view for 3D architectures and artifacts. This technique also seems to provide suitable quality in a cost-effective way for cultural heritage digitization projects since it uses photographs as a principle of 3D modeling. As discussed the characteristics of photogrammetry in section 2.3.2, it can provide data in various levels of quality and scales, thus acquires low-size 3D data that is why it has been considered as one of the 3D modeling techniques to share this form of data on the World Wide Web. As mentioned in the previous chapter, social networks such as Google Earth can utilize this technique to build and share architectural 3D models. Furthermore, the respondents of this study seem to be able to use this method with different backgrounds and experiences. Hence, the implication of this finding is that photogrammetry can be utilized for multidisciplinary purposes in various areas of science.

In general, implications derived from the findings of this study can be taken into consideration for two groups: Information professionals and professionals in the field of photogrammetry.

Implications of this research for the information professionals show that photogrammetry is gaining popularity in the field of documentation and visualization of cultural heritage sites hence, they should be aware of this technique as a 3D data production method and get ready to deal with photogrammetric data on the Web, museum collections and digital libraries. The concept of photogrammetric image quality, authenticity and metadata is crucial for the information professionals in the field of cultural heritage to have a better understanding of how this kind of data can be in high-quality and accuracy; in addition, what metadata issues and challenges are along their way in the perspective of documentation, retrieval and evaluation of results.

Implication of this research could be applied also for professionals who work in the field of photogrammetry. The findings of this research show that professionals are less aware of metadata issues in this field although metadata appears to be effective in determining the level of quality and accuracy by holding detailed image data at the time of production. In addition, to omit the difficulties toward retrieval of mass of data, providing a system to preserve efficient data about 3D models will increase the usability of information and cut costs of reproductions, in addition it can provide the possibilities of data evaluation. Furthermore, a review of findings seems to indicate that information professionals cannot therefore simply reply on photogrammetry professionals to supply appropriate images, but have to develop own awareness of technologies so that they can influence on acquisition of appropriate metadata from the beginning of photogrammetry process to the production of 3D results.

5.3 Future Research Ideas

The significance of the role of digital photogrammetry in cultural heritage domain was revealed in this study, in particular image quality, authenticity and metadata issues were explored in this technique. Although photogrammetry can be used in different disciplines, this research intends to look for its role in cultural heritage 3D modeling from the perspective of information science and archival studies. Conducting further research in this field can be done in a more technical way or less technical.

From more technical view point, further research can go deeply through image quality and authenticity issues by offering algorithms and methodologies for standardization of the photogrammetric process. Furthermore, metadata issues which are very unknown in this field; a lot of effort can be done in the respect of two-dimensional (2D) and 3D photogrammetric metadata and how they are associated since the 3D model is built from 2D materials. It would be interesting to examine how 3D metadata elements correlate with digital image metadata in an experimental research. Design of metadata standards for photogrammetric cultural heritage collections is highly needed since it has been a few years that digital photogrammetry has got popularity in digitization of cultural heritage objects and can lead to the mass production of 3D data.

Another issue that deserves further research in the field of information science concerns the usefulness of photogrammetry in social networks. For instance, social networks like Google Earth have provided an area where anyone can share their 3D architectural model. In addition, photogrammetry applications such as PhotoModeler (For explanation of 'PhotoModeler' see table 2.) have an ability to attach the 3D model to the Google Earth map. Furthermore, an assessment can be carried out on the level of quality and authenticity of 3D photogrammetric models in comparison to non-photogrammetric ones on Google Earth.

As previously mentioned in section 4.6.2: Image Quality and Authenticity; there is not much research done in the area of digital image quality issues in photogrammetry from cultural heritage point of view; hence, standardized guidelines are needed for determining image quality and authenticity in this field. Since when asked about image quality standards from a participant, he stated:

> "I have my own standards but am not aware of anything industry wide. there is no standard among professional in this field because, I gather, it is still so small and fragmented" (ARC1) (section 4.3.1)

User studies and exploration of photogrammetric data user behavior can also be effective to lead ongoing research on the right track. In brief, there are many future research possibilities to investigate photogrammetry in cultural heritage from technical or non-technical perspectives, just a few of which are suggested here.

