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MASTERARBEIT

Simulation of Interactive Virtual Spaces

Creating a Virtual Archaeological Model of the Queen Meresankh III Mastaba

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Abstract

This project aims at exploring the potential of interactive spatial information visualisation in the context of Digital Archaeology. It researches theoretical aspects of virtual spaces as well as a practical case study looking at different ways of conveying archaeological information and displaying research work. A virtual model of the Queen Meresankh III Mastaba in Giza, Egypt has been used as a case study to show how interactive simulation tools can be utilised for archaeological visualisations. It investigates technologies for the following:

a. exchanging spatial information in digital documents,

b. visualising information in its spatial, geographical and historical contexts,

c. providing a walkthrough of a virtual space.

Possible software solutions for these categories are tested and evaluated in terms of functionality, usability, and applicability. The selected technologies - Adobe 3D PDF, Google Earth, and Unity function as spatial information systems. Besides providing real-time spatial experiences, the applications are tested specifically for archaeological and architectural information visualisations. The implemented functions focus on navigation and orientation, enhancing the understanding of archaeological inscriptions with translations, and implementing additional information about objects. Adobe 3D PDF focuses on the exchange of spatial information in digital documents (a), and advanced customised functions such as encoding metadata and linking to external databases are tested. Google Earth integrates maps, pictures, documents, 3D models, videos, etc. and relates the data to its spatial, geographical, and historical context (b). The game engine, Unity, supports customised user interaction, offers advanced rendering techniques, and provides a walkthrough of a virtual space (c).

Spatial information systems encourage users to explore and support their understanding of archaeological issues and architectural structures. Compared to non-interactive media such as pre-rendered movies and animations, interactive visualisations allow the user to control, combine, and to become actively involved with the information. Potential applications are used as an interactive teaching and learning tool, implementation in interactive exhibitions and museums, and also archaeological discovery process by facilitating information visualisation and exchange in research project support to name a few. New technologies offer a wide range of possibilities for bringing together formerly scattered or isolated information and thereby making archaeological data accessible. It is shown how archaeological information can be graphically visualised taking into account its spatial, temporal and thematic contexts. Spatial information visualisation is not yet established in the profession of archaeology, architecture or building science but it proves to have great potential.

Keywords: digital archaeology, information visualisation, 3D PDF, Google Earth, Unity, Meresankh III

To my parents

Contents

Preface

This thesis project has been initiated at the beginning of 2009 as an interdisciplinary project dealing with aspects of architecture, archaeology, and computer science. While defining and specifying the project's scope, a cooperation with both national and international museums and universities evolved. Besides collaborations between various institutes at the Vienna University of Technology, this thesis project was kindly supported by the Museum of Fine Arts in Boston, Museum of Fine Arts in Vienna and the Institute for Egyptology at Vienna University.

The idea behind this project developed from the question of whether current visualisation technologies could possibly be used and adapted for scientific purposes. Computers have infiltrated and changed nearly every aspect of our daily activities. More and more of the digital media we are surrounded by in our everyday lives facilitates interactive information sharing and collaboration worldwide. Web 2.0 illustrates the shift from passive information viewing towards interactive handling of digital content.

The interactive aspects of exploring both space and information are a key feature in this project. Interaction is tested to see if visualisation applications in architecture and other disciplines could serve as tools to present, share, and interact with spatial information for scientific purposes.

Preliminary reports of the ongoing research project have been presented at the *"14th International Congress, Cultural Heritage and New Technologies"* 2009 in Vienna and at the *"Workshop on Spatial Analysis in Past Built Environments"* held at the Freie Universität Berlin in 2010.
Parts of this thesis project have been published in the proceedings of the *"14th International Congress: Cultural Heritage and New Technologies"* titled "C*reating a Virtual Archaeological Model of the Queen Meresankh III Mastaba with Adobe 3D PDF"* (Stangl, Ferschin, Jánosi, & Kulitz, 2010).

1. Introduction

Every step in archaeological work from documentation, interpretation, communication, and publication deals with a huge amount of diverse information.

- Documenting archaeological excavations in both analogue and digital formats create a large amount of complex information from different media types. Information is often documented by different teams, stored in various data formats or even physically distributed in different locations.
- Doing archaeological research requires access to specific information which is often difficult to find. Libraries do not fulfil the requirements of providing comprehensive knowledge anymore. Sometimes it is not possible to access to the desired information sources without conducting an exhaustive research. Looking for information in online archives or databases often results in an information overload and a lack of the specifically required information.
- For publication purposes, information needs to be structured to communicate the research results. This conventional information structures, hierarchically or thematically, very often takes information out of its original context.

For archaeological applications, spatial information visualisation serves as means to encode visual and other information types in virtual models. Spatial information systems help to organise information during the documentation phase, support the research process, and can be implemented in digital publications. Digital information systems structure information, making it understandable and potentially exposing information to a wide audience.

Traditionally, information visualisation is defined as "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition" (Card, Mackinlay, & Shneiderman, 1999, p. 7). Ferschin et al. define information visualisation as a scientific discipline which „tries to generate visual structures from abstract data types, to achieve a better insight into complex data structures and also to provide new methods of interacting with data" (2004, p. 1).[1] This project explores a combination of spatial and information visualisation showing how research results together with high information density can be presented with the help of spatial information visualisations.

Interactive access to information encourages the recipient get actively involved with the subject. Interactive visualisation "allows the user to control, combine, and manipulate different types of information or media" (Burkhard, 2004, p. 4).

Building virtual models of real objects and encoding additional information into spatial objects creates a rich Virtual Environment

[1] An overview of information visualisation is given by Card et al. (1999) in *Readings in Information Visualization: Using Vision to Think*.

(VE). There are a number of scientific and educational applications which use VE techniques. Full immersive hardware and software VE applications continue to be costly and complex. For some scientific and training applications, complete immersion using whole-body input devices is mandatory although there are a number of scientific and educational applications where a "light" VE already fulfils the objectives. In many scientific applications, immersion and perfect realism are not the primary goals, but rather to use VE techniques to provide access to information and data models.

Recently huge progress in computational performance and 3D graphics of standard desktop computers has been made. Aside from high end solutions, this project investigates innovative and interactive visualisations focusing on hardware and software solutions for standard desktop computers.

Chapter 1 introduces different projects using digital information visualisations in Archaeology. The project's case study object - the Mastaba of Queen Meresankh III - and its significance for Archaeology is discussed.

Chapter 2 is devoted to theoretical aspects of the topic of virtual spaces. Concepts and functions of virtual spaces are introduced, and different forms of interaction and conceptual issues in modelling are discussed.

Chapter 3 looks at technologies for exchanging digital documents, visualising information in its overall context, and technologies for creating a virtual walkthrough experience. Three visualisation applications - Adobe 3D PDF, Goole Earth, and Unity - are tested and evaluated in the application to the case study of the Mastaba of Queen Meresankh III. The applications illustrate the variety and potentials of available visualisation technologies. Each application has its own background, characteristics, and limitations. The case study reviews each technology individually by reviewing the application's navigation, interface, usability, workflow, and other characteristics.

Chapter 4 concludes the case study and takes into account the strengths and specifications of each visualisation technology. Potential areas of application for the reviewed technologies are proposed and an outlook recommends future work of the project in different directions.

1.1. Digital Visualisations in Archaeology

The following projects exemplify different approaches to spatial information visualisation in Digital Archaeology using computer-based techniques and information technology for documenting, managing and visualising archaeological data. Common to all projects is the idea of developing tools and methods to encode and summarise information in its spatial context, and to provide interactive access to this information.

Theban Mapping Project

The Theban Mapping Project (www.thebanmappingproject.com) is an online archaeological database providing interactive information about Thebes. Focusing on the Valley of the Kings in Egypt the collected information is presented together with 3D computer models in a web interface. The tombs of the Kings Valley are shown in a scalable interactive map linking to further information about the tombs including detailed descriptions, video clips, maps, plans, and images. A perspective view of the tomb's 3D model serves as a reference for further information about specific parts.

Of special interest is a 3D tour through the tomb of Tausert and Setnakht (KV14). This predefined tour shows a narrated walk-through across the tomb's digital 3D model. The graphics are rendered abstractly (Fig. 1.2) while photos of the interiors surfaces are overlaid at various stops throughout the tour (Fig. 1.3, 1.4). Clicking on the yellow framed areas, the overlays can be viewed in detail and the tour is paused. A floor plan on the right side of the interface depicts the current location in the tomb. The user can either follow the tour chronologically or use the map to jump to a certain room and continue the tour from there.

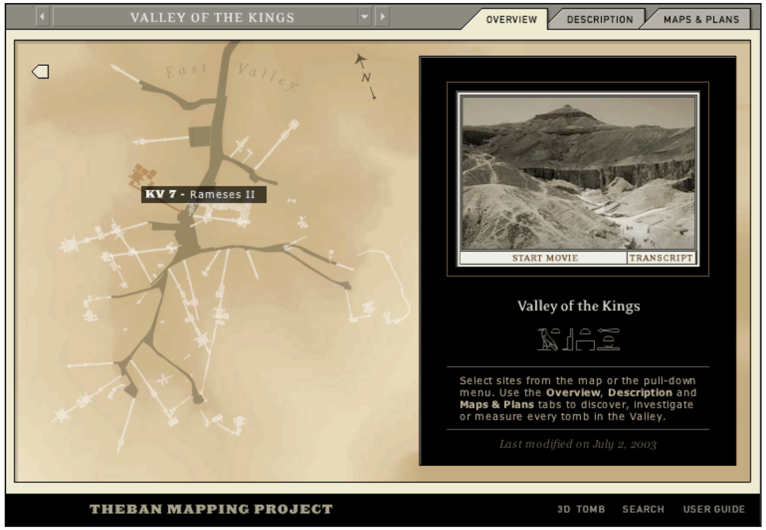

Fig. 1.1 Atlas of the Valley of the Kings (Theban Mapping Project, 2010).

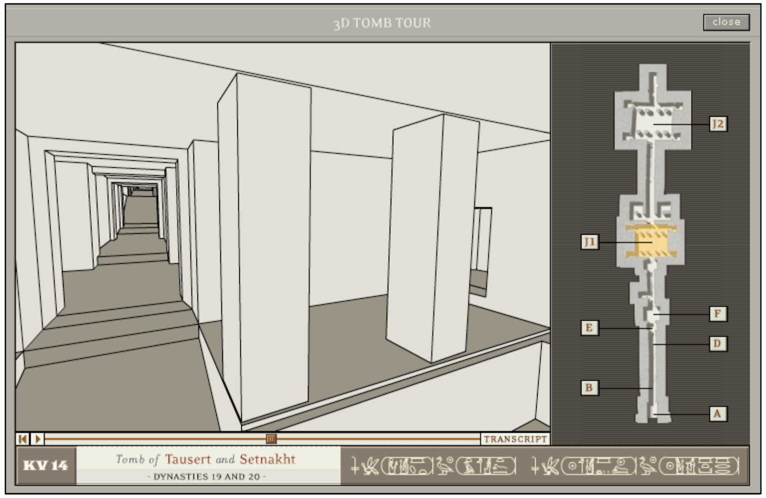

Fig. 1.2 3D model of tomb KV 14 (Theban Mapping Project, 2010) .

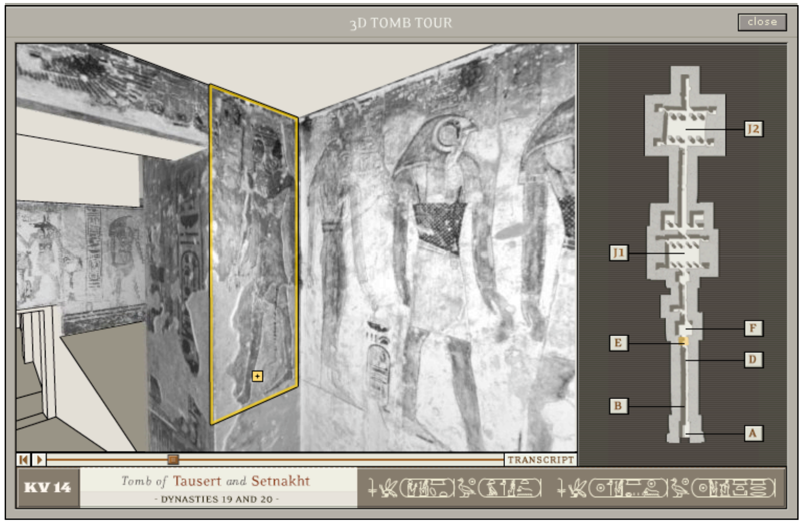

Fig. 1.3 Corridor in tomb KV 14: Overlaid photos of the interior surfaces during the walkthrough (Theban Mapping Project, 2010).

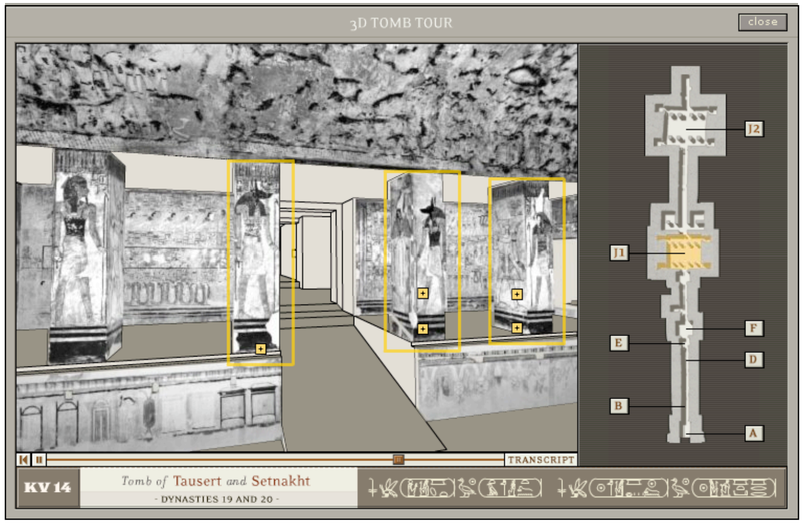

Fig. 1.4 Tomb of KV 14: Overlaid photos of the interior surfaces during the walkthrough (Theban Mapping Project, 2010).

ISEE - Method to Link Data in a 3D Environment

The project which was presented at the CAA 2007 in Berlin (Pecchioli, Mohamed, Carrozzino, & Leitner) proposes an intuitive method of accessing information in an interactive 3D model. The case study was a georeferenced 3D environment of the Piazza Napoleone in Lucca, Italy and included historical and architectural information of the urban development.

Relevant information about objects is provided regarding the user's current view in the 3D model. By freely navigating in the 3D environment, an ordered list of relevant information is generated from the underlying database taking into account the overlap between the currently viewed zone and the information zone (Fig. 1.5). The relevance of information is determined according to algorithms factoring in the overlap, and generating a ranked list of information which is constantly updated as the user moves in space.

Fig. 1.5 Concept of an interactive 3D viewer with the viewed area represented as a "green sphere" (left) and two information zones represented as "red spheres" (right) (Pecchioli, et al., 2007, p. 3).

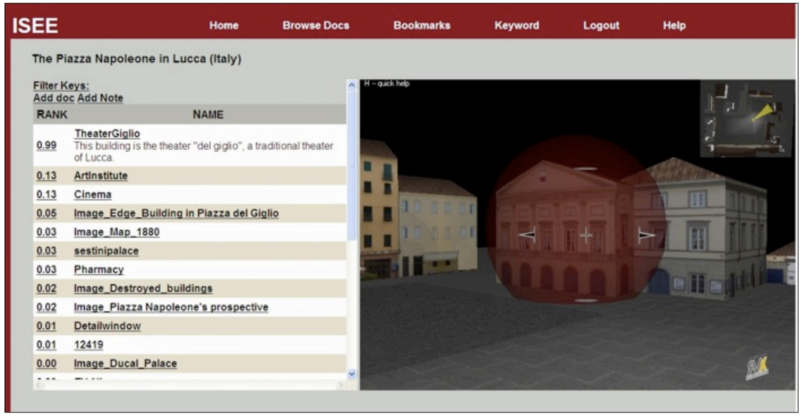

Fig. 1.6 Interface of the web based 3D viewer ISEE showing the Piazza Napoleone in Lucca, Italy (Pecchioli, 2010).

In order to address a wide audience, the project was developed to be able to run on common hardware and data could be transferred via the Internet (Fig. 1.6). This method was tested in a real world situation where the given information corresponds to the user's real geographic position using a GPS location device.

This project developed a method to handle and visualise large quantities of information in an interactive 3D environment. Additionally, it proposes an augmented reality (AR) solution which provides the user with additional information according to the real world current position. Further information about ISEE can be found on http://isee.kitabi.eu/.

The Giza Archives

The Giza Archives Project is listed as both a reference and a related visualisation project. It is an archaeological online database (www.gizapyramids.org) and offers the user the following: tombs, photographs, finds, expedition diary pages, maps and plans, books and articles, unpublished manuscripts, and interactive web technologies (scalable satellite photos, maps, and 360-degree panoramas). The digital library is based on the archive of the Museum of Fine Arts, Boston and provides free online access for scholarly research purposes on the Giza Necropolis. It is constantly extended and updated but also seeks to implement new technologies of providing access to online information.

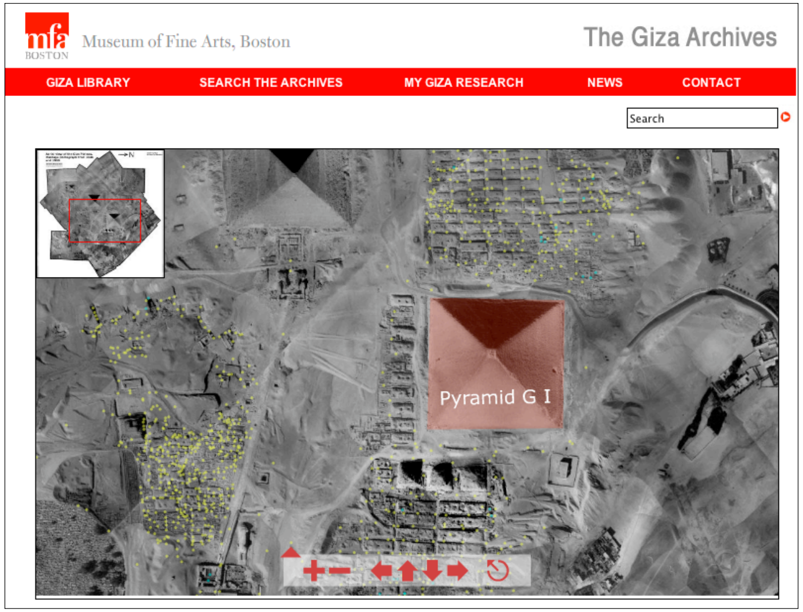

Fig. 1.7 Overview of Visual Search on an aerial photo of the Giza Plateau (The Giza Archives, 2010b).

Fig. 1.8 Detail of Visual Search on an aerial photo of the Giza Plateau (The Giza Archives, 2010b).

Besides text based database queries the visual search function allows users to browse the archive based on a scalable aerial view of the Giza Plateau (Fig. 1.7, 1.8). Rollover buttons on each tomb link to a database query providing additional information about the highlighted area on the map. Dots overlaid on the map link more than a thousand 360° degree panoramas.

The Virtual Forum of Carnuntum

A virtual three-dimensional model of the Forum Carnuntum (Austria) based on prospected data has been constructed as a cooperation project of the Department of Digital Architecture and Planning (IEMAR) at Vienna University of Technology and the Central Institute for Meteorology and Geodynamics (ZAMG), on behalf of the Archaeological Museum Carnuntinum. The project was exhibited in the Museum Carnuntinum in Bad Deutsch-Altenburg and enabled the visitor to discover virtually the ancient life at the Forum Carnuntum.

Fig. 1.9 Footstep-based navigation (P. Ferschin, personal communication, June 4, 2010).

The visitor navigates in an interactive walkthrough using footsteps in the virtual forum and receives visual feedback on a large projection screen. The visitor witnesses people's conversations, ancient ceremonies, and rituals which could have happened in the forum.

The project allows the visitor to have a virtual experience of a possible reconstruction within the forum. It shows how interactive navigation is implementable in an archaeological exhibition.

Fig. 1.10 Virtual Forum of Carnuntum (P. Ferschin, personal communication, June 4, 2010).

Fig. 1.11 Virtual Forum of Carnuntum (P. Ferschin, personal communication, June 4, 2010).

Google Earth as an Information System

A project by Kulitz and Ferschin (2009) proposes to use Google Earth as an information system to document and visualise archaeological excavations and research work. Google Earth serves as a geo-browser to store and provide network access to different forms of visual data: maps, photos, videos, panoramic images, virtual models. Research results using data from excavations in Elephantine and Siwa, are visualised within the 3D space of Google Earth. Since the dimension of time is of large interest in archaeological visualisations particular attention is paid to attribute the dimension of time to 2D and 3D information (Fig. 1.12).