5.4 Chapter Summary

In conclusion, the findings of this study present the role of photogrammetry in cultural heritage domain and explore the image quality, authenticity, and metadata issues related to this technique. This chapter aims to provide answers to three research questions of this study; in addition to present the implications of research and suggest some future research ideas of photogrammetry issues in the cultural heritage domain.

REFERENCES

3D photography. (n.d.). In *Welcome to Knowledgerush*. Retrieved May 01, 2010, from http://www.knowledgerush.com/kr/encyclopedia/3D_photography/

3D warehouse. (n.d.). *Google 3D warehouse*. Retrieved March 15, 2010, from http://sketchup.google.com/3dwarehouse/

Arayici, Y. (2008). Towards building information modelling for existing structures. *Structural Survey*, *26*(3), 210-222. doi: 10.1108/02630800810887108

ASPRS Mission Statement. (n.d.). *ASPRS - American Society for Photogrammetry and Remote Sensing*. Retrieved April 15, 2010, from http://www.asprs.org/society/mission.html

Background - Photosynth. (n.d.). *Photosynth - Use your camera to stitch the world*. Retrieved May 15, 2010, from http://photosynth.net/Background.aspx

Basics of photogrammetry. (2006, October 24). *Geodetic Systems, Inc. - Home Page*. Retrieved June 01, 2010, from http://www.geodetic.com/whatis.htm

Beraldin, J. A. (2004). Integration of laser scanning and close-range photogrammetry: The last decade and beyond. *The XXth ISPRS congress, Commission VII* (pp. 972-983).

Bouma, G. D., & Atkinson, G. B. (1997). *A Handbook of Social Science Research: A Comprehensive and Practical Guide for Students.* (2nd ed.). Oxford: Oxford University Press.

Brennan, J. (2008). Rectified photography. *Building Conservation.com*. Retrieved April 16, 2010, from http://www.buildingconservation.com/articles/rectified/rectified.htm

Burtch, R. (2004). *History of photogrammetry*. Lecture presented at Center for Photogrammetric Training in Ferris State University, Michigan. Retrieved February 25, 2010, from http://www.scribd.com/doc/16556123/History

Bustos, B., Fellner, D. W., Havemann, S., Keim, D. A., Saupe, D., & Schreck, T. (2007, June 23). Foundations of 3D digital libraries: Current approaches and urgent research challenges. In *First international workshop on digital libraries foundations. In conjunction with ACM IEEE joint conference on digital libraries (JCDL 2007).* Retrieved March 20, 2010, from http://www.inf.uni-konstanz.de/cgip/bib/fi les/ BuFeHa07.pdf

Card, S. K., Mackinlay, J. D., & Shneiderman, B. (1999). *Readings in information visualization: Using vision to think*. San Francisco, Calif.: Morgan Kaufmann. Retrieved February 25, 2010, from ACM Portal.

Certified photogrammetrist (ASPRS). (2009). *ASPRS - American Society for Photogrammetry and Remote Sensing*. Retrieved May 18, 2010, from http://www.asprs.org/membership/certification/certification_guidelines.html#Certified_Photogrammetrist

Chalmers, M., Ingram, R., & Pfranger, C. (1996). Adding imageability features to information displays. In *Proc. ACM symp. on user interface software and technology (UIST96)* (pp. 33-39). Seattle.

Chen, C. (2002). Information visualization. *Palgrave journals*, 1-4. doi: 10.1057/palgrave/ivs/9500009

Chen, C. (2004). *Information visualization: Beyond the horizon*. Retrieved March 02, 2010, from http://books.google.com/books?id=cZfpebuEX4gC&printsec=frontcover&source=gbs_v2_summary_r&cad=0#v=onepage&q&f=false

Chen, L. C., Teo, T. A., & Liu, C. L. (2006). The geometrical comparisons of RSM and RFM for FORMOSAT-2 satellite images. *Photogrammetric Engineering & Remote Sensing*, *72*(5), 573-579.

Clarke, T. A., & Fryer, J. G. (1998). The development of camera calibration methods and models. *The Photogrammetric Record*, *16*(91), 51-66.