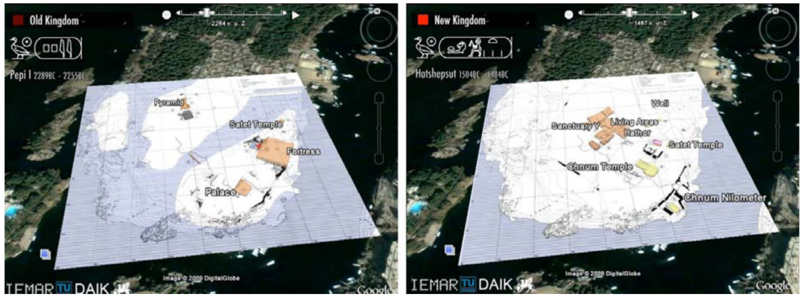

Fig. 1.12 Stages of development of Elephantine (Kulitz & Ferschin, 2009, p. 96).

3D models of reconstructed buildings are shown together with plans and sections. Videos serve as digital site notebooks and photos are positioned taking into account the viewpoint and viewing direction. Existing building parts and different levels of uncertainties of reconstructed elements are represented using different colours or by allowing the user to switch between possible versions of reconstruction. This project illustrates the potentials of Google Earth as a visualisation tool, particularly focusing on spatial and temporal referencing containing different kinds of media within its geographical context.

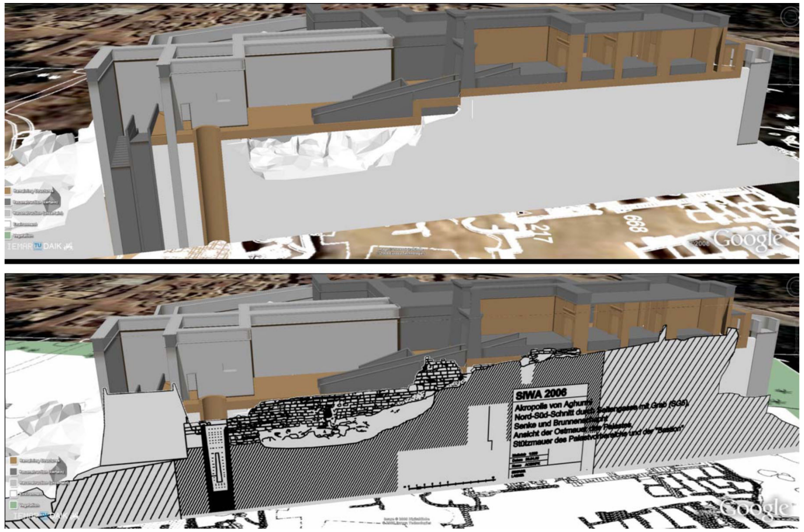

Fig. 1.13 3D-section (top) with integrated 2D-section (bottom) 3D model by Florian Hollweger (Kulitz & Ferschin, 2009, p. 95).

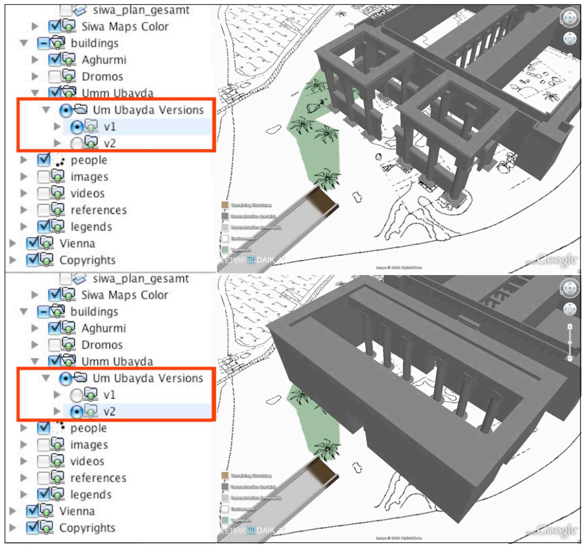

Fig. 1.14 Variations of hypothetical reconstruction of the Temple of Umm Ubayda, Siwa. 3D model by Florian Hollweger (Kulitz & Ferschin, 2009, p. 95).

Reconstruction of the Temple of Satet in Elephantine

This project was realised by Peter Matejowsky (2006) within the scope of a Master's Thesis. It focuses on the spatio-temporal aspects of digital reconstruction and visualisation of the Satet Temple in Elephantine, South Egypt. It uses Adobe 3D PDF visualisation technology to document the temple‘s architectonic evolution from the Predynastic to the Ptolemaic period. The digital reconstruction distinguishes between archaeological remains and virtual reconstruction and allows the comparison at different potential reconstructions.

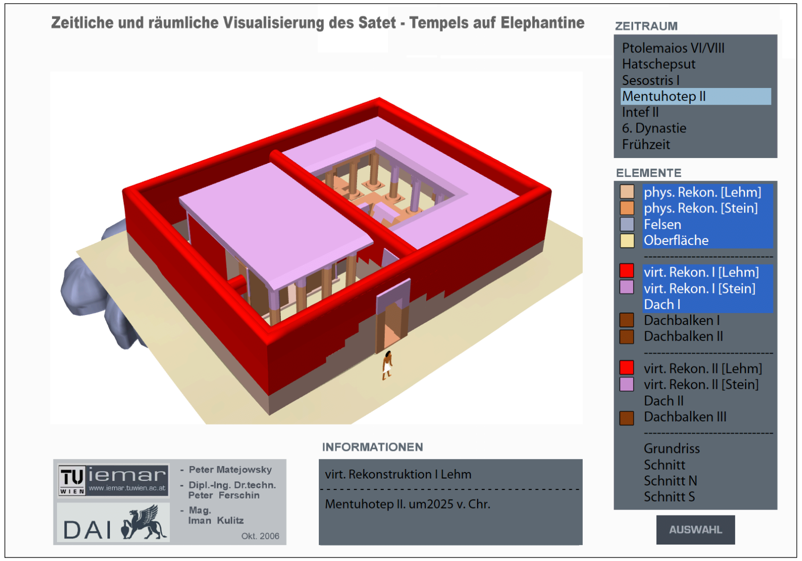

Fig. 1.15 Satet Temple under Pharaoh Mentuhotep II (reconstruction) (Matejowsky, 2006).

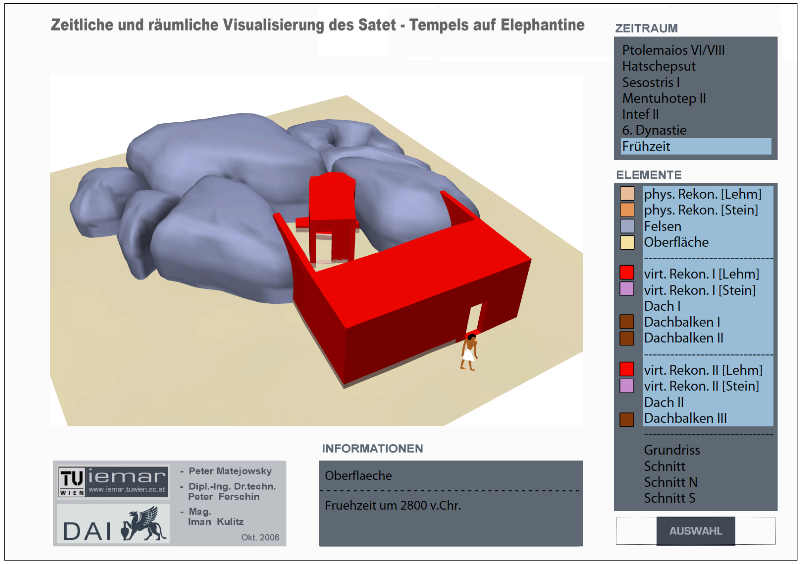

Fig. 1.16 Satet Temple in the Early Period (reconstruction) (Matejowsky, 2006).

The project shows how time and digital reconstruction variations can be visualised in an interactive digital building model using Adobe 3D PDF.

Conclusion

These projects show the variety of technologies and the different fields of applications of interactive spatial information visualisation in archaeology and architecture. The above-mentioned technologies range from desktop applications, scientific visualisations, and the design of interactive virtual exhibitions using high performance rendering and projection.

1.2. Funerary Architecture of the Old Kingdom

The mastaba was the typical tomb form in the old Egyptian history, with a rectangular superstructure and slightly outward sloping walls made of crude brick or limestone blocks (cf. Leick, 1988, p. 133). The name is derived from the Arabic word for bench; when seen from a distance, the mastaba resembles the shape of a bench. Early examples date to the First Dynasty and are found at Nagada, Tarkhan, and Saqqara.

Since the beginning, there have been two types of mastabas: one with a series of panelled niches, and the other with smooth outer walls. The panelled mastaba consisted of a superstructure with numerous 'cells' which were used as magazines for storing offerings. The cells in the middle of the mastaba functioned as burial chambers and were deepened below ground level. There have been several offering places on all four sides. The shape of the panelling resembles the facade of palaces (Fig. 1.17).

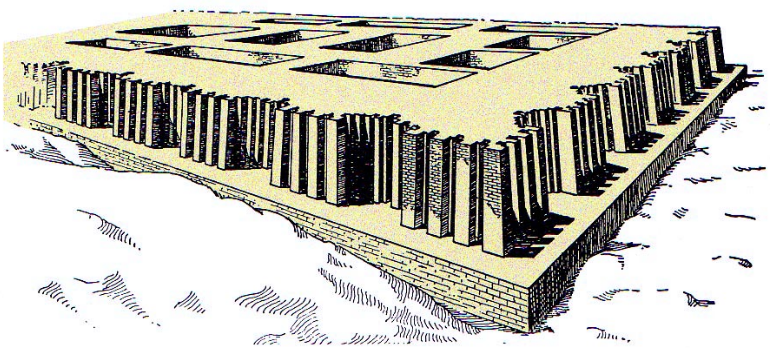

Fig. 1.17 Reconstruction of a panelled mastaba of the First Dynasty in Negade, Egypt (Jánosi, 2006, p. 7).

The second type of mastaba with smooth outer walls is usually oriented north-south with two open offering places on the eastern side. The burial chamber is dug into the ground and located beneath the superstructure. It was accessible from the roof via a deep vertical stone lined shaft (Fig. 1.18).

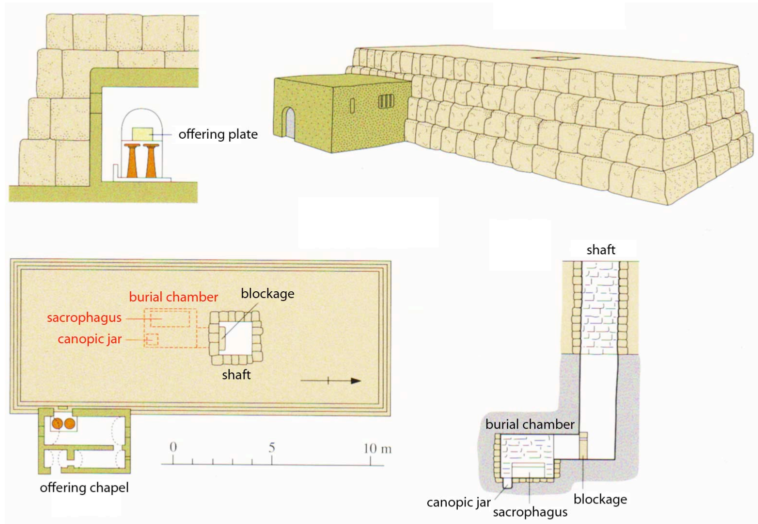

Fig. 1.18 Reconstruction of a typical mastaba under the reign of Cheops at Giza (4th Dynasty of the Old Kingdom). Adapted from Jánosi (2006, p. 52).

The offering places of both mastaba types were used for the offerings to the dead and included a false door. According to the Egyptian belief, the false door acts as the interface between this life and the afterlife.

While the panelled mastaba was prevalent in the first three dynasties, it was suppressed by the more simpler form with smooth walls in the Third Dynasty. The mastaba's superstructure was improved "by adding layers of brickwork around the base to prevent lateral penetration. It was this layer mastaba which developed into the layer or step pyramid of stone and finally into the true pyramid"

(Reisner, 1934, p. 580). During the transition of the Third to the Fourth Dynasty, the offering chapel was integrated into the mastaba structure and developed into decorated cross-shaped chapels. At that time, the mastaba became a popular tomb for eminent Egyptians such as members of royal families, high officials and their families, while kings were buried in pyramids.

Each mastaba is individual and unique, even though nearly all mastabas follow the same basic structure (cf. Jánosi, 2006, p. 5). The mastaba's shape and its spatial organisation of both substructure and superstructure have been subject to architectural evolution throughout time also showing regional differences.

Fig. 1.19 Mastabas on the Giza Necropolis, looking west. Adapted from Hawass (Hawass, 2003, p. 129).

Fig. 1.20 Double-mastabas in the norther part of the Eastern Cemetery (G 7000), Giza (Jánosi, 2006, p. 49).

Multiple cemeteries are located in Lower Egypt in the necropolises at Giza, Saqqara, and Dahshur. On the Giza Necropolis, several fields of mastabas in different sizes have been constructed with the pyramids, following an organised and uniform layout (Fig. 1.19). Under the reign of Cheops, the initial shapes of many mastabas were modified, changing the layout of the cemeteries substantially. In several building phases, chapels and chambers were incorporated into the initial solid mastaba; or two mastabas were joined to double-mastabas (cf. Jánosi, 2006, p. 55). During the Fourth and Fifth Dynasties the number of rooms increased and the mastaba evolved into a house-like building with an entrance hall, a columned hall, and multiple chambers (cf. Arnold, 2000, p. 148).

At the end of Chephren's reign (ca. 2555 BC), a new type of so called rock-cut tombs appeared. They were located in quarries close to the cemeteries and pyramid fields (Fig. 1.21). The typical layout shows a long, rectangular room with pillars or columns cut out of the rock, one or several false doors, and niches for the statues. The burial pit leads from the decorated chapel to a simple burial chamber. Following the concept of traditional mastaba forms, the outer walls of the rock-cut tombs were slightly sloped; exceptions had an additional mastaba superstructure on top of the tomb.

Fig. 1.21 Entrances to several rock-cut tombs in the former quarry for the Cheops and Chephren pyramid in Giza (Jánosi, 2006, p. 62).

In Giza, members of the royal family of King Cheops were buried in pyramid-like or expanded (double) mastaba tombs. Members of the royal family of King Chephren, however, used this new type of rock-cut tombs for their burials. The tomb of Queen Meresankh III, wife of King Chephren, is an example of this combination of a rock-cut tomb with a mastaba superstructure.

The mastaba architecture was superseded by rock-cut tombs which became the prevalent tomb type until late Egyptian history.

1.3. The Mastaba of Queen Meresankh III

The study model in this project is located in the archaeological site in Giza, Egypt. The Mastaba of Queen Meresankh III (G 7530sub) is in the Eastern Cemetery (G7000) of the Giza Plateau and was discovered by George A. Reisner of the Harvard University-Museum of Fine Arts, Boston Expedition in 1927.

Fig. 1.22 Egypt, Giza in Google Earth (29°58'42.92"N, 31° 8'13.32"E) (Google Inc., 2010a).

Fig. 1.23 Giza Necropolis in Google Earth (29°58'40.11"N, 31° 8'15.98"E) (Google Inc., 2010a).

The mastaba consists of an upper mastaba (G7530/7540) and a lower rock-cut tomb (G 7530sub). The tomb G 7530sub is made up of three rooms and a subjacent burial chamber (Fig. 1.21). The main chamber continues to a smaller chamber to the north and an offering chamber to the west. A rectangular pit approximately 2 meters square and 5 meter deep in the floor of the offering chamber leads to the burial chamber below with a granite sarcophagus. The sarcophagus when excavated, was plundered (Reisner, 1927, p. 78). Today, the sarcophagus and its skeleton are exhibited in the Egyptian Museum in Cairo.

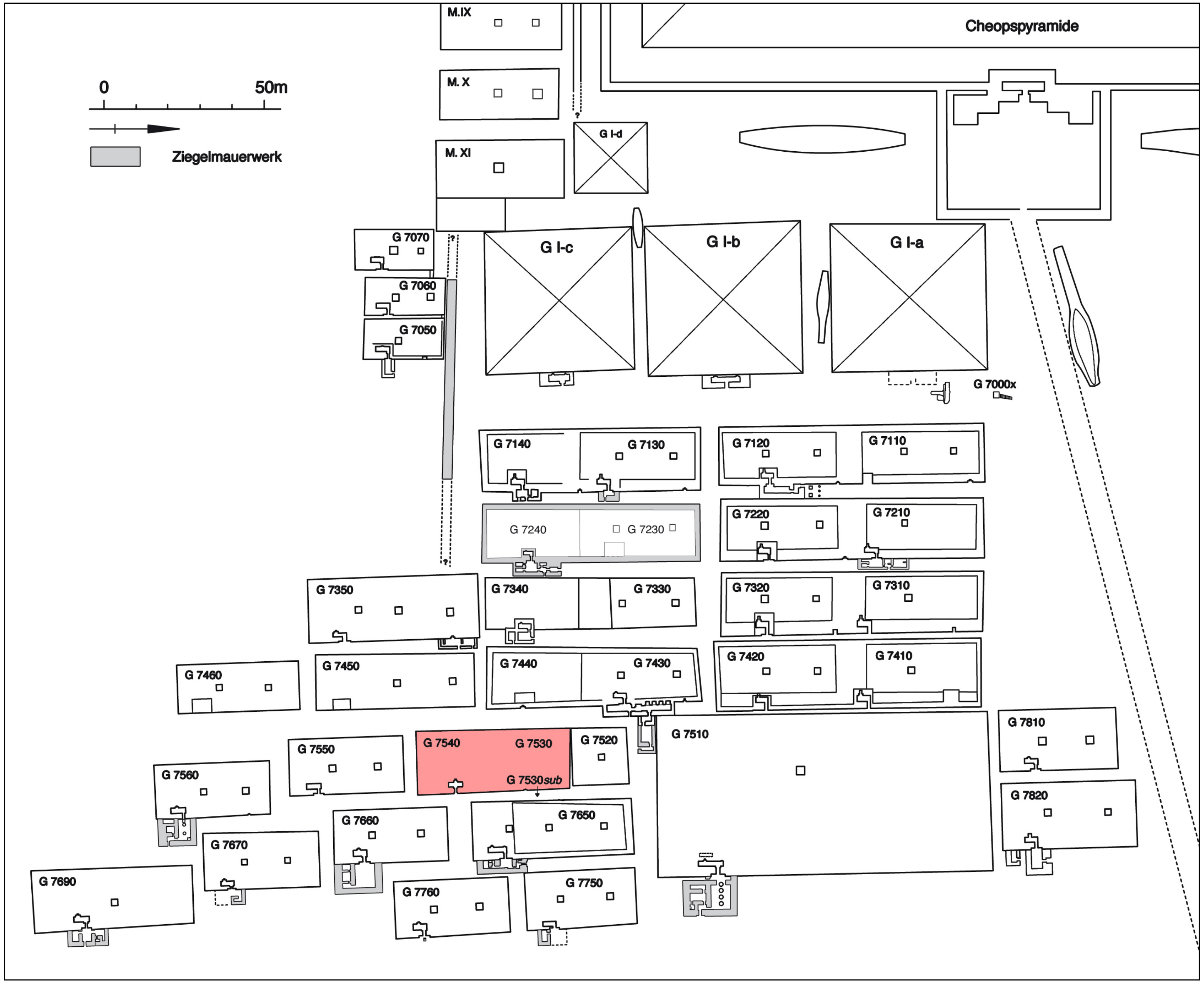

Fig. 1.24 Plan of Eastern Cemetery G 7000 (marked: Mastaba of Queen Meresankh III). Adapted from P. Jánosi (personal communication, May 20, 2009).

Reisner vividly describes the moments of the tomb's discovery in 1927:

> "On the very last day of the season the gangs were clearing the eastern face of the third mastaba in the fifth row from the west, when a doorway was unexpectedly revealed in the rock under the eastern wall of this mastaba. […] Above the doorway were inscribed the titles of a princess and queen named Meresankh. As soon as the debris in the doorway was photographed we cleared away enough of the sand at the top to crawl in; and getting our heads, one at a time, just inside the doorway, we saw a rock-cut offering chapel consisting of three rooms. The entrance to the main room was blocked by a cone of sand and stone, on the top of which we were lying. Our eyes were first startled by the vivid colors of the reliefs and inscriptions around the northern part of this large chamber. None of us had ever seen anything like it."
>
> (Reisner, 1927, p. 64)

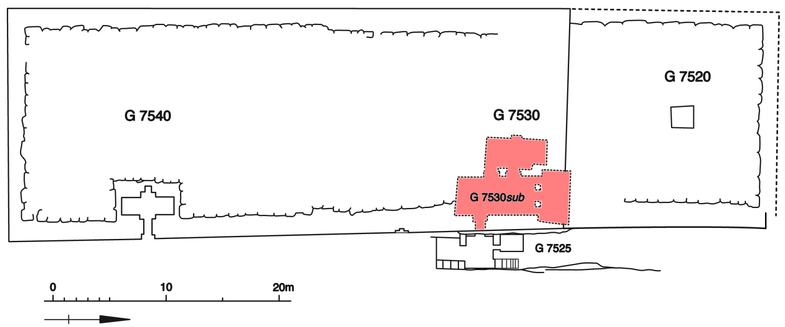

Fig. 1.25 Position of tomb of Queen Meresankh III (G 7530sub) in G 7530/7540. Adapted from P. Jánosi (personal communication, May 20, 2009).

The mastaba of Meresankh is considered as the best preserved tomb chapel in the Eastern Cemetery with a large amount of statuary cut into the tomb walls (Fig. 1.21) (cf. Dunham & Simpson, 1974b, p. 7). Inscriptions on the casing blocks date the mastaba to the Fourth Dynasty of the Old Kingdom ca. 2600 - 2480 BC (cf. Dunham & Simpson, 1974b, p. 7). "An overall assessment of the archaeological and art historical evidence presented by mastaba G7530/7540 and the rock-cut tomb of Meresankh III (G7530sub) suggests that the two chapels are connected through their decorative programs, including the iconography and stylistic features, and may date to the same period, namely the end of the Fourth Dynasty" (Flentye, 2006, p. 75).

Meresankh is the daughter of Hetepheres II and Prince Kawab, and as mentioned before she was married to the pharaoh Chephren. It is believed that the mastaba was originally planned as a tomb for her mother, Hetepheres II, but instead she donated it to her daughter Meresankh. This theory is based on inscriptions on the black granite sarcophagus which state that the sarcophagus was given to Meresankh by her mother (cf. Dunham & Simpson, 1974b, p. 8).[2]

[2] An overview of the mastaba is given by D. Dunham and W. K. Simpson in *The Mastaba of Queen Mersyankh III* (1974a).

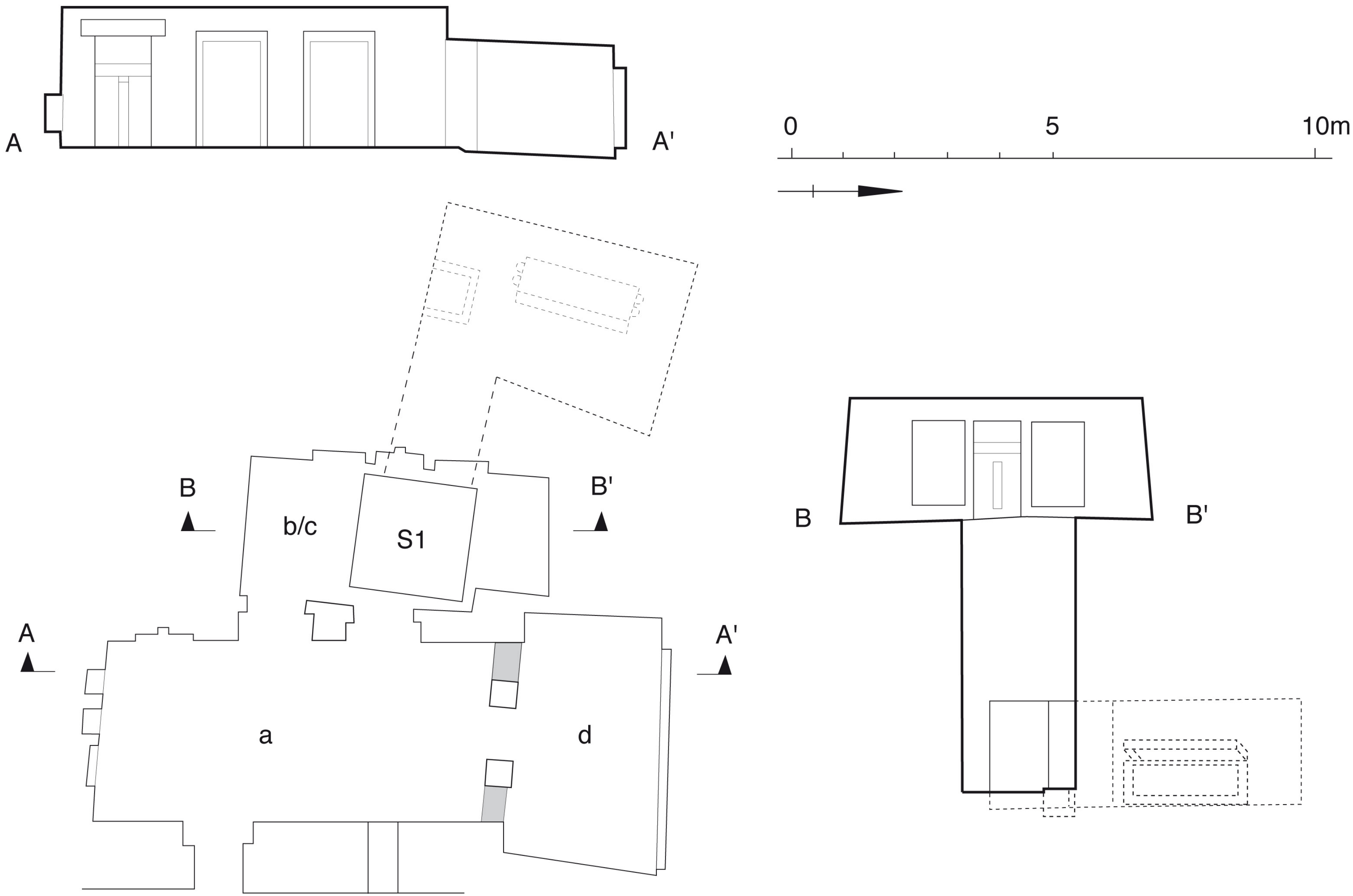

Fig. 1.26 Plans of tomb of Queen Meresankh III (G 7530sub) (P. Jánosi, personal communication, May 20, 2009).

1.3.1. Archaeological Interest

The mastaba is of great archaeological relevance as it is unusual and recognisable in many ways. Unlike most mastabas of the Eastern Cemetery, the mastaba (G7530/7540) does not include a burial shaft (cf. Flentye, 2006, p. 71). Furthermore, the tomb chapel is unusual as it is placed beneath the large mastaba. The entrance is approached by descending stairs from both the south and north sides entering the main chamber approximately two meters below ground level from a narrow open court. There are multiple rock-cut standing figures in wall niches in one of the first tombs, which became a popular decoration in subsequent eras (cf. Jánosi, 2006, p. 71). Most statues are standing, life-sized figures and represent the principal women of the family: Meresankh, Hetepheres (mother of Meresankh), and the daughters of Meresankh (Fig. 1.22) (cf. Dunham & Simpson, 1974b, p. 20). In the main room smaller seated figures in scribal position are situated in the lower part of the south wall.

Besides the extensive use of statuary, there are scenes in relief presenting extraordinary preservation of the vivid colours, Fig. 1.28, as well as great technical and artistic achievements of the sculptors and painters (cf. Dunham & Simpson, 1974a, p. 1). The wall's rich iconographic program shows 'daily life' scenes such as craftsmen working, sowing of seeds, bird trapping, and boat combats in the water. The paintings are mostly accompanied by hieroglyphic texts.

This mastaba served as an example of many tombs of the Fifth Dynasty in terms of decorative programs and iconography (cf. Jánosi, 2006, p. 71).

Fig. 1.27 Row of rock-cut statues in Chapel Room, looking north-east (Hawass, 2003, p. 203).

1.3.2. Interest from a Visualisation Point of View

Why choose an archaeological study model? Archaeology is a challenging field to test new visualisation technologies in a rich and complex environment. Digital Archaeology uses documentation and visualisation methods to explore how new technologies can contribute to scientific archaeological work. It applies visualisation techniques to structure and visualise information. Archaeology provides the opportunity to encode visual and other information in real built environments thereby making it accessible and understandable.

Increasing computing power allows larger amounts of different types of information to be processed. This creates many new ways to make archaeological information accessible for exhibitions, academic teaching, and scientific research.

Besides archaeological and visualisation interests, the Mastaba has been chosen as a study model because of its size, complexity, and quantity of readily accessible information.

Fig. 1.28 Main chamber looking north-east (Hawass, 2003, p. 202).

2. Virtual Spaces

"We want to create the effect of interacting with things, not with pictures of things."
(Bryson, 1996, p. 63)

The first attempts of creating interactive Virtual Environments[3] (VE) with 2D Graphical User Interfaces (GUI) date back to the early 1960s. Ivan Sutherland first developed an interactive device to draw vector lines on a computer screen named Sketchpad at the MIT Lincoln Laboratory (Fig. 2.1). The Sketchpad "made fundamental contributions in the area of human–computer interaction, being one of the first GUI. It exploited the light-pen, a predecessor of the mouse, allowing the user to point at and interact with objects displayed on a screen. The light-pen anticipated many contemporary interactive conventions of direct manipulation, including clicking a button to select a visible object, and dragging to modify it" (Blackwell & Rodden, 2003, p. 3). Since this pioneering breakthrough in human-computer interaction, a long path of multidisciplinary research and development has been followed to develop contemporary high-end Computer Aided Design (CAD) and Virtual Reality (VR) simulations.

"In many ways, the major impact of virtual reality technology on scientific visualisation is in providing a "real-time" intuitive interface for exploring data while facilitating the use of scientific visualisation in the research process."
(Bryson, 1996, p. 65)

Fig. 2.1 1963: The Sketchpad developed by Ivan Sutherland uses a light-pen to interact with objects on the screen (Schwarz, 1997, p. 61).

[3] The terms Virtual Environment (VE) Virtual Space, and Virtual Reality (VR) are used interchangeably.

Today, VR applications have evolved into valuable tools and face a multitude of applications in many disciplines and professions science, industry, and entertainment. To name but few applications, VR technologies are used in building simulations, urban planning, teaching, surgical testing and training, pilot training programs, video games or for decision making during the aircraft and automobile design (Fig. 2.2). However, "in some cases, the advancement of tools and techniques for achieving greater visual realism has distracted from the development of other directions that enhance a virtual experience, such as interactivity, sound or touch" (Roussou & Drettakis, 2003, p. 51).

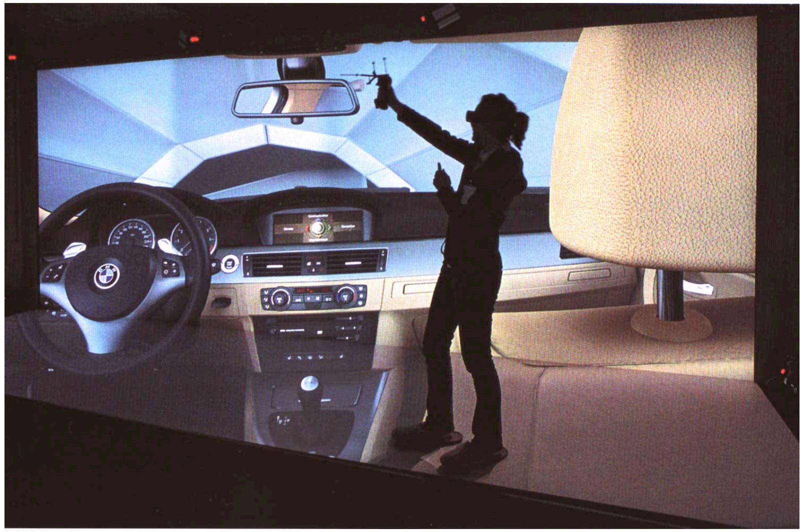

Fig. 2.2 2007: Powerwall (10x3m) in BMW research and innovation centre, Munich: high-end visualisation equipment (Kaltenbach, 2007, p. 1490).

2.1. Definition

Despite its diversity, most definitions of VE follow a similar direction and describe VE as "the representation of a computer model or database, which can be interactively experienced and manipulated by the virtual environment participant(s)" (Barfield & Furness, 1995, p. 4). Similarly, Bryson defines VR as "the use of computer and human-computer interfaces to create the effect of a three-dimensional world containing interactive objects with a strong sense of three dimensional presence" (1996, p. 62). Distinguishing VE from other media, Shiratuddin et al. describe VR "as immersive virtual environments made of systems that allow participants to experience interactive computer generated worlds from a first-person perspective, as opposed to pre-rendered movies, videos or animations" (2008, p. 4). Taking a phenomenological position Qvortrup defines virtual spaces as a "technologically supported representation of space experience" (2002, p. 7).

2.2. Concepts of Virtual Space

Looking at Virtual Spaces from a theoretical and methodological point of view, there has not always been a consensus about the relationship of virtual and real spaces. Qvortrup (cf. 2002, p. 6) opposes a phenomenological approach of virtual space to the positivistic concept which constitutes virtual space as a parallel world to the real world and to the dualistic position which defines cyberspace as a parallel representation of real space.

2.2.1. Phenomenological Concept

The phenomenological concept of space can be considered as a cognitive theory where space is constituted by the observer´s practical and cognitive experience of space. That means virtual space does not represent the real world as such but it matches the constitutional aspects of the human beings' space experience. Qvortrup defines virtual reality techniques as the "representations of fundamental space experience attributes and not of attributes of space as such" (2002, p. 5).

> "When we build cyberspaces we neither build parallel worlds with their own ontologies, nor do we build models that simply reflect the real space or the real world. When we build cyberspaces we build space experience representations."
> (Qvortrup, 2002, p. 6)

Following Qvortrup, "the basic issue is not that the virtual reality constructed virtual space is similar to the real world such as a photo is similar, but that the constitutional aspects of human beings' experiential and practical construction of space are represented" (2002, p. 17).

2.2.2. Positivistic Concept

The positivistic approach defines that "the relationship between the human observer and external reality is a causal relationship between a factual world and its mental copy“ (Qvortrup, 2002, p. 13). Following John Locke and David Hume, who state that "extension, figure, size and motion are primary qualities existing in space independently of the perceiving subject“ (Qvortrup, 2002, p. 13), it is possible to talk about space and its qualities independently from the observation of space in this context. Transforming this perspective to virtual space, "the final aim of virtual reality techniques is to provide the information age's parallel to Mercator's map techniques of the 16th century, a representation tool thanks to which the map can look like a real space“ (Qvortrup, 2002, p. 14).

2.2.3. Dualistic Concept

Similar to the positivistic approach, the dualistic concept implies that space exists as such and therefore, "a parallel space exists or can be constructed with its own ontology" (Qvortrup, 2002, p. 14). Following the dualistic concept, the "cyberspace constitutes a world, which due to virtual reality techniques exists as a world with its own ontological reality in parallel to the so-called actual world" (Qvortrup, 2002, p. 15).

2.3. Issues in Modelling the Real World

In a scientific context, information visualisation of real world objects and phenomena always aims at reducing the complexity of the modelled object. The reduction is necessary because models depict limited representations of the real world. Kristensen et al. describe this process as conceptual abstraction, or "how concepts are formed and related to observed phenomena" (2004, p. 234). Figure 2.3 shows three parts in the conceptual modelling process: target system, referent system, and model system.

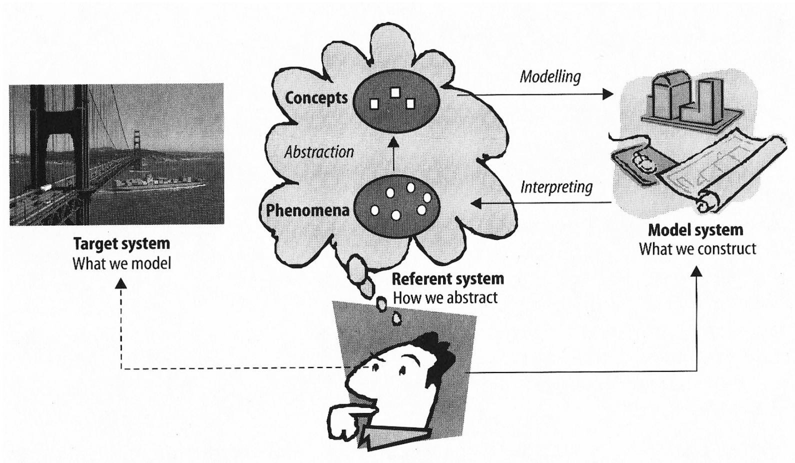

Fig. 2.3 Conceptual modelling: A target system is modelled by abstracting the referent system and constructing the model system (Kristensen, et al., 2004, p. 235).

> "The target system represents the part of the world under scrutiny or the problem to be solved. Once we start examining the target system, we start forming ideas about it, fitting it into conceptual frameworks that we have, analysing and abstracting it in various ways. This takes place in the referent system, our conceptual world, so to speak. The referent system is part of a modeller's mind: private and restricted to the individual modeller. The referent system is made explicit by creating a model or representation of it - the model system - and is thus sharable. The referent system is an abstraction: we capture and focus on certain details of the target system for our interest and purpose."
> (Kristensen, et al., 2004, p. 235)

Ott et al. argue that a decision where information is included, neglected, or deliberately excluded from the model has to be made due to the purpose of the model and technical constraints (cf. 2001, p. 21). "This opens up the question of how to reduce the number of dimensions to something that is manageable for especially human vision" (Mylov, 2002, p. 67). According to Ott et al. (cf. 2001, p. 21) the identification of relevant and irrelevant features has to be driven by the objectives and the required quality of the model. Still, the "reduction of the real world underlies subjective decisions" and "depending on different persons, situations and subjects a system may be transferred into differing models" (Ott & Swiaczny, 2001, p. 21). When deriving information from a model, one has to be aware of the discrepancy between the real world and its conceptualised representation in the model.

2.4. Spatiality and Space Experience

The experience viewing a computer generated simulation can be described as personal presence, that is "the extent to which one feels like one is in the virtual environment" (Shiratuddin, et al., 2008, p. 9). Following the phenomenological concept by Qvortrup, three constitutional aspects of space experience are identified: proto-spatiality, movement spatiality, body spatiality (Table 2.1).

Tab. 2.1 Constitutional aspects of space experience (Qvortrup, 2002, p. 19).

Phenomenological categories	Forms of perception/ experience	Virtual reality techniques
Proto-spatiality	Binocular parallax	Passive stereo
Movement spatiality	Motion parallax	Active stereo
Body spatiality	Interaction	Interaction and motion capturing devices, etc.

The base of space experience is the proto-spatiality formed by the visual binocular perception including the depth dimension. It refers to the way human beings perceive space using two eyes and ears.

The second aspect of space experience, movement spatiality, is constituted in the changing position of the subject and in the changing relation to other objects. Body spatiality takes account of the interaction between the observer and the environment. According to the phenomenological theory, space experience is not a passive mechanism, but it results from an active exploring and researching process in the environment (cf. Qvortrup, 2002, p. 18). This understanding of space allows equivalent representations in virtual reality technologies to be found.

Proto-spatiality is achieved by polarised glasses or shutter glasses [4] providing a passive stereo image of the represented space. Secondly, the movement of the user in the environment leads to a different view of the space which can be defined as active stereo.

The third aspect within virtual spaces, body spatiality, is achieved through devices allowing the observer to interact with virtual objects and change their positions, properties etc. Following the phenomenological theory, it is these three aspects which form the space experience of virtual spaces. Table 2.1 shows the three categories of space experience, its forms of perception, and its equivalent in VR technologies.

[4] Polarised glasses and shutter glasses simulate stereoscopic viewing and create the illusion of a 3D image by restricting the light that reaches each eye.

2.5. Virtual Reality Functions

Virtual reality techniques do have multitude applications such as simulations for design, architecture, and urban planing, navigation simulation for pilots and ships, training and educational purposes in medicine, and the support of scientific collaboration on distances, right up to the simulation of social worlds or artistic applications. Thinking of a general categorisation, these different applications can be grouped according to functional criteria into the three following usage categories: reference function, support function, and parallel world function (cf. Qvortrup, 2002, p. 20).

First, virtual spaces can serve as a reference to real space by creating an as-if experience (reference function). Here VR methods are used to simulate real space, objects and bodies for architecture, navigation training, entertainment etc.

The second category is the support function, where virtual space supports activities in the real world. Dynamic maps serve as an example, which represent the surrounding area from a different perspective, possibly with geographical and social information showing more information than the observer can get in the real world. Similar Augmented Reality (AR) systems enhance the current point of view with additional virtually generated information. Creating a mixed reality the virtual and the real world are merged in a way that the virtual space provides information (visual, acoustic, tactile information etc.) according to the observers position or other criteria in the real world.

The parallel world function takes advantage of the possibility to create spaces that function according to their own rules. Logic and constants being valid in the real world do not necessarily apply to the virtual world. But even in deciding on a different interpretation of logic and constants in the virtual world this decision as such still takes the real worlds categories and space experience as a reference.