Craig, N. M. (2010, January 5). Automatic reconstruction conduit (ARC) 3D. *AnthSpace@PSU: Anthropology analytical cartography and geographic information system lab at the Pennsylvania State University*. Retrieved May 15, 2010, from http://www.personal.psu.edu/nmc15/blogs/anthspace/2010/01/automatic-reconstruction-conduit-arc-3d.html

Denzin, N. K., & Lincoln, Y. S. (2000). *Handbook of qualitative research*. Thousand Oaks, Calif.: Sage Publications.

Dorffner, L., Kraus, K., Tschanner, J., Altan, O., Külür, S., & Toz, G. (2000). Hagia Sophia: Photogrammetric record of a world cultural heritage. *International Archives of Photogrammetry and Remote Sensing*, *33*(B5/1), 172-178.

Eden, B. L. (2005). The future of 2D and 3D: Information visualization in information organizations. In *3D visualization techniques: 2D and 3D information visualization resources, applications, and future*. Chicago, IL: ALA TechSource.

El-Hakim, S. F., MacDonald, G., Lapointe, J., Gonzo, L., & Jemtrud, M. (2006). On the digital reconstruction and interactive presentation of heritage sites through time. In *The 7th international symposium on virtual reality, archaeology and cultural heritage Vast*. Retrieved May 13, 2010, from http://www.3dphotomodeling.org/VAST2006-243-250.pdf

Emery, D., Toth, M. B., & Noel, W. (2009). The convergence of information technology and data management for digital imaging in museums. *Museum Management and Curatorship*, *24*(4), 337-356. doi: 10.1080/09647770903314712

ERDAS product information: ERDAS imagine. (n.d.). *ERDAS, Inc. -- The earth to business company*. Retrieved April 15, 2010, from http://www.erdas.com/tabid/84/currentid/1050/default.aspx

EXIF information. (n.d.). *Digicam help: Digital camera help for beginners and beyond*. Retrieved May 16, 2010, from http://www.digicamhelp.com/glossary/exif-data/

Flick, U. (2002). *An introduction to qualitative research*. London: SAGE Publications.

Geospatial metadata standards. (n.d.). *FGDC: Federal Geographic Data Committee*. Retrieved April 15, 2010, from http://www.fgdc.gov/metadata/geospatial-metadata-standards

Glossary. (n.d.). In *Repair and maintenance manuals - Integrated publishing*. Retrieved May 20, 2010, from http://www.tpub.com/content/photography/14209/css/14209_375.htm

Glossary - ArcGIS resource centers. (n.d.). *ArcGIS resource centers: Integrated support and community resources*. Retrieved May 15, 2010, from http://resources.arcgis.com/zh-CN/glossary/term/1915

Glossary - News, guides and tips. (n.d.). *Comcorder info*. Retrieved May 18, 2010, from http://www.camcorderinfo.com/content/Glossary.htm

Glossary - SketchUp Help. (n.d.). *Google SketchUp*. Retrieved May 18, 2010, from http://sketchup.google.com/support/bin/answer.py?hl=en&answer=154080

Glossary of digital photography terminology. (n.d.). *Digital photography and Photoshop tips and tricks*. Retrieved April 02, 2010, from http://www.digital-photography-tips.net/digital-photography-terminology.html

Glossary of remote sensing terms. (n.d.). *Canada Centre for Remote Sensing*. Retrieved May 18, 2010, from http://cct.rncan.gc.ca/glossary/index_e.php?id=196

Google Earth. (n.d.). Retrieved March 15, 2010, from http://earth.google.com/

Google SketchUp. (n.d.). Retrieved March 15, 2010, from http://sketchup.google.com/intl/en/product/gsu.html

Grün, A., Remondino, F., & Zhang, L. (2004). Photogrammetric reconstruction of the Great Buddha of Bamiyan, Afghanistan. *Photogrammetric Record*, *19*(107), 177-199.

Guidelines for handling image metadata: Version 1.0.1. (2009, February). *Metadata Working Group (MWG)*. Retrieved February 14, 2010, from http://www.metadataworkinggroup.org/specs/

Guidelines for procurement of professional aerial imagery, photogrammetry, Lidar and related remote sensor-based geospatial mapping services. (2008). *Photogrammetric Engineering & Remote Sensing*, 1286-1295. Retrieved May 10, 2010, from http://www.asprs.org/publications/pers/2008journal/november/highlight1.pdf

Henke, K., & Grussenmayer, P. (2002). Architectural photogrammetry: Basic, theory, procedures and tools. In *ISPRS Commission 5 tutorial*. Corfu, Greece.

Huttenlocher, D. P., Klanderm, G. A., & Rucklidge, W. J. (1993). Comparing images using the Hausdorff distance. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *15*(9), 850-863.

Karras, G. E., Petsa, E., Dimarogona, A., & Kouroupis, S. (2001). Photo-textured rendering of developable surfaces in architectural photogrammetry. In *International symposium on virtual and augmented architecture (VAA01)*. Retrieved April 2, 2010, from http://www.survey.ntua.gr/main/labs/photo/staff/gkarras/Karras_Vaa01.pdf

Kasser, M., & Egels, Y. (2001). *Digital photogrammetry*. London: Taylor & Francis.

Koutsoudis, A., Arnaoutoglou, F., & Chamzas, C. (2007). On 3D reconstruction of the old city of Xanthi. A minimum budget approach to virtual touring based on photogrammetry. *Journal of Cultural Heritage*, *8*(1), 26-31. doi: 10.1016/j.culher.2006.08.003

Lensch, H. P., Goesele, M., Kautz, J., & Seidel, H. (2001, September). A framework for the acquisition, processing, transmission, and interactive display of high quality 3D models on the web. In *Tutorial notes for DAGM 2001*. Retrieved March 15, 2010.

Also published as Research Report MPI-I-2001-4-005, Max-Planck-Institut für Informatik, Germany.

Lerma, J. L., Navarro, S., Cabrelles, M., & Villaverde, V. (2010). Terrestrial laser scanning and close range photogrammetrynext term for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study. *Journal of Archaeological Science*, *37*(3), 499-507. doi: doi:10.1016/j.jas.2009.10.011

Lynch-Johnt, B. A., & Perkins, M. (2008). *Illustrated dictionary of photography*. Retrieved May 29, 2010, from http://books.google.com/books?id=ERoH4jlrU5IC&pg=PA15&dq=blocked-up+shadows+crushed&lr=&as_brr=3&as_pt=ALLTYPES&ei=6K-XSZnbJJvgkATZ_OjlCQ#v=onepage&q=blocked-up%20shadows%20crushed&f=false

Martynenko, A. (2001). Digital earth based on metadata electronic standard. *Proceedings of the 21st ICA international cartographic conference* (Vol. 4, pp. 2747-2752).

Meng, L., & Forberg, A. (2005). 3D building generalisation. In W. Mackaness, A. Ruas, & T. Sarjakoski (Authors), *Challenges in the portrayal of geographic information: Issues of generalisation and multi scale representation*. Retrieved March 14, 2010, from http://129.187.175.5/lfkwebsite/fileadmin/user_upload/publications/meng/paper/chap11-final.pdf

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks: Sage Publications.

Modeling a city: A guide for creating your Google Earth environment. (n.d.). *Google 3D Warehouse*. Retrieved April 25, 2010, from http://www.google.com/intl/en/sketchup/3dwh/pdfs/modeling_a_city.pdf

More detail about _MG_1388. (2010, March 7). In *Flickr - Photo Sharing*. Retrieved April 16, 2010, from http://www.flickr.com/photos/29742565@N04/4415623785/meta/ (Originally photographed 2010, March 7)

National geospatial data standards. (n.d.). *USGS - Sience for a changing world: National geospatial data standards*. Retrieved April 15, 2010, from http://nationalmap.gov/gio/standards/

NSL photography's glossary of photographic terms - D [Web log post]. (2008, January). Retrieved May 17, 2010, from http://www.nslphotographyblog.com/2008/01/nsl-photographys-glossary-of_8277.html

Paparoditis, N., & Dissard, O. (2002). 3D data acquisition from visible images. In M. Kasser & Y. Egels (Authors), *Digital photogrammetry* (pp. 168-218). CRC Press.