2.6. Forms of Interaction

The user's interaction with space and information is the main aspect of virtual information visualisation. Real-time interaction is what fundamentally distinguishes VR simulations from pre-rendered animations or movies. Shiratuddin et al. describe interactivity as the "interaction between computer and user which takes place through changes of location views, typed commands, voice commands, mouse clicks, or other means of interfacing" (2008, p. 14). Crucial to all forms of interaction is the immediate and continuous response of the system to the user's inputs and actions. "The way people perceive and interact with visualisations can strongly influence their understanding of that data as well as the usefulness of the visualisation system" (Zudilova-Seinstra, Adriaansen, & Liere, 2009, p. 3).

Referring to input devices, Shiratuddin et al. (cf. 2008, p. 8) distinguish between direct and implicit style of interaction. Direct interaction is achieved through input devices like keyboard or mouse and allow the user to navigate or point at objects. Implicit style of interaction includes the tracking of hand, arm, head or eye movements and the translation into actions within the VE. "Implicit style of interactions are more complex to design compared with direct style interactions" (Shiratuddin, et al., 2008, p. 8).

This project's case study focuses on direct interaction using a keyboard and mouse. However, it would be possible to implement implicit interaction, e.g. through a head mounted display which tracks changes in the head's position and reflects these changes in the displayed image. Game engines particularly support more advanced input devices natively.

Independent whether direct or implicit input devices different aspects contribute to the user's interaction in virtual spaces (Fig 2.4). This project focuses on the aspects of navigation, information/metadata and modification. Collaboration and communication in virtual spaces is deliberately omitted from this project's scope.

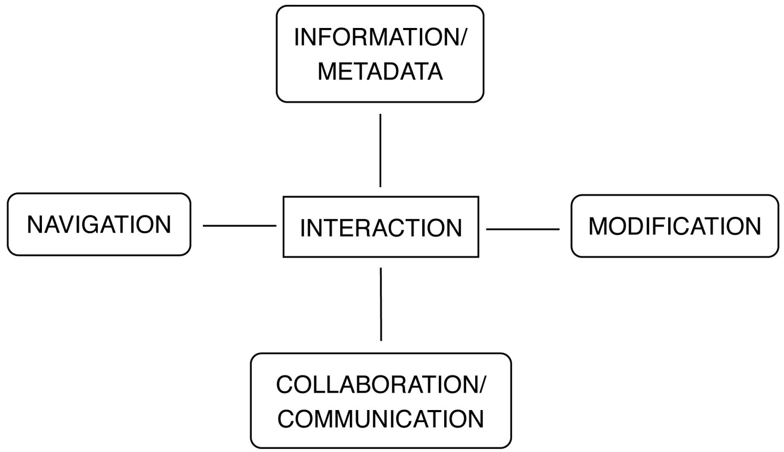

Fig. 2.4 Forms of interaction in virtual spaces.

2.6.1. Navigation

Navigation is the key feature of experiencing and gaining information from both 2D and 3D information systems. The different types of navigation that are described in the following focus on navigation in 3D space. Navigating freely in 3D spaces allows the user to inspect objects from all positions and directions. However, sometimes in order to maintain reality constraints, the user is not supposed to take any possible position in space, e.g. the space within walls or looking at a building from below ground level. Though, for analysis purposes, the "impossible view" might bring new insights as it contributes to see new potential relationships. Boeck et al. distinguish between direct camera control and indirect camera control (cf. 2005, p. 262). Direct camera control allows the user to directly control the position and orientation of the camera using an input device. Indirect camera control instantly moves the camera to a certain place by a single command.

Many VE applications refer to real life experiences and use metaphors in its choice of navigation. "Metaphors explicitly mimic concepts that are already known by the user in another context, in order to transfer this knowledge to the new task in the new context" (Boeck, et al., 2005, p. 261). A common metaphor is the walk-through, which corresponds to the experience of real walking. It is a continuous way of moving through space usually at a person's eye level and similar to normal walking speed. This form of navigation lets the user experience space similar to a real walkthrough. A virtual walkthrough supports the estimation of distances and proportions within a virtual space.

Flying or hovering over an area refers to the experience of looking at space from an airplane or balloon. This object centered navigation takes a bird's eye perspective and allows one to get a good overview of an area. In combination with a zoom function, the overall picture and small-scale scenes can be viewed. Another common way of navigating in VE is to orbit around a central object. It uses the object in hand metaphor and enables the user to examine an object from all directions as if the object is held in the user's hand or the user moves around an object while keeping a constant distance to the central object.

Other forms of navigation are referred to as indirect or discrete navigation. It permits the user to jump or "teleport" oneself from one point of space to another. "In an evaluation study, users sometimes complain about 'getting lost' when the camera automatically moves to the new location" (Boeck, et al., 2005, p. 264). In many cases, a reference map indicating the current position helps the user to maintain orientation.

A smooth, intuitive, and easy to use navigation is crucial to maintain the users attention and satisfaction with the simulation. Obstacles and discomfort with navigation can very quickly generate disorientation and causes frustration and disinterest.

2.6.2. Information and Metadata

Using VE as information spaces for scientific visualisations, it is essential how information is revealed and made accessible. Due to limits in perception, not all information is usually visible at once. In this context, metadata provides additional information about an object which contributes to its further description. Besides an object's geometrical properties (size, position, shape, material, texture, etc.), metadata as additional information can be encoded in objects which is revealed by clicking on the intended object, moving the mouse cursor over that object, or performing any other user interaction. The concept of metadata is particularly powerful for scientific applications as it allows the integration and handling of a large amount of information. Furthermore, metadata can include links to other objects or information sources, thereby creating a comprehensive information network.

2.6.3. Modification

Dealing with virtual objects makes it possible to modify objects in a way which (a) would not be possible, (b) would be irreversible or (c) very costly with real objects. Given the option to interactively modify objects, their properties, or display options, opens a wide range of possible applications which have no or hardly any analogue alternative. Modification of virtual objects not only reveals new options to explore space and information but also attracts the user's attention and encourages an active involvement with the subject.

2.7. Summary

Virtual spaces have evolved from early machine-centered applications towards open and intuitive implementations where the technology almost disappears behind the user's interface. Virtual spaces for scientific visualisations can support and enhance the discovery process.

By necessity, constructing a virtual model, reduces complexity to create a representation of real world objects or abstract information. The abstraction process is driven by the objectives and the required quality of the model. Users are able to freely navigate in virtual models, interact with information and operate with virtual objects. Interaction is achieved through direct input devices (mouse, keyboard, joystick etc.) or implicitly by tracking the user's actions and movements (head mounted display, motion capture, etc).

Along with technical improvements, more and more disciplines and professions are using interactive spatial visualisations for developing and refining ideas, theories, and products. However, "despite the advancements in virtual archaeology, the use of VR by specialists for archaeological research purposes has been sparse; even when VR tools are available, archeologists prefer to use other media (drawing, photography and traditional modelling)" (Roussou & Drettakis, 2003, p. 57).

Bryson sums up the advantages of interactive visualisation by stating, "real-time interaction encourages exploration" (1996, p. 65). This encouragement needs to be utilized and developed further to make the most out of the potential of virtual space applications.

3. Implementation - Case Study

The case study tests interactive simulation tools for archaeological visualisations for the following purposes:

a. exchanging spatial information in digital documents,

b. visualising information in its spatial, geographical and historical contexts,

c. providing a walkthrough of a virtual space.

Possible software solutions for these categories are tested, evaluated, and compared in terms of functionality, usability, and applicability. For each of these tasks, the technology best fitting the given objective is chosen and tested by applying it to the case study, the Mastaba of Queen Meresankh III in Giza, Egypt. The digital building model represents the present situation of the tomb including the sarcophagus which is now in the Egyptian Museum in Cairo. Recently added building elements to the mastaba are not taken into account, i.e. protective elements at the entrance or stairs in the pit. The wall paintings are illustrated using ink drawings publishes by Dunham and Simpson (1974a). It is also used as a reference for the hieroglyphic translation and information embedded as metadata. Complete colour images of the mastaba walls have not been available at the time of modelling but could be implemented in future works on the project. The rock-cut figures in the wall niches are represented by grayscale images.

Fig. 3.1 Mastaba of Queen Meresankh III (main room, north wall, looking northeast).

3.1. Information Sources and References

The information source for creating the digital model of the mastaba of Queen Meresankh III comes from both publications (books, papers, etc.) and online archives (*The Giza Archive*). The work is mainly based on the publications, *The Mastaba of Queen Mersyankh III* by Dunham and Simpson (1974a), and *The Tomb of Meresankh, a Great-Granddaughter of Queen Hetep-Heres I and Sneferuw* by G. Reisner (1927). Dunham and Simpson's work provides a comprehensive description of the tomb, including plans, ink drawings and the hieroglyphic translations. Reisner's publication is considered as the first publication after the tombs excavation in 1927. Other plans are used from the book *Die Gräberwelt der Pyramidenzeit* published by P. Jánosi (2006).

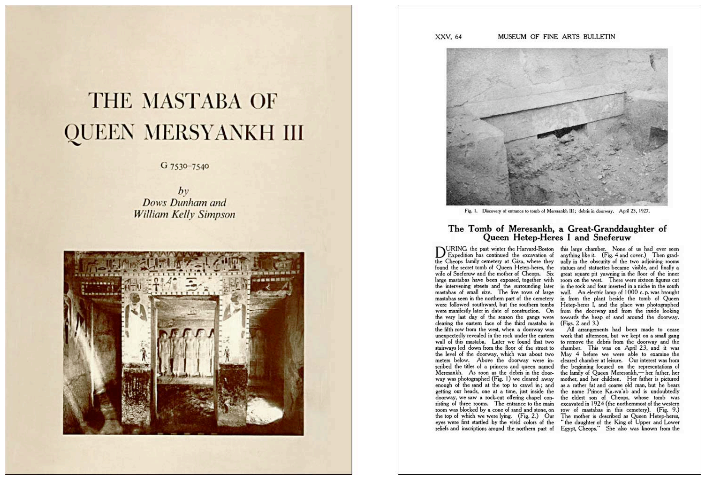

Fig. 3.2 Cover page: Dunham, D., & Simpson, W. K. (1974). The Mastaba of Queen Mersyankh III (G 7530-7540) (left); Title page: Reisner, G. A. (1927). The Tomb of Meresankh, a Great-Granddaughter of Queen Hetep-Heres I and Sneferuw (right).

The secondary sources of information are online archives and databases. *The Giza Archive*[5] provides a fully searchable database and contains information such as a large collection of photos, plans, aerial images, 360-degree panoramas (QuickTime VR), manuscripts, and diary pages. In addition, original material provided by Peter der Manuelian, Director of *The Giza Archives Project* at the Museum of Fine Arts, Boston is included in the 3D model and used as a reference.

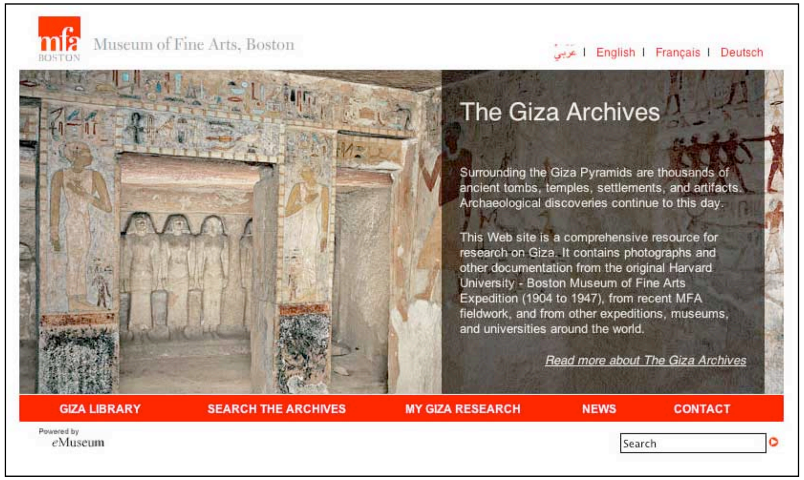

Fig. 3.3 Web page of the Giza Archives (The Giza Archives, 2010a).

[5] The Giza Pyramids: http:// www.gizapyramids.org

3.2. Constructing the 3D Model

Primary the digital model is constructed using the 3D modelling software Cinema 4D (Version 11.0), based on floor plans, sections, and elevations (Fig. 3.6) in the publication *The Mastaba of Queen Mersyankh III* by Dunham and Simpson (1974a). The publication was also used as a source of information for the tomb's architecture and hieroglyphic translations.

The goal of the digital model is to provide a basis for real time interactive visualisations. Therefore, the focus during the modelling process was to generate a 'lightweight' model suitable for real time visualisation systems. The geometrical complexity of the model and the graphical resolution of the texture images are optimised in order to facilitate performance requirements.

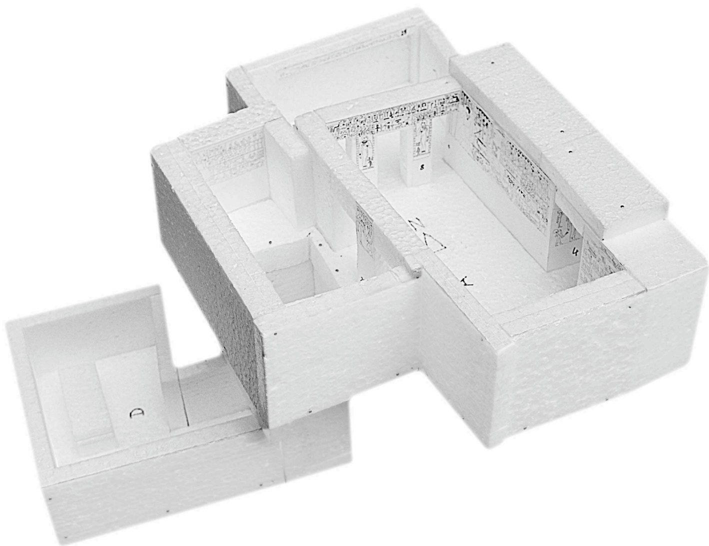

Fig. 3.4 Handmade working model of the mastaba of Queen Mersyankh III.

Before constructing the digital model, a handmade working model on a scale of 1:50 was built. It helped to understand the spatial configuration of the tomb and to get an overview of the decorative program. It was also useful as a reference for constructing the digital model.

Geometry

In the digital model, the mastabas of the Eastern Cemetery are represented using volumetric models. The mastabas are constructed based upon an overview plan of George A. Reisner (1942, Map 3) and illustrates the conceptual layout of the pyramids and the main mastabas in the Eastern Cemetery (G 7000).

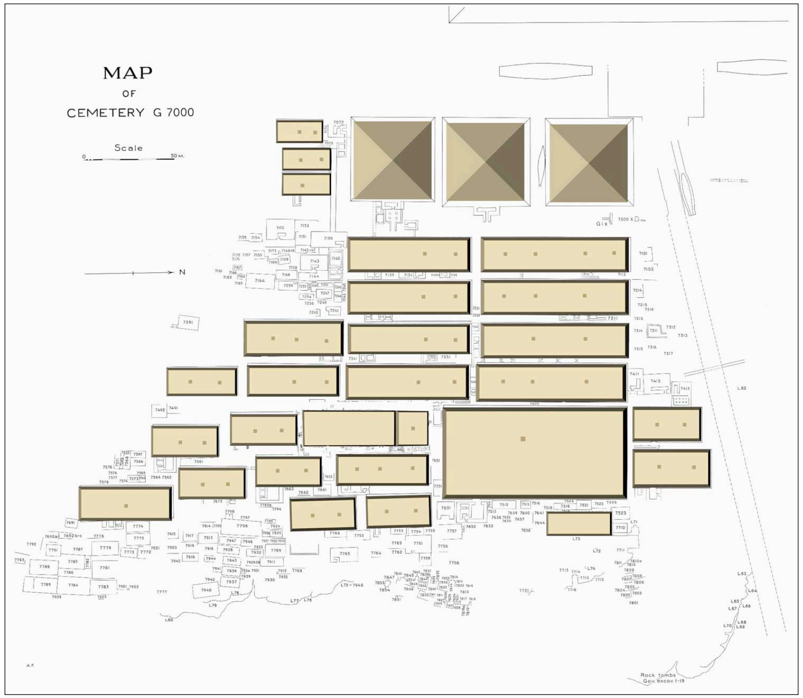

Fig. 3.5 Aerial map and top view of the 3D model of the Eastern Cemetery.

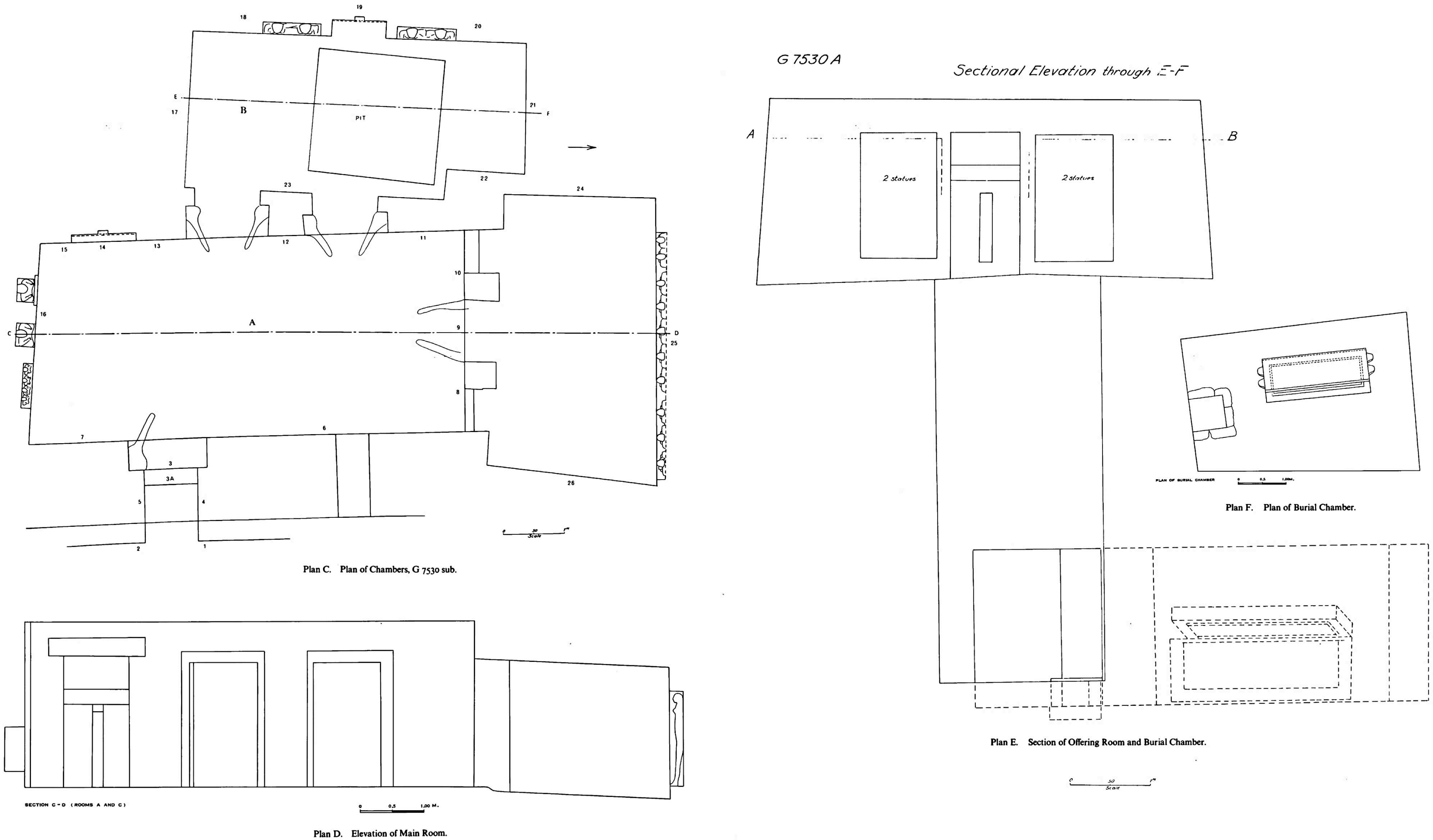

Fig. 3.6 Floor plans, sections, and elevations used to construct the 3D model (Dunham & Simpson, 1974a, p. 39f.).