Patias, P. (2006). Cultural heritage documentation. In *International summer school "Digital recording and 3D modeling"*. Retrieved February 12, 2010, from http://www.photogrammetry.ethz.ch/summerschool/pdf/15_2_Patias_CHD.pdf

Photogrammetric terms [Web log post]. (2006, August 01). Retrieved May 01, 2010, from http://venutm.blogspot.com/2006/08/photogrammetric-terms.html

Photogrammy: User community site for PhotoModeler & photogrammetry. (n.d.). Retrieved March 13, 2010, from http://www.photogrammy.de/

PhotoModeler - Accurate and affordable 3D photogrammetry measurement and scanning. (n.d.). *PhotoModeler - Measuring and modeling the real world*. Retrieved May 15, 2010, from http://www.photomodeler.com/index.htm

PhotoModeler - Glossary. (n.d.). *PhotoModeler - Accurate and affordable 3D photogrammetry measurement and scanning*. Retrieved April 09, 2010, from http://www.photomodeler.com/support/glossary.htm

Pickard, A. J. (2007). *Research methods in information*. London: Facet.

Pitikakis, M., Salamin, P., Thalmann, D., & Catalano, C. (2009, March 27). *Deliverable D2.4.1 of task T2.4: State-of-the-art report on 3D content in archaeology and cultural heritage* (Rep.). Retrieved February 14, 2010, from The FOCUS K3D Consortium website: http://195.251.17.14/downloads/project-deliverables/D2.4.1-final.pdf

Rau, J. Y., Chen, N. Y., & Chen, L. C. (2002). True orthophoto generation of built-up areas using multi-view images. *Photogrammetric Engineering and Remote Sensing*, *68*(6), 581-588.

Remondino, F., & Fraser, C. (2006). Digital camera calibration methods: Considerations and comparisons. *International Archives of Photogrammetry, Remote Sensing and the Spatial Sciences*, *36*(5), 266-272.

Remote sensing glossary - R. (n.d.). *CASDE: Virtual Nebraska*. Retrieved May 04, 2010, from http://www.casde.unl.edu/glossary/r.php

Shiaw, H. Y., Jacob, R. J., & Crane, G. R. (2004). The 3D vase museum:a new approach to context in a digital library. In *JCDL' 04* (pp. 125-134). ACM.

SOCET set software overview. (n.d.). *BAE systems GXP geospatial exploitation products*. Retrieved May 15, 2010, from http://www.socetgxp.com/content/products/socet-set

Standards for the preparation of digital geospatial metadata. (1997). *National Mapping Program: Technical Instructions*. Retrieved March 2, 2010, from http://rockyweb.cr.usgs.gov/nmpstds/acrodocs/meta/PMETA997.PDF

Statistics glossary: Residual. (n.d.). *StatSoft: Electronic statistics textbook - Creators of statistical analysis software and services*. Retrieved May 15, 2010, from http://www.statsoft.com/textbook/statistics-glossary/r/button/r/

Strynatka, R. (2009, February 23). OGC standards working group: IGS-IGM [Web log post]. Retrieved May 02, 2010, from http://fiducialmark.blogspot.com/2009/02/ogc-standards-working-group-igs-igm.html

Stuerzlinger, W. (1999). Imaging all visible surfaces. In *Proceedings of the 1999 conference on Graphics interface '99* (pp. 115-122). San Francisco, CA: Morgan Kaufmann Inc.

Styliadis, A. D. (2007). Digital documentation of historical buildings with 3-d modeling functionality. *Automation in Construction*, *16*(4), 498-510. doi: 10.1016/j.autcon.2006.09.003

Styliadis, A. D., Akbaylar, I. I., Papadopoulou, D. A., Hasanagas, N. D., Roussa, S. A., & Sexidis, L. A. (2009). Metadata-based heritage sites modeling with e-learning functionality. *Journal of Cultural Heritage*, *10*(2), 296-312. doi: 10.1016/j.culher.2008.08.014

Terras, M. M. (2008). Current issues in digital imaging. In *Digital images for the information professional* (pp. 185-204). Aldershot, England: Ashgate.

Texture [Def. 3]. (n.d.). In *Wiktionary, a wiki-based open content dictionary*. Retrieved May 20, 2010, from http://en.wiktionary.org/wiki/texture

The GIS forum beta. (n.d.). Retrieved March 13, 2010, from http://www.thegisforum.com/

The photographic glossary. (n.d.). *Bristol commercial photographer and wedding photographer - Peter Ashby-Hayter*. Retrieved May 01, 2010, from http://www.peterashbyhayter.co.uk/glossaryF.html

Tolerance. (n.d.). *Dictionary, Encyclopedia and Thesaurus - The Free Dictionary*. Retrieved May 18, 2010, from http://www.thefreedictionary.com/tolerance

Virtuozo trademark details. (n.d.). *Electronics zibb: Electronics news, blogs, suppliers*. Retrieved May 16, 2010, from http://electronics.zibb.com/trademark/virtuozo/29737753

Willis, J. W., Jost, M., & Nilakanta, R. (2007). *Foundations of qualitative research: Interpretive and critical approaches*. London: SAGE.

Xu, C., Xinyan, Z., & Daosheng, D. (2008). Ontology based semantic Metadata for imagery and gridded data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *37*, 743-748.

Yastikli, N. (2007). Documentation of cultural heritage using digital photogrammetry and lasers canning. *Journal of Cultural Heritage*, *8*, 423-427. doi: 10.1016/j.culher.2007.06.003

APPENDIX 1: SAMPLE of INTERVIEW INVITATION

Dear…

I saw your blog/ models in Google Earth/ company website and I am very interested to know more about your work. As a Master student in Digital Library Learning (a cooperative effort between Oslo University College, Tallinn University and University of Parma), I am currently conducting research on Photogrammetry as a three-dimensional modeling technique for cultural heritage sites.

I would like to study the metadata features, standards and effectiveness of pictures taken for photogrammetry and how they are associated with the image qualifications. As you (work in… manage…), your knowledge in the area would provide key information and opinions to this study. I would like to invite you to participate in an online chat interview. The interview would last maximum half an hour and would be arranged at a time convenient to your schedule.

I look forward to hearing from you and appreciate your interest in my research.

Best regards,

Mehrnoosh Vahdat

APPENDIX 2: INTERVIEW QUESTIONS

1. What sort of work do you do in your company?
2. What is your background?
3. How long have you been working in this area?
4. How is your job related to photogrammetry?

   (Photogrammetry is a 3-dimensional coordinate measuring technique that uses photographs as the fundamental medium for measurement.)
5. What is the purpose of photogrammetry in your opinion? Do you think this technique plays an important role in cultural heritage documentation?
6. Do you use any standards regarding image qualifications as a base to acquire the 3D model?

   (Image format file, resolution, …)
7. How do you define quality authenticity or image data accuracy?

   (The attributes of image which leads to a more accurate 3D result)
8. Do you consider any metadata standards for images?
9. If you retrieve any picture to use as a 2D material, what are the metadata features you would consider more?
10. Do you think that image metadata contributes to the image quality? If yes, in which way? (example)
11. What kind of image metadata is crucial in photogrammetry? (example)
12. How can image metadata be useful for quality assessment?
13. How does image metadata affect the photogrammetry result (3D model)?

14. Are the initial image metadata useful and accessible by the users of 3D models? Or is it just useful for the process of building the 3D object?
15. How the image metadata affect the 3D metadata?
16. Are there any other important issues in this regard that we have not discussed?

APPENDIX 3: GLOSSARY

Camcorder:

"Camcorder is a transportable camera with the video tape recorder built in or otherwise attached" ("Glossary – News", n.d.)

Dublin Core:

"The Dublin Core is a metadata element set. It includes all DCMI terms (that is, refinements, encoding schemes, and controlled vocabulary terms) intended to facilitate discovery of resources" ("Guidelines for handling", 2009)

Ground truth:

"Information acquired by field study for the purpose of calibration and/or verification of remotely sensed data" ("Glossary of remote", n.d.)

Hausdorff distance:

"The Hausdorff distance measures the extent to which each point of a 'model' set lies near some point of an 'image' set and vice versa. Thus, this distance can be used to determine the degree of resemblance between two objects that are superimposed on one another" (Huttenlocher, Klanderm, & Rucklidge, 1993)

Orthogonal Image:

"An image taken from a top down or parallel angle" ("Glossary - SketchUp", n.d.)

Photogrammetrist:

"A professional who uses photogrammetric technology to extract measurements and make maps and interpret data from images" ("Certified photogrammetrist", 2009)

Residual:

"the difference between the observed values and the corresponding values that are predicted by the model and thus they represent the variance that is not explained by the model" ("Statistics glossary", n.d.).

Tolerance:

Tolerance in (Engineering / Mechanical Engineering) the permitted variation in some measurement or other characteristic of an object or workpiece ("Tolerance", n.d.)