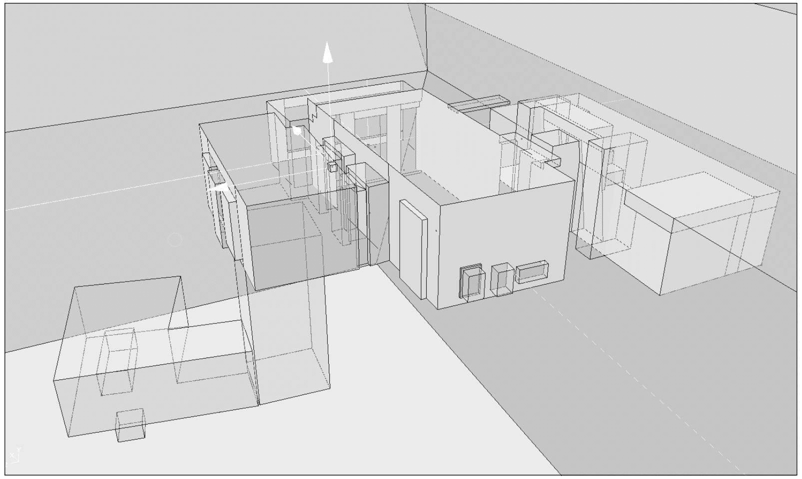

Fig. 3.7 Polygonal 3D model in Cinema 4D.

The entrance to the tomb's chamber and the interiors show the highest level of geometry and texturing detail. The geometrical model of the mastaba is constructed as a polygonal model based on scaled floor plans. Because the chamber is positioned underground, the rooms are created as a negative space of the mastaba superstructure. Each wall consists of one or more independent polygons depending on the geometrical complexity. The room heights are modelled according to sections and elevations, and also follow measurements from the publication. Small details in particular, like the dimensions of niches or the depth of false doors, are modelled according to numerical specifications. The rock-cut standing figures in the wall niches are represented by grayscale photographs from the *The Giza Archive* online database.

Textures

The chosen texturing method follows a non-photorealistic and abstract representation of the mastaba's decorative program. The wall's relief paintings and hieroglyphs are illustrated by the ink drawings from the publication of Dunham and Simpson (1974a). The ink drawings, which are broken up on several pages in the publication, are combined to form a single image for each wall. A material with this image is defined and individually assigned to each decorated wall. If a wall includes hieroglyphs, a second image is produced which shows the English translation in place of the hieroglyphs. The second image showing the translation is assigned to a duplicate of the original wall. For testing purposes, a third texture with colour photographs of the current situation in the tomb is created. However, good colour photos are not available of all walls. The three representations of the wall's decoration (ink drawing, translation, photo) are to be selected by the user.

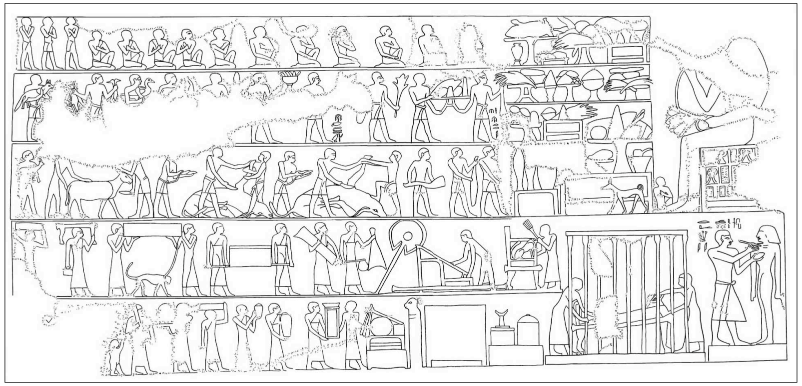

Fig. 3.8 Assembled ink drawing (main room, south wall) (Dunham & Simpson, 1974a, p. 76ff.).

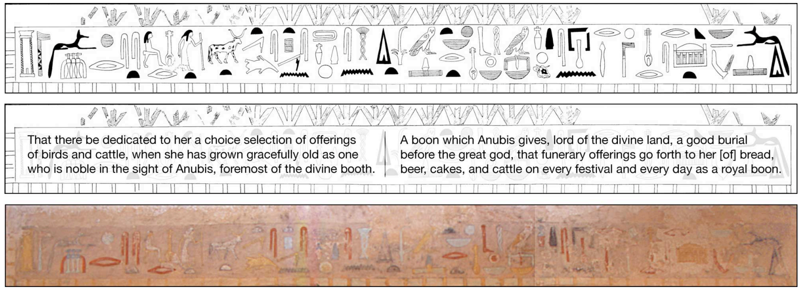

Fig. 3.9 Images created for texturing: ink drawing (top), translation (middle), photo (bottom) (main room, part of north wall).

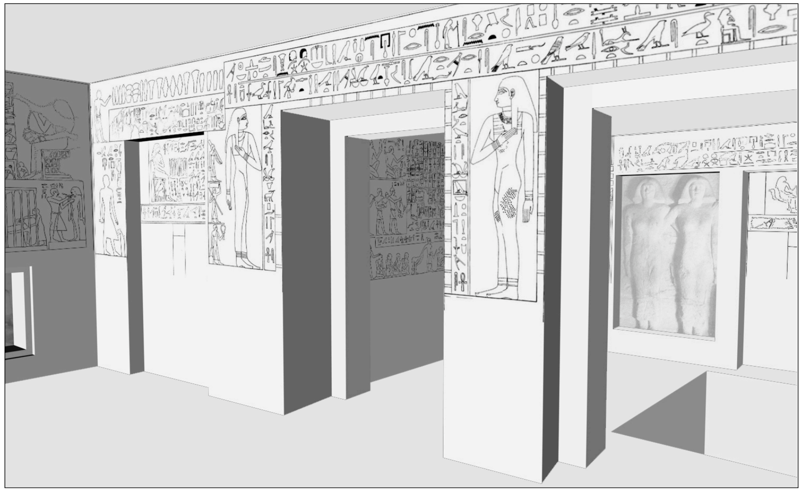

Fig. 3.10 Textured rendering in Cinema 4D (main room looking southwest).

The subsurface of the model uses a high resolution site plan of the Eastern Cemetery (Reisner, 1942, Map 3) digitally provided by *The Giza Archive*.

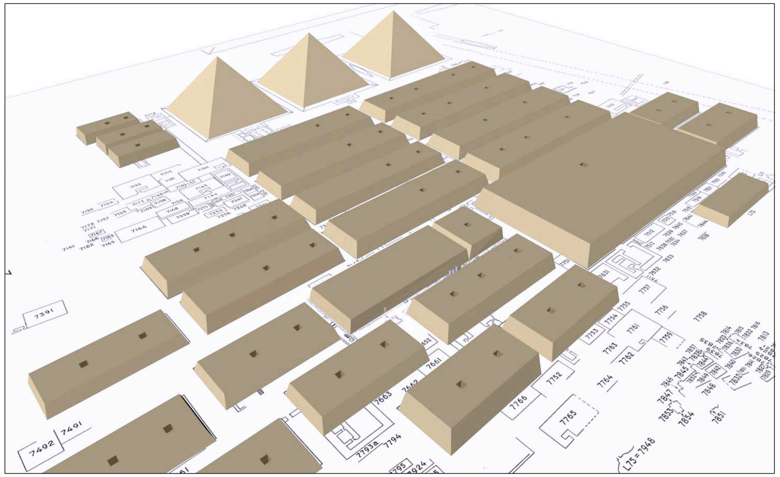

Fig. 3.11 Polygonal 3D model of Eastern Cemetery in Cinema 4D.

General Notes on Modelling

Before starting modelling, it is necessary to have a concept about the scope and goals of the visualisation as well as who might be the target audience. Geometry and defined materials depend very much on the purpose of the model and can vary significantly depending on the level of detail. These decisions affect the focus and detailing of the model and the type of included information. Secondly, most of the geometric information should be at hand (plans, drawings, etc.) as well as further information included as metadata.

3.3. Non-photorealistic Rendering

> *"The freedom to encode an impression rather than being forced to follow physical constraints is considered the key to conveying information."*
> *(Strothotte & Schlechtweg, 2002, p. 6)*

The term non-photorealistic rendering (NPR) was coined in the mid 90's and describes computer-generated images which "emphasize specific features of a scene, expose subtle attributes, and omit extraneous information" (Gooch & Gooch, 2001, p. 2). The origin of NPR images are handmade drawings and its "deviance from such features as uniform scale, the lifelike use of color, and the precise reproduction of all details of images as seen by the human eye" (Strothotte & Schlechtweg, 2002, p. 3).

In contrast, photorealistic computer graphics use "algorithmic techniques that resemble the output of a photographic camera and that even make use of the physical laws being involved in the process go photography" (Strothotte & Schlechtweg, 2002, p. 1). Therefore, the quality of photorealistic renderings is judged by how similar they look compared to photographs taken by a real camera. NPR representations, however, are judged by how well they visualise and communicate a specific information or meaning. NPR is used to "provide information that may not be readily apparent in photographs or real life" (Gooch & Gooch, 2001, p. 1). As one of the reasons why NPR is important, Strothotte et al. argue that it is particularly capable of communicating information: "There is ample evidence that non-photorealistic renditions are in fact more effective for communicating specific information than photographs or photorealistic renditions in many situations" (2002, p. 8). Using images for conveying information and meaning is by far not new to the age of photography or even computers. "Artists have made effective use of deviating from realistic renditions of scenes" (Strothotte & Schlechtweg, 2002, p. 6). But also in the area of scientific and technical illustrations NPR images are a powerful tool to communicate specific information. Examples of this are illustrations in medical textbooks or in products' user manuals. These images often leave out unnecessary or distracting details and sometimes even use simple symbols to show additional information.

3.3.1. Non-photorealistic Rendering in Archaeology

Besides photorealistic representation of objects or buildings, there is a trend in archaeological visualisations which shifts focus to the "development of more 'believable' environments, while maintaining the accuracy and validity of the visualised data" (Roussou & Drettakis, 2003, p. 51). Compared to photorealism, a NPR representations of archaeological sites or objects offer more flexibility to include uncertainties, variants or other information in visualisations.

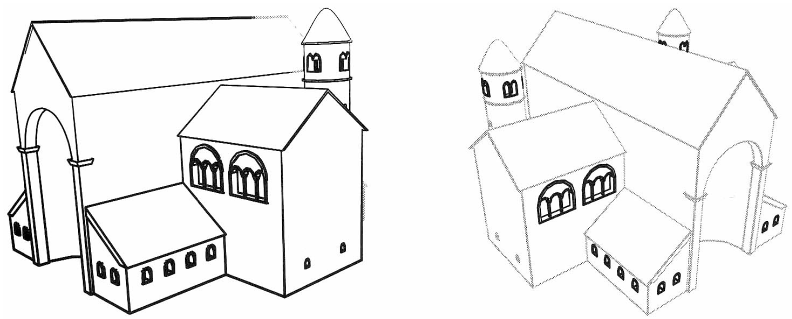

Fig. 3.12 Visualisation of uncertainties and drawn deductions: uncertainty rises with growing distance from the ground; in addition, the rear part of the building could not be proven to look like this from the excavation findings (left); the windows are likely to be in the same style as other windows of the same stylistic period - Romanesque (right) (Strothotte & Schlechtweg, 2002, p. 320).

NPR supports "representations such as vertical cuts of an artefact, but also the ability to abstract out detail of a monument, and concentrate the viewer's attention on specific parts" (Roussou & Drettakis, 2003, p. 57). As an example of a virtual reconstruction, NPR is used to document uncertainties and drawn deductions (Fig. 3.6). NPR images are also combined with photographs to illustrate size relations (Fig. 3.7).

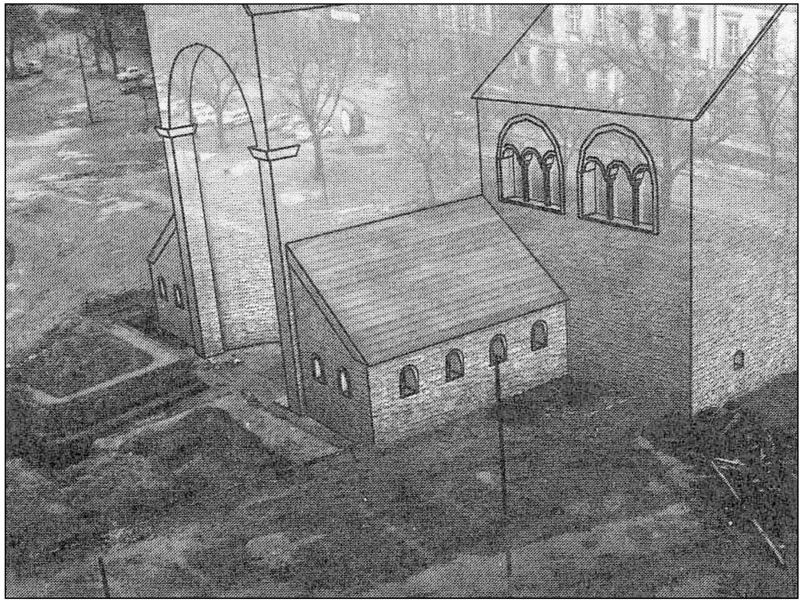

Fig. 3.13 Combining a NPR visualisation and a photograph of the excavation site clarifies size relations (Strothotte & Schlechtweg, 2002, p. 320).

> "Using such a non-photorealistic technique has the advantage that the viewer is immediately confronted with an abstraction, thus subconsciously underlining the hypothetical aspect of the reconstruction. A photo-realistic rendering of the same element would imply "historical truth", which may not be desirable."
> (Roussou & Drettakis, 2003, p. 57)

The term 'non-photorealistic rendering' was highly disputed and other alternative names used in research papers are 'artistic rendering', 'illustrative rendering', or 'expressive graphics'.

An overview and the underlying technical principles of NPR are described by T. Strothotte and S. Schlechtweg in *Non-Photorealistic Computer Graphics. Modeling, Rendering, and Animation* (2002), and by B. & A. Gooch in *Non-Photorealistic Rendering* (2001).

In this project's case study, NPR is used to highlight the object's outline and the displayed information. It allows the user to focus on the information presented without pretending a level of detail which is not verified.

3.4. Exchange of 3D Data

Archaeology very often deals with spatial objects such as findings, tombs, or other buildings. More and more digital documentation technologies (3D laser scanner, structured-light 3D scanner, photogrammetry) are used on site and in laboratories to generate digital 3D models of objects. Sometimes it is difficult to fully describe objects in a natural language or with 2D representations such as plans, drawings, or pictures. For the recipient, it is often hard to put these individual parts together in order to get a comprehensive view of the subject. In spite of that, it is still not common to share and publish 3D information in today's archaeological scientific community. In order to facilitate the exchange of spatial information in digital documents, it requires (a) a file format which can store 3D data, and (b) a software which is able to read and display this file format.

Besides common 3D file formats like 3DS, VRML, X3D, OBJ, there are other formats like IFC or DAE which are specifically designed to serve as an interoperable file format for exchanging 3D data models between different software platforms. Nevertheless, none has become prevalent as a standard format for data models so far.

For the exchange of 2D data, the PDF (Portable Document Format) is established as a digital publishing and exchange standard. The PDF was developed by Adobe in 1993 and is an open standard, independent of the operating system and application software. It is commonly used to represent documents containing texts, images and 2D vector graphics. However, since Version 7 (2004), PDF also supports 3D information which can be embedded in PDF documents and interactively visualised with Adobe Reader (freeware). Adobe Acrobat supports various data formats [6] including 3DS, DAE, VRML, and U3D. The option to embed and view 3D models in PDF files enables it to be used as a medium for the exchanging interactive spatial models. Using the common PDF allows ease of use by the end user and does not require any additional software besides Adobe Reader to view 3D objects.

3.4.1. Adobe 3D PDF

This case study uses Adobe 3D PDF to illustrate the technical possibilities and practical implementation of 3D PDF in an archaeological context. It serves as a visualisation technology for 3D information systems offering interactive navigation within digital landscape and building models.

Adobe 3D PDF allows a user-friendly and interactive spatial exploration of digital 3D models. There are various fields where implementations of 3D PDF may be used, for instance in e-publications (web, DVD), or in archaeological teaching as an interactive learning tool.

Apart from giving a 3D spatial experience, the main emphasis of this case study is to provide the user with additional information about the tomb and its objects (metadata), as well as to link to other information sources (databases).

[6] A full list of all supported file formats is available at:
http://www.adobe.com/manufacturing/resources/3dformats/

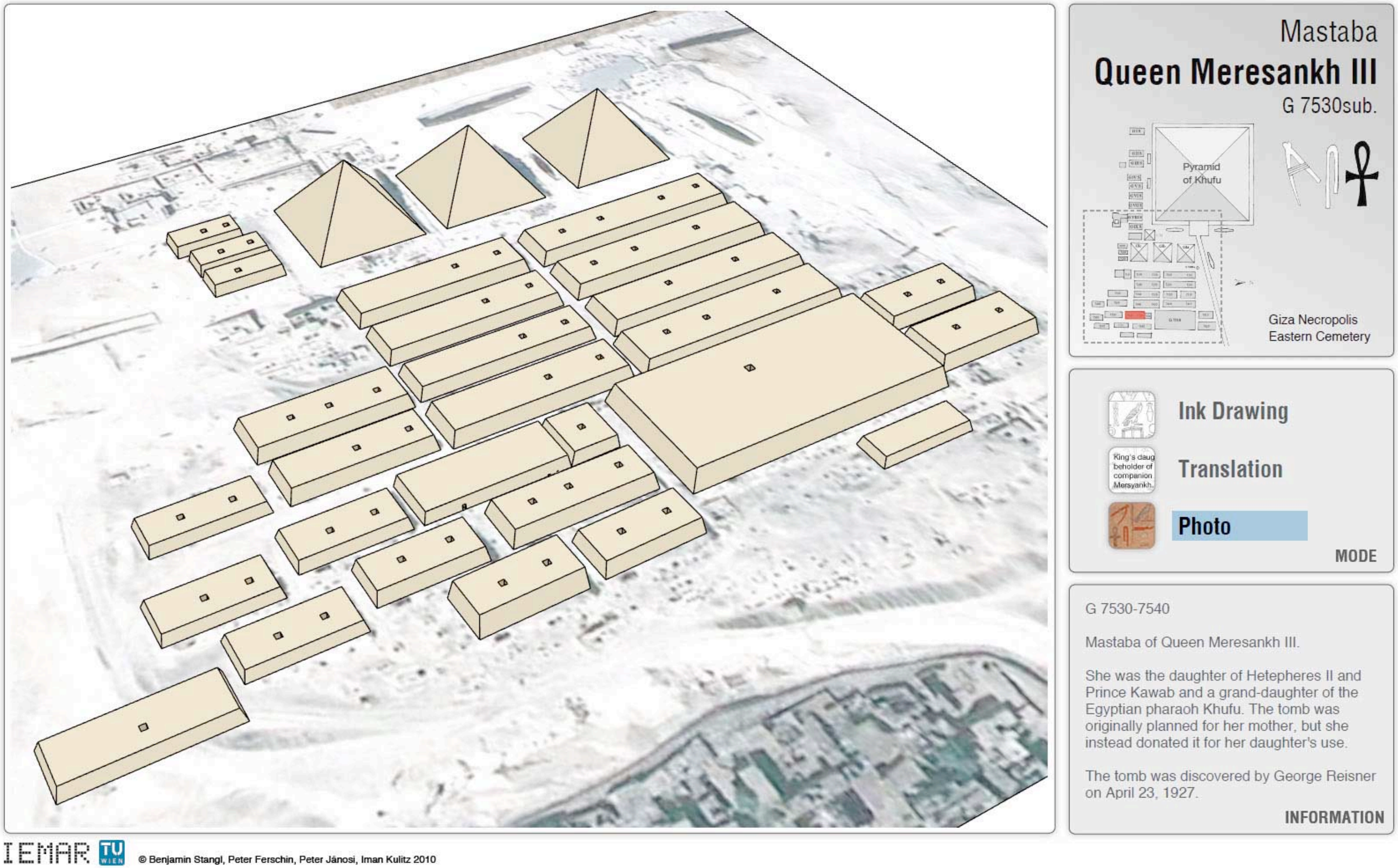

Fig. 3.14 Overview of the Eastern Cemetery in Adobe 3D PDF.

Interface

The graphical users interface (GUI) in this case study consists of a main window displaying the 3D model and a panel on the right side depicting additional information for the user (Fig. 3.14). The right panel is structured in three sections. From top to bottom a site plan of the Eastern Cemetery at Giza indicates the position of the Mastaba, a list provides different decoration options (ink drawing, translation, photo), and a text field relates metadata to objects.

Navigation

As 3D PDF aims at providing a spatial experience to end-users with common consumer hardware and software, the project focuses on navigation solutions using a standard mouse with click and scroll functionality. The embedded navigation of Adobe Reader supports both direct navigation (spin, pan, walk, etc.) and indirect navigation by choosing a predefined camera. The "Spin" option best suites large scale navigation from a bird's-eye perspective. Dragging the mouse rotates the scene in connection with the mouse wheel for zooming in and out. Using the "Walk" option gives a first-person walkthrough experience at a constant elevation level. Dragging horizontally pivots horizontally around the scene, while dragging vertically up and down moves forward and backward in the scene. Diagonal dragging allows to move sideways. Difficulty may occur when navigating through different levels in small scales (e.g. stairs) as there are no physics simulations taken into account. In this given situation it might be useful to switch between different navigation alternatives, or using the "Pan" option which moves the model vertically and horizontally.

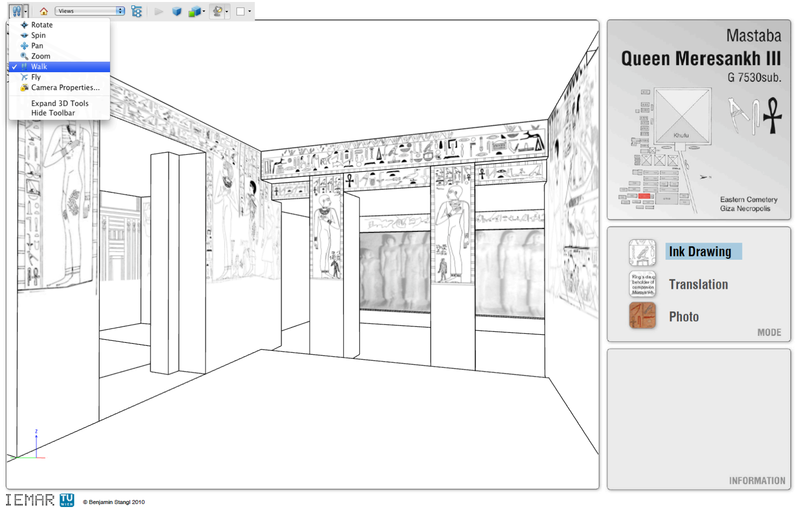

Fig. 3.15 Navigation options (main chamber looking north).

Predefined camera positions are important for assisting navigation in 3D PDF and help the user to instantly return to certain locations in 3D space. Choosing a camera in the "View" menu in the 3D toolbar jumps to a given camera position. Multiple camera positions can be predefined in the CAD modelling software and are importable to the 3D PDF.

Cross Section Tool

Besides the navigation tool, Adobe Acrobat includes the function to create interactive 3D cross sections[7]. The cross section tool is a useful function to examine 3D models and to understand its spatial structure (Fig. 3.10). It allows the model to be cut along a virtual plane and to look inside the model. These sections are non-destructive and for examination purposes only. The cutting plane

[7] The cross section tool is only supported by the full version of Adobe Acrobat and is not offered in Acrobat Reader.

can be aligned to either the x, y, or z axes and tilted along the two other two axes. Dragging a slider left or right moves the cutting plane through the model in real time while all cut elements are outlined. Cross-sectional views can be saved and are added together with all cross-section properties as a camera position in the "View" menu for later use.

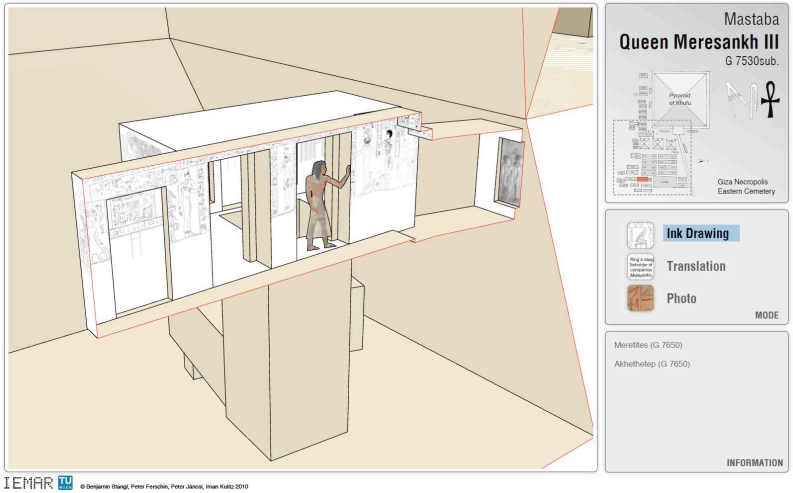

Fig. 3.16 Cross Section of mastaba G 7530sub.

Additional Functions

In addition to the built-in tools (navigation, cross section, views, etc.), 3D PDF provides the possibility to customise and enhance user interaction by using JavaScript for Acrobat API (Application Programming Interface). These additional functionalities enhance the interactivity of the information system. In this case study, three additional functions using JavaScript are implemented to show the advanced possibilities of user interactivity: change of decoration mode, display metadata of objects, and link to external databases on the web.

The JavaScript in this case study adapted the scripts presented by P. Ferschin et al. at the CORP 2006 conference in the paper "MAIS4D – An Example of Spatial and Temporal Visualisation Methods for Urban Development in 4 Dimensions" (Ferschin, et al., 2006) to the project's requirements.

Change of Decoration Mode

The mode panel on the right side of the GUI allows the user to choose between one of three different decoration modes (Fig. 3.11): The ink drawing mode shows the exact outline of the hieroglyphs emphasising the clarity of the relief paintings. The translation mode hides the hieroglyphs in the background and provides an English translation at the same position enabling to read the information encoded in the hieroglyphs. In photo mode, the walls are textured with images from the present situation in the tomb. However, appropriate colour photos are not available of all walls.

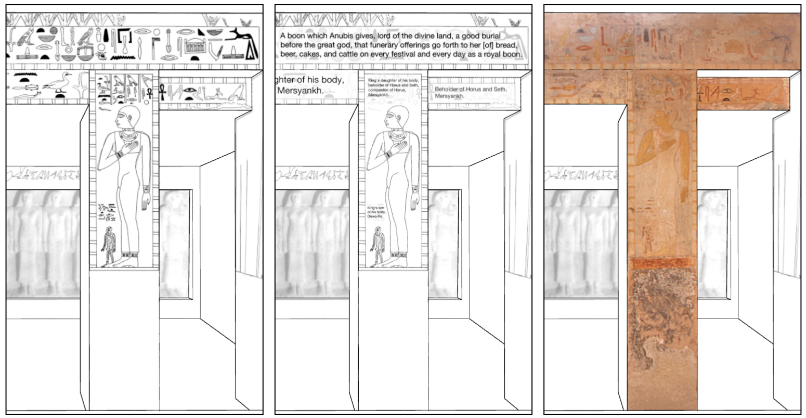

Fig. 3.17 Decoration modes: Ink Drawing, Translation, and Photo.

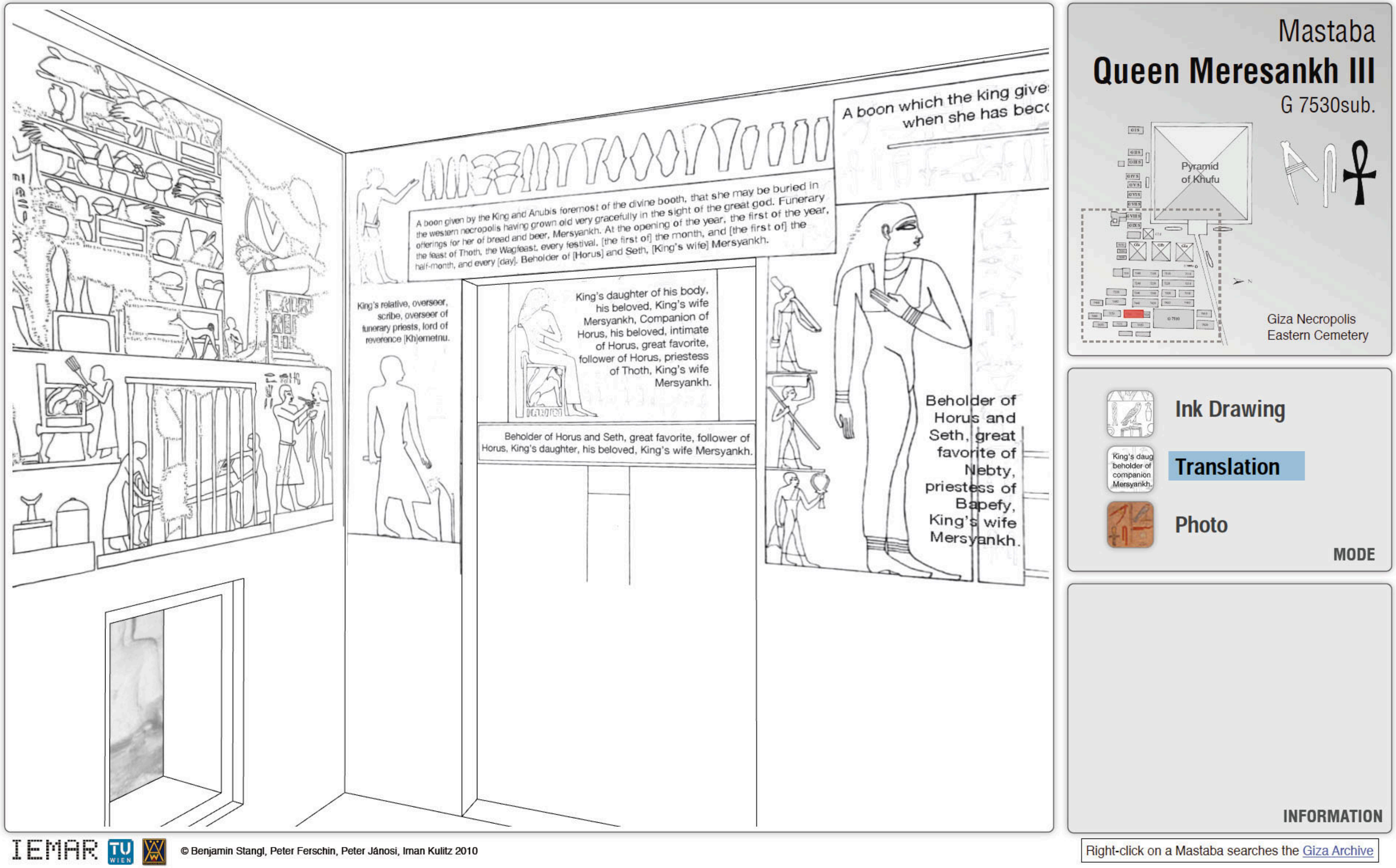

Fig. 3.18 Translation mode (main chamber looking southwest).

Metadata

Besides spatial information, descriptions about objects are embedded as interactive metadata. Interesting facts or objects' characteristics are displayed in the information panel as the user moves the mouse over an object (Fig. 3.13). This ensures that the information always corresponds to the current point of view and that the user can decide upon the amount and depth of information.

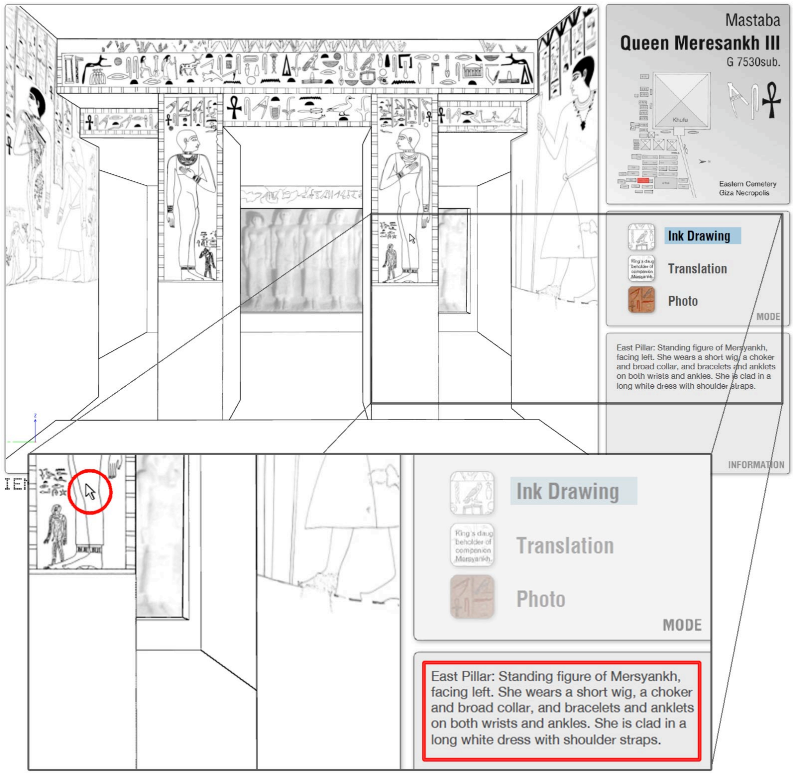

Fig. 3.19 Metadata as a mouse over an event (main chamber looking North).

External Linking

The encoded metadata provides short information about an object. When the user wishes to get more and detailed information about a tomb, statue or painting, it is possible to use 3D objects as "link buttons" via JavaScript. The link (URL) is encoded in the 3D object's metadata and the link is activated by clicking on an object.

The linking function is combined with a query in the Giza Archive database (www.gizapyramids.org). Each tomb in the Giza Necropolis has a unique code e.g. G 4911 or G 7530. Clicking on an a linked object searches in the Giza Archive's database for the tombs code and opens up a website with the query results. In this way it is possible to use 3D PDF as a visual search tool and combine it with information of online databases and websites.

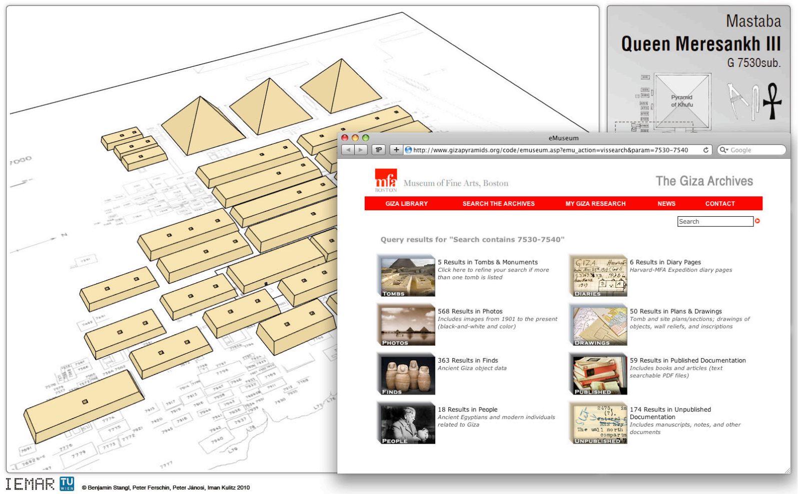

Fig. 3.20 External linking as a query in the Giza Archive database.

Workflow and Usability

After the modelling process is completed, the model needs to be exported into a file format which is supported by Adobe Acrobat (3DS, DAE, VRML, U3D, etc.). Adobe Acrobat does not maintain texture information for all of its supported file formats. The U3D file format is chosen because the imported 3D models can be internally embedded in PDF documents using this file format. U3D is not natively supported as an export format in most CAD modelling applications like 3ds Max, Rhino, Cinema 4D, or Maya, which makes it necessary to interpose another application in the workflow. In this case study, Deep Exploration (Right Hemisphere) is used to convert the Cinema 4D file into the U3D file format. Converting files from one format to another may result in data loss. Texture information is often especially difficult to maintain during the import and export processes. Therefore, it is recommended to review the data after each import and export. In Adobe Acrobat, the U3D file is then inserted into a standard PDF file which serves as the project's background. Interactive functions are added using JavaScript allowing additional customised user interactions: changing the visibility of objects, reading out metadata, and external linking to websites or databases.

Viewing 3D PDF files only requires the freeware Adobe Reader, whereas creating or editing PDF files requires the proprietary software Adobe Acrobat.

Encountered Issues

Besides the work needed to properly import the model in Adobe Acrobat (see Workflow and Usability), there have been some other issues encountered while working with 3D PDF.

Despite the different navigation tools ("Spin", "Walk", "Pan" etc.) offered for spatial navigation, it is sometimes difficult to navigate properly through small rooms or spaces especially when situated at different heights. As the "Walk" tool only pivots horizontally around the scene, it is necessary to use it in combination with, e.g. the "Pan" tool, to climb stairs or overcome heights.

When first using interactive models in Adobe Acrobat it might be necessary to change some of the default settings in the preferences menu. It was proven to be beneficial to enable double-sided rendering, disable selection for the *Hand tool* (3D & Multimedia), and to enable internet access to all web sites (Trust Manager), in order to support external linking.

Summary and Outlook

The case study of 3D PDF shows how the standard exchange format PDF can be used to give access to 3D information models using Acrobat Reader. Spatial models can be visualised within a PDF document supporting interactive navigation, embedded metadata, and other customised functions via JavaScript. Straightforward handling and easy publishing qualify Adobe 3D PDF as a good tool for exchanging archaeological 3D information. Adobe 3D PDF, as an exchange and visualisation technology for 3D information, is not yet commonly used in architectural and archaeological works. However, particularly due to the option of encoding metadata to 3D objects, it has high potential for the exchange of spatial information in a scientific context.

An additional compass feature depicting the current location and orientation on an index map is considered for future work and needs further technical investigations. Other improvements could be made by enhancing the navigation function with other devices such as a 3D mouse, joystick, or iPhone.

3.5. Geovisualisation

Geovisualisation takes advantage of developments in computer and communication technology, and facilitates the visualisation of interactive and dynamic geospatial information. It comprises strategies of scientific visualisation, cartography, image analysis, information visualisation, exploratory data analysis, and geographic information systems, "to provide theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data" (Kraak & Ormeling, 2003, p. 175). Geographic information systems (GIS) are technologies to collect, store, retrieve, transform, and display spatial data based upon its geographical location in the real world (cf. Kraak & Ormeling, 2003, p. 8). Compared to other information systems, data in GIS contains a geographical address and is linked to a specific location. GIS applications have been successfully used in archaeology for many years, providing tools to structure information for survey and analysis purposes.

Besides classical desktop GIS software (ArcGIS, GRASS GIS, SAGA GIS, Quantum GIS), there is a growing number of geovisualisation tools such as Google Maps, Bing Maps, Wikimapia, or OpenStreetMap which share geographical data over the web. Web mapping tools allow the user to explore and interact with the displayed information and to query the underlying database for cities, streets or other points of interest. Compared to conventional printed maps, the option to zoom, pan, and select different layers of information allows the user to visualise much more information. "The objective of combining sound, animation, text and (video) images with the map is to get a better understanding of the mapped phenomena as a whole" (Kraak & Ormeling, 2003, p. 171).

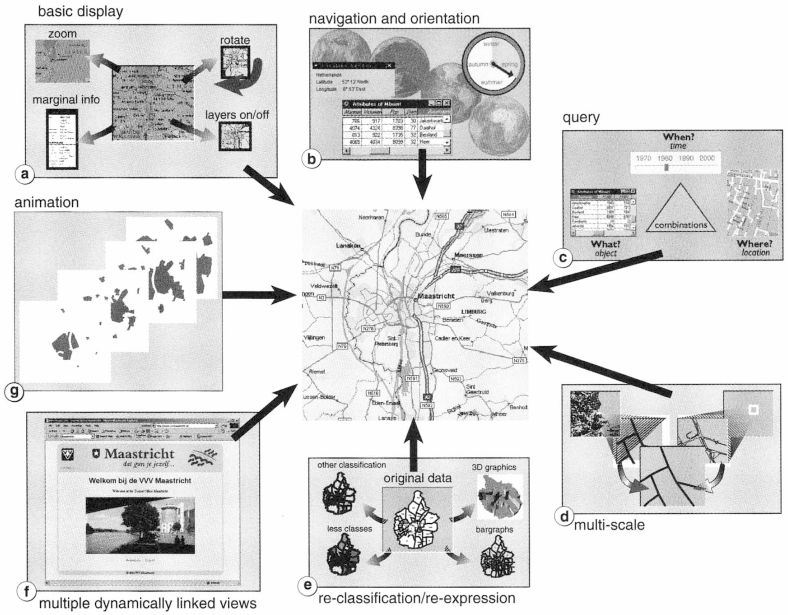

Fig. 3.21 Functionalities in geovisualisation (Kraak & Ormeling, 2003, p. 178).

According to Kraal & Ormeling (cf. 2003, p. 177f.), geovisualisation environments should provide facilities for the following options (Fig. 3.21):

a. Basic display: tools to pan, zoom, scale, transform, and rotate;

b. Orientation and identification: where is the view located, what the symbols mean;

c. Query data: access to query the spatial database;

d. Multi-scale: different data-sets and data densities for different scales (level of detail concept);

e. Re-expression: offer different mapping methods for displaying data;

f. Multiple dynamically linked views: combination of multimedia (video, sound, text, etc.) representing related aspects of the data;

g. Animation: illustration of changes in spatial data and representation of complex processes.

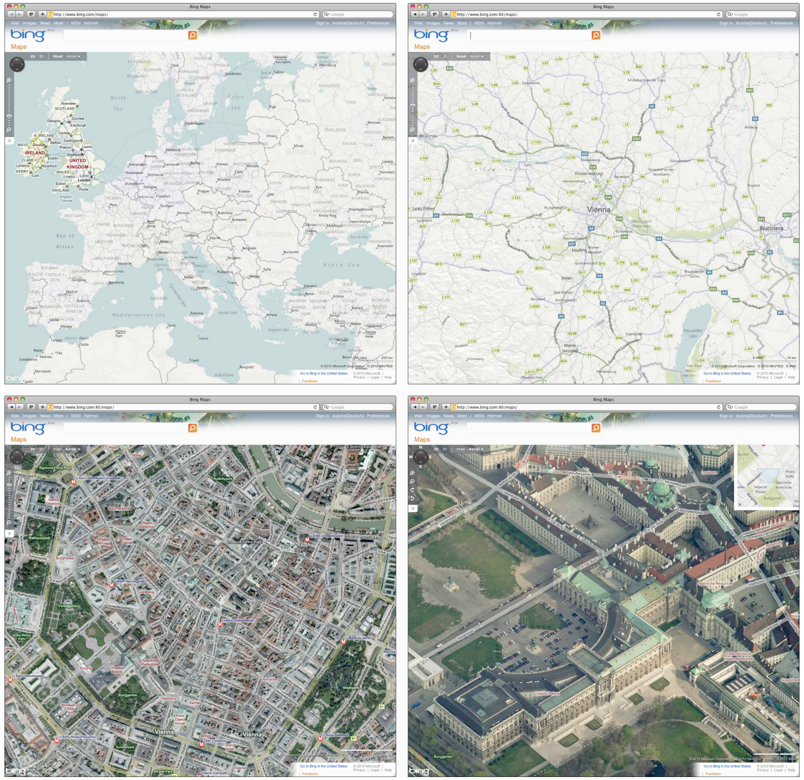

Fig. 3.22 Bing Maps showing different viewing modes and information sets according to the current scale (Microsoft, 2010).

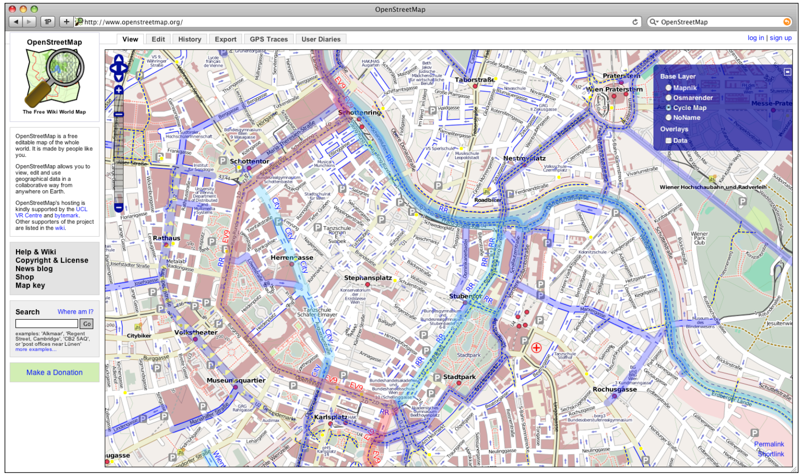

Fig. 3.23 OpenStreetMap showing bicycle paths in Vienna. OpenStreetMap allows one to view, edit and use geographical data in a collaborative way (OpenStreetMap contributors, 2010).

Bing Maps, Google Maps, OpenStreetMap, and Wikimapia are examples of online geovisualisation tools which provide user interaction. Besides different viewing modes (map, satellite, 3D earth), Google Maps allows the user to switch between layers for photos, videos, public transportation, Wikipedia entries, webcams, and more. These objects are represented by symbols or small previews and can be activated via mouse-over actions or clicking. Activating an object shows hidden information or links to other databases. "This interactivity and the possibility to use the WWW to link distributed databases also makes web maps good instruments to explore the different databases" (Kraak & Ormeling, 2003, p. 18).

Compared to Google Maps and Bing Maps where most content is generated and audited by the companies, Wikimapia and OpenStreetMap combine the approach of Wikis and web mapping to provide an editable up-to-date map whose content is mainly generated and audited by the users themselves.

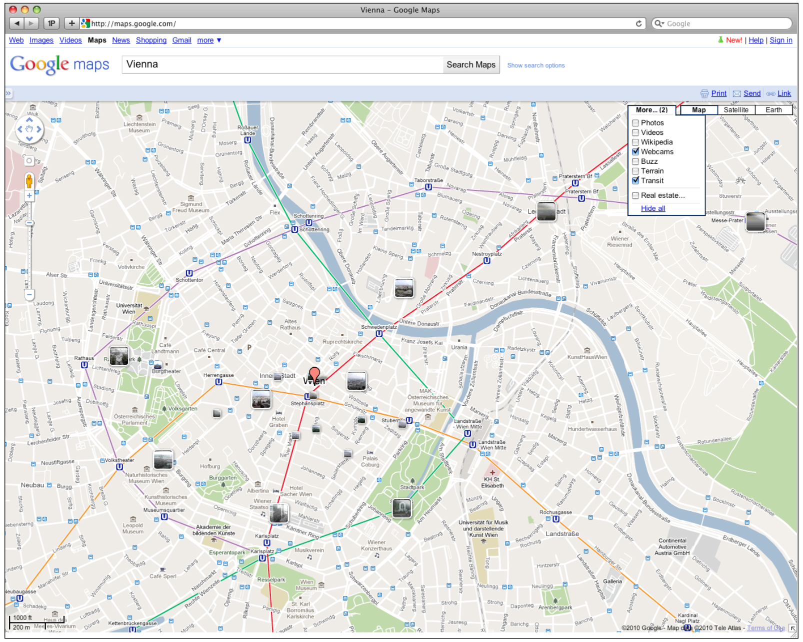

Fig. 3.24 Google Maps showing a city map of Vienna, subway plan, and location of webcams (Google Inc., 2010b).

3.5.1. Google Earth

Google Earth is a standalone geo-browser that provides access to an interactive digital model of the earth. The virtual globe is based upon high resolution satellite images which are linked to a steadily growing pool of other information that go far beyond conventional maps or satellite images. It includes terrain information in 3D, selectable layers for borders, cities, streets, 3D-buildings, and further information which is shared by other users through photos, panorama images or videos.

The integration of user generated data into the virtual globe and its support of *real* 3D navigation in space is specific to Google Earth is, while most other GIS or web mapping tools only support a bird's eye view. Using Google Earth as a visualisation tool, it serves as a platform to integrate and visualise placemarks, paths, polygons, 3D models, photos, and image overlays. Generally speaking, every piece of information in Google Earth is geocoded to its geographical location on the virtual globe using its geographic coordinate system (latitude, longitude). Additional attributes to data include altitude, rotation, or time reference. Compared to *classical* GIS software, Google Earth is oriented towards visual representation of information than an analytical approach. Google Earth is available for various platforms (Windows, Mac, Linux) and requires an internet connection for the data to be loaded in real time.

Visualising data on a virtual globe directly links information to its original geographical location. A common problem in most 3D visualisations is that the digital models somehow float in an eternity of space, and that there is a sudden end at the model's edges, which lack a connection to its further surrounding. Google Earth application allows geographical data from the web to be linked with user generated 2D and 3D information. Besides the small spatial relations of information, as e.g. the position of one wall's painting to an adjacent one, a broader spatial and geographical context supports a comprehensive view and global integration of information.

This project's case study uses Google Earth as a visualisation tool to present the model of the Queen Meresankh III mastaba together with further information (photos, publications, plans, etc.) in the context of the Giza Necropolis. The following visualisations use Google Earth Version 5.2.

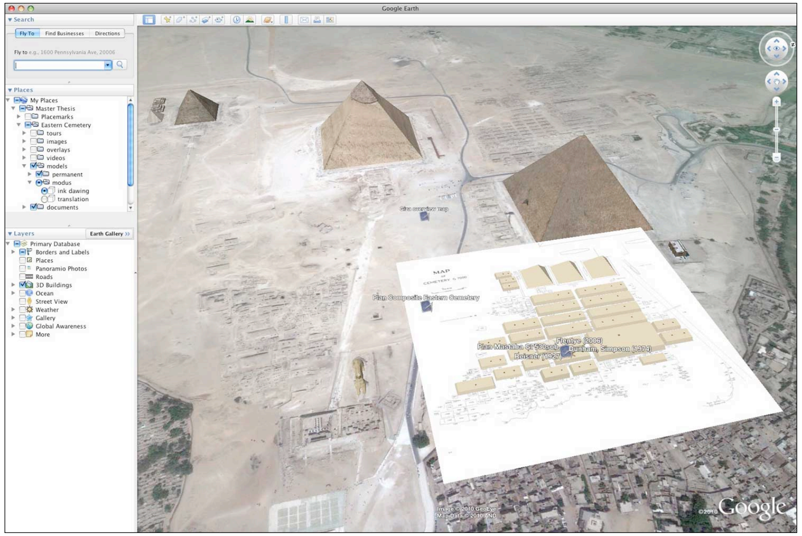

Fig. 3.25 Google Earth interface (model of Eastern Cemetery in the Giza Necropolis).

The interface of the Google Earth application consists of a 3D viewer, and a sidebar on the left side to search for places, organise embedded objects (placemarks, images, maps, 3D models, etc.), and activate layers (boarders, roads, etc.). The 3D viewer provides interactive navigation controls on the top right corner including a compass. The Places panels supports hierarchic structuring and lists all the embedded objects. It is used to add or edit objects and indicates whether an object or folder is visible.

Google Earth uses the KML (Keyhole Markup Language) file format to describe its objects and geographic data. In addition to the out of the box functions which can be directly authored in the Google Earth interface, it supports more elements (objects) and further specifications of objects by directly scripting the KML file. This enhances functionality, allowing customisation of Google Earth visualisations, and includes time attributes, screen overlays, tour controls, and more.

Fig. 3.26 Model of Eastern Cemetery in the Giza Necropolis.

Navigation

Google Earth provides the following navigation options for the 3D viewer: zoom in/out, tilt, rotate, and look around from a single vantage point. It supports navigation using mouse, keyboard, and the controls in the 3D viewer. The mouse proved to be the best tool to navigate on an overview level. However, Google Earth also supports joystick or 3D mouse control. These tools are especially helpful for precise navigation on small spots or inside building models. Placemarks also help to navigate from one point to another. A double click on a placemark zooms in on the location of the placemark.

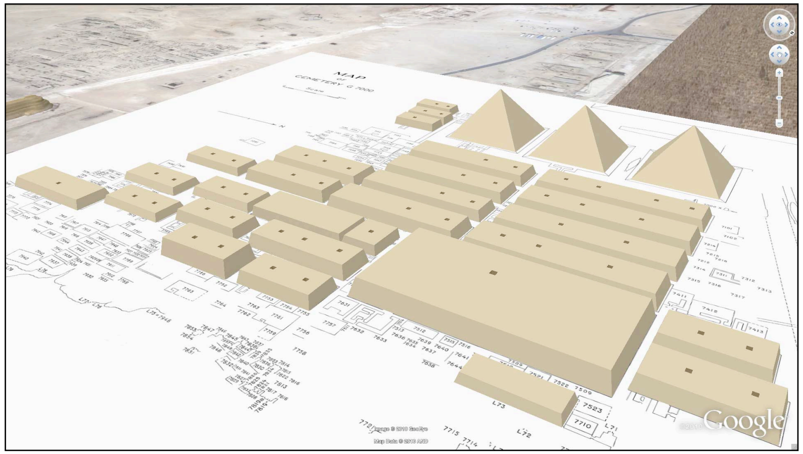

Fig. 3.27 Eastern Cemetery overview.

Tours

Google Earth (Version 5 or higher) also supports a touring feature which allows to record and play tours, besides live user navigation. A tour records navigation in the 3D viewer and can also include audio. Automated tours are integrable in exhibitions or presentations to illustrate spatial relations.

Integration of Multimedia

Google Earth can visualise different media including 2D and 3D data: maps, plans photos, panorama images, 3D models, and placemarks including videos, HTML websites, flash documents, and more. 3D models are importable in the COLLADA file format, or via Google SketchUp [8]. The model's geographical position can either be defined by hand according to the satellite image, or numerically by entering its geographic coordinates.

Fig. 3.28 Main chamber of the Mastaba of Queen Meresankh III (looking north).

[8] http://sketchup.google.com/

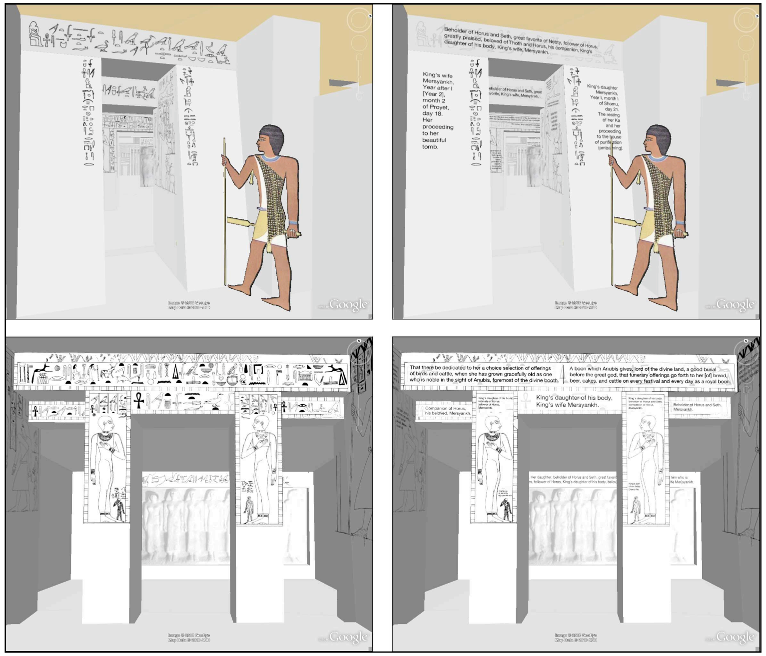

Fig. 3.29 Entrance and Main Room: ink drawing (left), translation (right).

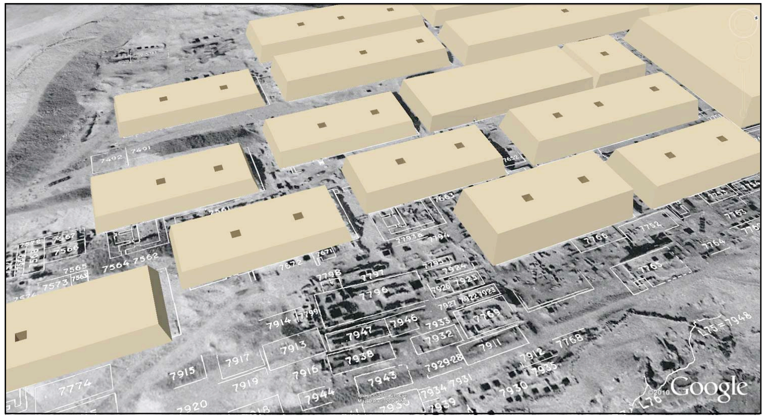

Fig. 3.30 Combination of satellite image, mastaba's numbering, and 3D model.

Plans or maps can be integrated as image overlays on top of the Google Earth's satellite image. The overlay's altitude can either be set as meters above ground level or clamped to the ground. Photos are freely positioned in space from where the photo is taken. Videos can be embedded in placemarks via a YouTube link. A folder's contents can be shown as options (radio button selection) allowing for a user to choose only one of the folder's files. Different versions or variations of a model can be visualised at the same geographical position (Fig. 3.29).

Workflow and Usability

The Google Earth standalone application functions as both editor and visualisation software. Objects are integrated, modified, and stored in the Places panels. Generally, all objects in this case study are integrated using the Google Earth GUI. Google Earth exclusively imports 3D models in the COLLADA file format which is supported as an export format in most CAD applications. Due to compression issues, most photos and image overlays are integrated in the JPG format, whereas transparent image overlays use the GIF format. The tours are recorded using the integrated tour feature and a 3D mouse for navigation.

Network Links

Google Earth gives multiple users access to its data as KMZ files via a network link. The KMZ files contain all the information and linked media, and are saved on a web or network server. Other users who have access to the server can view the data in Google Earth. That way it is possible to instantly share content between multiple users, even if they are in different locations. Publishing data via a network link is a read-only reference, but other users can save the data locally on their hard drive. Changes to the KMZ file on the server are immediately available to all users.

3.5.2. Google Earth API

Fig. 3.31 Preview of the *Virtual Ancient Egypt* project showing the project site in Giza (realised by the Department of Digital Architecture and Planning, Vienna University of Technology).

A more advanced way of sharing Google Earth data is to integrate content to customised web pages using the Google Earth plug-in and the JavaScript API. The plug-in supports full 3D capabilities of Google Earth, and is available for all popular platforms and web browsers. This case study will be implemented in the Google Earth *Virtual Ancient Egypt* [9] project of the Department of Digital Architecture and Planning, Vienna University of Technology. It joins several visualisations of different sites in Egypt (Elephantine, Siwa, Abydos, Dahshur, Giza…), imposing a coherent geographical and temporal structure on all included projects.

The GUI consists of a layer panel (left), a 3D window (middle), and a navigation panel (right). The navigation panel on the right side allows the user to choose the projects according to their geographical location or time periods. A timeline in the 3D window reflects the selected time period and the objects are displayed according to the time span of the selected period. Automated tours help to explore the individual projects along predefined paths. The layers panel on the left side allows to switch individual objects or layers on and off.

The *Virtual Ancient Egypt* project currently supports the integration of the following multimedia files in placemarks: photos, publications, plans, videos (YouTube), and photo albums from Picasa or flickr. All media objects support full screen mode, and publications can be printed out or saved locally.

Fig. 3.32 Guided tour through the Mastaba of Queen Meresankh III.

[9] The Virtual Ancient Egypt project is still work in progress and the following visualisations are a preview of the final project.

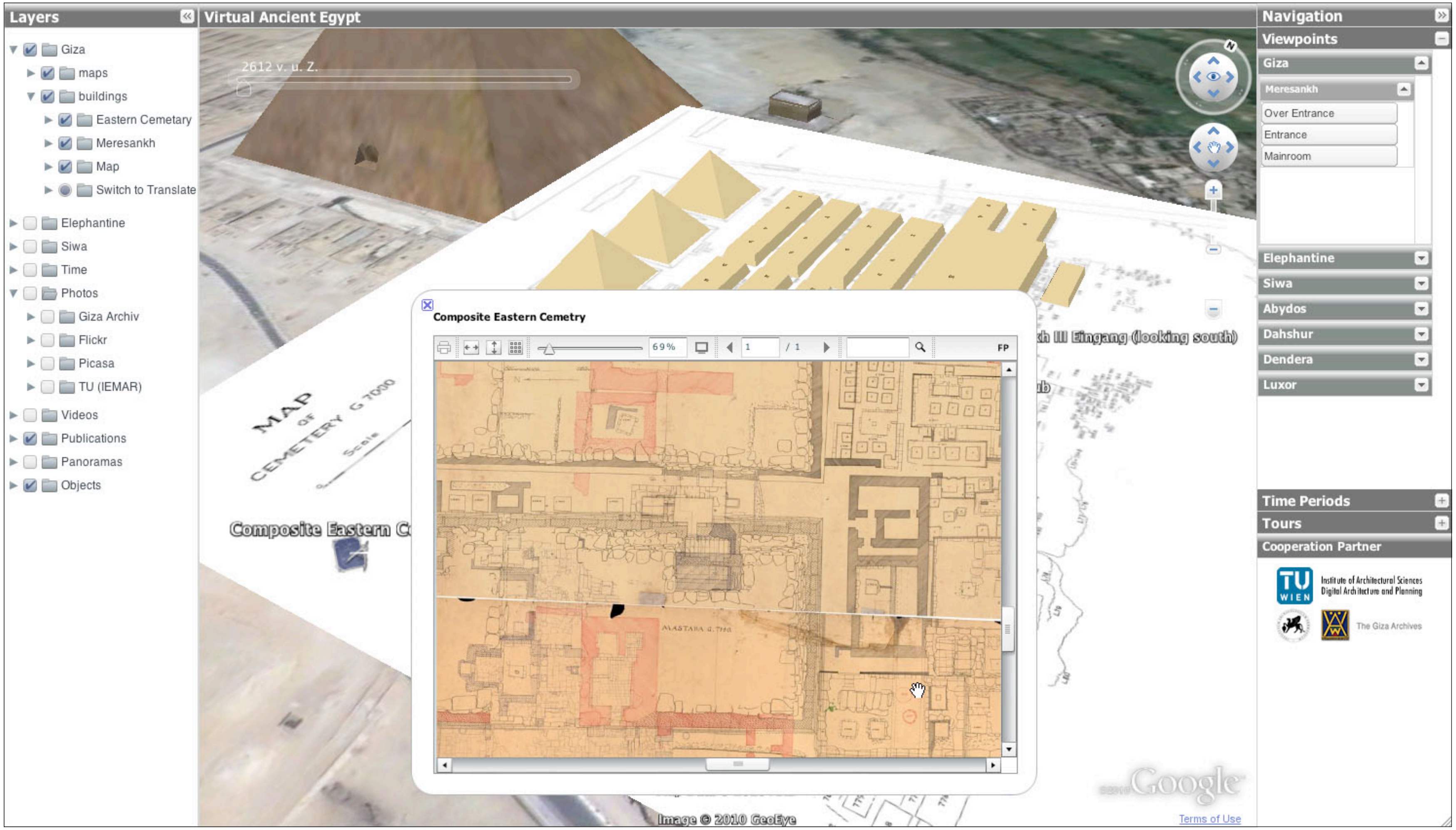

Fig. 3.33 Placemark showing a high resolution composite plan of the Eastern Cemetery.

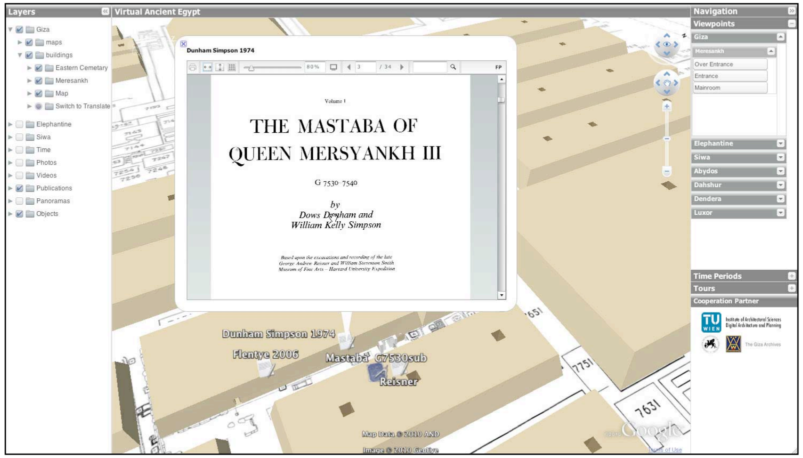

Fig. 3.34 Placemark showing a publication of Dunham and Simpson.

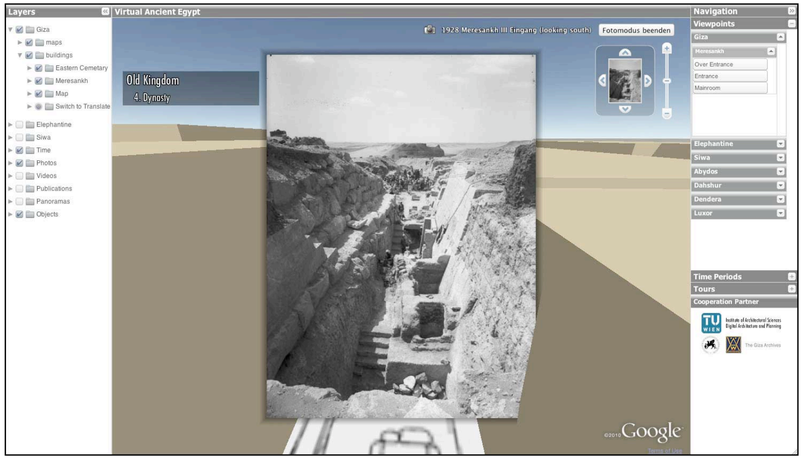

Fig. 3.35 Photo mode: entrance of mastaba from the date of its discovery.

Encountered Issues

The navigation in Google Earth using mouse or keyboard is mainly designed to work on an overview level. Navigating close to ground level or inside buildings requires either special navigation tools like the 3D mouse or recorded tours.

A presentation view including customised layer selection would be an interesting feature, as the Google Earth standalone application functions as both editor and visualisation tool. However, it is possible to hide the sidebar and toolbar, and to display image overlays inside the 3D viewer. More customised features are available in the web browser plugin.

The graphics of both the Google Earth standalone application and the web browser plugin are restricted because of a limited number of polygons and maximum image resolution. Importing large and more complex models with rich textures also reduces performance. Google Earth automatically limits the maximum texture size due to the graphic card specifications (usually between 2048 and 8192 pixels). This becomes a problem especially for large single image overlays using high resolution images.

Summary and Outlook

Google Earth offers archaeologists a tool to present their models in an interactive way on the virtual building site. Visualising archaeological information in Google Earth puts the information in its spatial, geographical, and historical contexts.

Web-based versions make visualisations available for communicating research results to a wide audience. Automated tours are a useful navigation tool and offer the user a guided experience which can be enhanced with audio commentary or background music. Including multimedia objects such as photos, videos, or publications to the spatial visualisation conveys a comprehensive view of a subject. Google Earth could become a useful tool for researchers, scholars, and the general public alike.

Transferring large data sets on the web also requires a concept for visualising different levels of detail which will be considered in future work of the *Virtual Ancient Egypt* project.

3.6. Virtual Experience

Providing access to archaeological information and research work for a broader audience requires a good strategy of how best to communicate this information, e.g. in museums, websites or public relation's work. Images or short video clips are commonly used to visually convey information. However, information is remembered best when the recipient actively interacts with the information. Interactive simulations provide on opportunity to create interest and to intuitively convey information. Game engines challenge users to explore virtual three-dimensional spaces from a first-person perspective and to interact with objects in that space.

A main strength of game engines is to provide a realistic walk-through experience which gives the user a good sense of scale and proportion of spaces and objects. Collision control and gravity simulation also add to a realistic spatial experience. Collision control is supported by almost all current game engines and defines solid objects such as floors, walls, etc. which prevent the user from walking through. It allows the user to walk on a terrain and floors or to climb stairs and ramps in combination with gravity simulation.

Game engines support a variety of real-time rendering qualities (lighting, shadows, various mapping techniques etc.) that add to an experience close to reality. Most simulations in computer games create a virtual reality (VR) by involving a high level of immersion and personal presence. In this project, however, it is more the possibility to develop easy to use visualisations according to the project's requirements, than creating photorealism with game engines. Visualisations using game engines can be implemented in virtual museums, integrationed in website, or as other standalone visualisations. There are several game engines available, mostly commercial applications: Quest3D, Unity, CryEngine, Unreal Engine, etc.[10] Some of the commercial engines offer a free edition including Unity. Of the available game engines, this project's case study uses Unity due to its,

- close integration with Cinema 4D,
- Windows and Mac support,
- JavaScript support,
- high graphical fidelity,
- free of charge availability (Unity 2.6.1),
- web integration (supporting IE, Firefox, Safari).

3.6.1. Unity

> *"Average home computer users today are drawn into the world of computer graphics through computer games."*
> *(Shiratuddin, et al., 2008, p. 10)*

Unity serves as an example of visualisation using a game development tool and contributes to the notion that game engines could also be used for non-entertainment applications. This area of application is referred to as Serious Games, that is the "application of game concepts, technologies, and ideas to non-entertainment applications, which may include games used for advertising, education, simulation, and training" (Shiratuddin, et al., 2008, p. 12).

[10] A detailed list of game engines is available at: http://en.wikipedia.org/wiki/List_of_game_engines/

Fig. 3.36 Main chamber looking north (Unity).

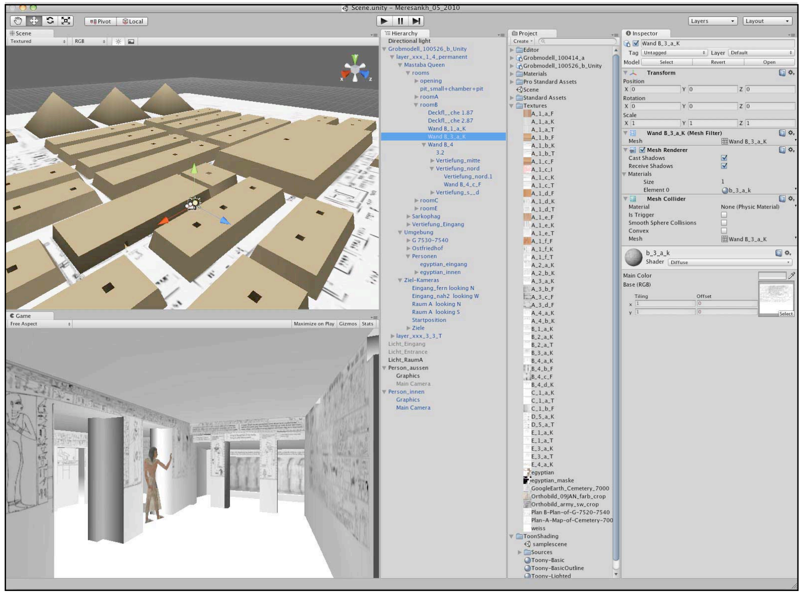

Fig. 3.37 Screenshot of the Unity modelling interface.

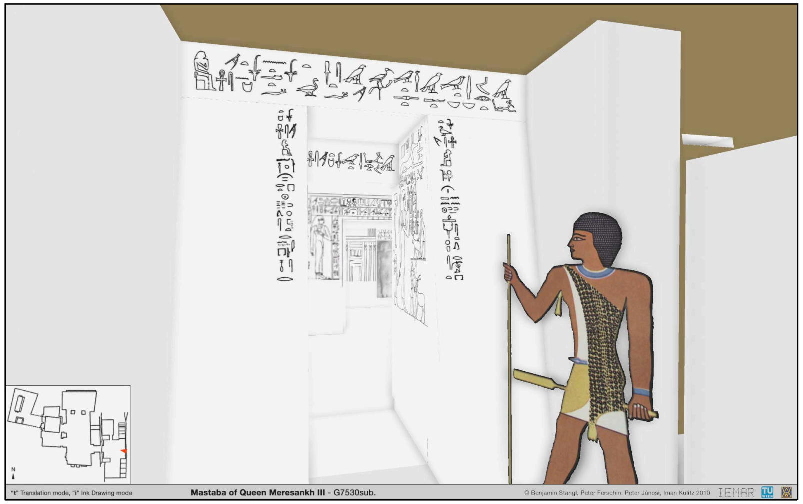

Fig. 3.38 Mastaba entrance (Unity).

Unity is very flexible and open for defining powerful customised interaction techniques according to the visualisation's needs. In this case study, four project specific functions exemplify the options Unity offers for developing individual functionalities.

The interactive functions are:

- adapted first person navigation,
- orientation map,
- overlays and sound integration,
- change of decoration mode.

Navigation

Unity offers many options to specify the navigation to the simulation's requirements. A first person controller is the user's representation in the virtual space. Attached to the controller are the main camera and scripts defining how the user steers the controller. A standard first person controller is included in the project's asset folder whose parameters can be adjusted to the project's requirements (Fig. 3.39). Taking into account the project's scale, it is important to define the controller's parameters including size, walking speed and field of view. Due to collision control issues, the controller size is important, for instance when walking through a door or examining narrow spaces. The slope limit and step offset allow upper limits to be defined for climbing stairs and ramps. If the simulation requires a user to overcome obstacles or barriers, the values for gravity and jump speed need to be adjusted accordingly.

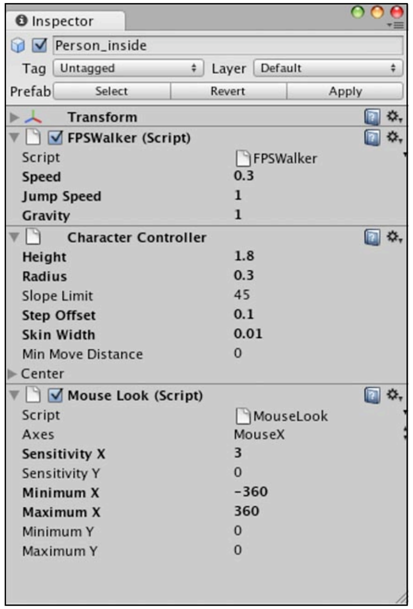

Fig. 3.39 First Person Controller options in Unity.

The user walks around by default using the keyboard arrow keys and the mouse to look left-right or up-down when running the simulation. More advanced input devices like joysticks, gamepads, or other controllers can be used to customise the navigation.

Orientation Map

It is relatively easy to loose one's bearings when exploring unknown virtual spaces in a first person's perspective. In order to maintain the overview, a 2D orientation map on the bottom left side of the GUI interface depicts the user's current position and viewing direction. The orientation map would also support showing the position of multiple moving objects, respectively another user's location in a multiplayer environment.

Interactive Content and Metadata

Further interactive functions were added using JavaScript. By attaching custom scripts to objects, these objects are made to respond to certain user actions.

Screen Overlays and Sounds

Additional information about objects is activated when the user enters a room or approaches a certain object. This information is either displayed on parts of the screen or given to the user as audible information. Unity uses so-called "triggers" which allow to cause certain events, in this case to start playing an audio file or to display a text or image on the screen (Fig. 3.40).

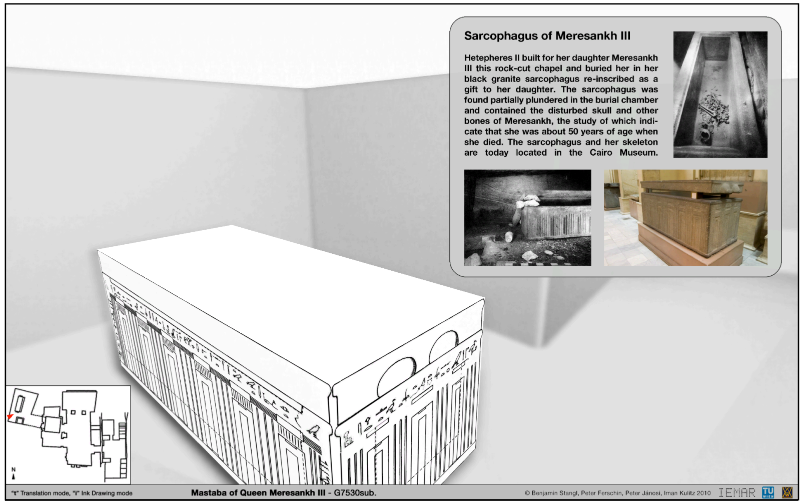

Fig. 3.40 Burial chamber looking northeast: A screen overlay provides additional information when approaching the sarcophagus (Unity).

Change of Decoration Mode

The default mode renders the ink drawings of the wall decorations. The user can change the decoration mode by pressing "**t**" on the keyboard to switch to the **t**ranslation. This mode depicts the English translation of the hieroglyphs on the walls; pressing "**i**" changes back to the **i**nk drawing.

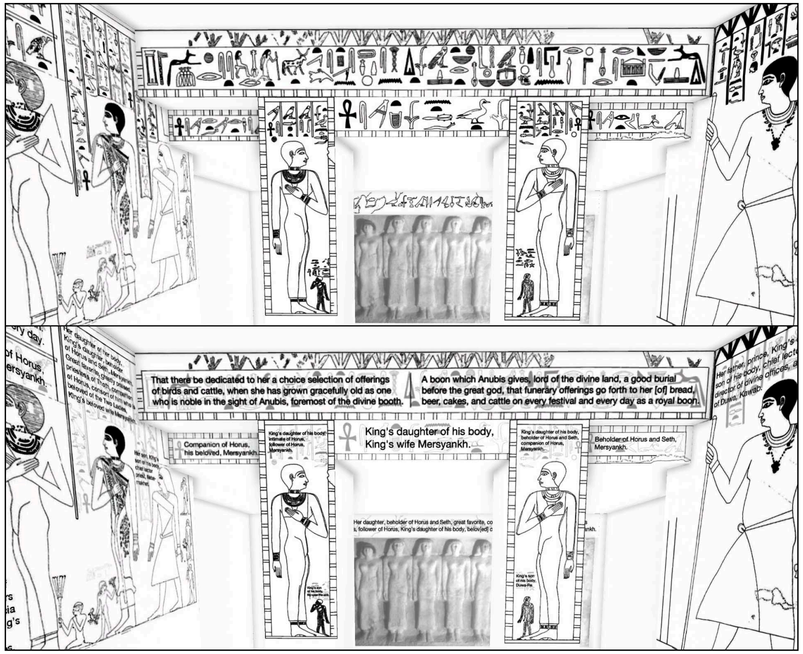

Fig. 3.41 Main room looking north in ink drawing mode, top, and translation mode, bottom (Unity).

Workflow and Usability

Unity provides an intuitive work environment and supports the major file formats of 3D models, textures, sounds, and scripts. All related files are stored in the project's assets folder and remain editable. Modified files are immediately recognised and updated when saving, contributing to a smooth workflow.

In order to run the scene outside of the Unity editor, it is necessary save the scene as a build. Building a scene creates an executable file which runs the visualisation as a standalone application. Unity also allows to create builds which run in a web browser and can be integrated in web pages.

There are several tutorials available on the Unity website to learn the program. An integrated reference manual and a Unity Wiki [11] also provide good support for most common problems.

Encountered Issues

The project's orientation towards abstract and non-photorealistic rendering somehow contradicts the game engine's aim of realism. Some adjustment is needed to achieve a clear abstract rendering which was obtained by using a lightmap shader in combination with the real-time ambient occlusion image effect. A non-photorealistic rendering highlighting the object's outline would be a preferable issue in further updates of Unity.

Another issue is that to optimise fast graphics rendering, by default Unity reduces high resolution images for imported textures. A script which changes the maximum texture size for all imported textures was used, as some wall paintings rely on large image textures.

[11] http://www.unifycommunity.com/wiki/

Summary and Outlook

Unity, an up to date and powerful simulation tool, is suitable for serious information visualisations in a scientific context, due to its rich adaptability. This case study used Unity to show how interactive features can be implemented in Unity through JavaScript code. Unity provides a rich simulation environment and the field of game development tools is definitely worth pursuing for serious scientific simulations.

Future applications could be developed to publish the simulation on mobile devices such as iPhone or iPad, and to integrate the simulation in an online networking environment. This would allow remote and collaborative access communicating via online chat or voice chat.

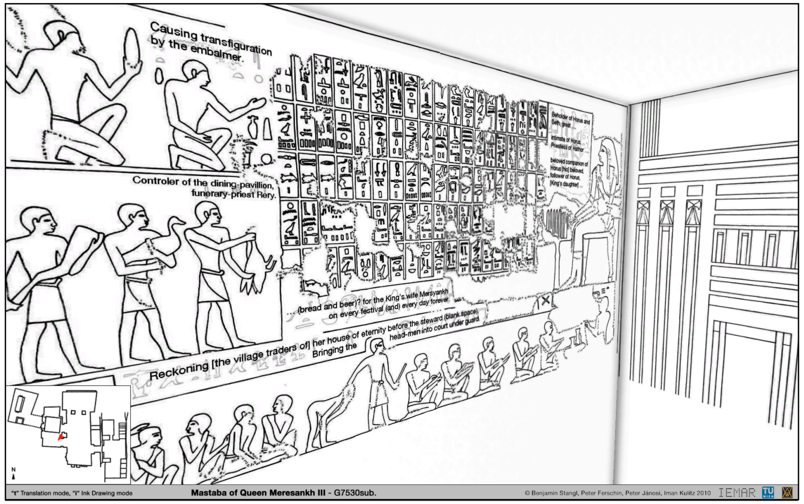

Fig. 3.42 Offering (West) room looking southwest (Unity).

4. Conclusion

The following chapter proposes potential areas of application for the reviewed technologies in an archaeological context, taking into account the strengths and specifics of each visualisation technology. This chapter also provides a summary and an outlook on potential extensions of the project in different directions.

4.1. Areas of Application

4.1.1. Documentation

Due to Google Earths ability to embed multiple media formats simultaneously (pictures, documents, movies, 3D models, etc.), it can serve as a comprehensive information system for integrating data of archaeological excavations. Information which is documented by different teams, stored in various data formats, or physically distributed in different locations is geocoded on a common platform and made accessible through the Google Earth application. Therefore, Google Earth is particularly powerful not only to be used as a final visualisation application, but already in the project development phase and during the data acquisition process. Visualisations in Google Earth can help to support the scientific exchange and discovery process because of the high information density.

4.1.2. Electronic Publication

> *"The medieval library, the printed book, and library classifications have each transformed and reordered knowledge. Internet and digital technologies will have a profound effect in archaeological theory and practice."*
> *(Richards, 2006, p. 213)*

The PDF is widely accepted as a distribution and exchange format for digital publications in archaeology and other disciplines. Embedding digital 3D models into PDF files adds another dimension to digital publishing and makes it particularly interesting to distribute and exchange spatial information within electronic publications. The ability to link to other information sources such as databases, online publications, or other information on the web is the major strength of electronic publications. Digital publications instantly facilitate connection and understanding of the information within its framework. Moreover, digital publications enable an accurate re-use and reproduction of previously published information for further research.

On account of 3D PDF's free viewing software (Adobe Reader) and convenient use with standard desktop equipment, it is suitable wherever interactive spatial information should be disseminated to many users. Adobe 3D PDF documents can be published as part of electronic PDF publications, provided as a downloadable file on the web, or integrated in presentations. Likewise the security settings of standard PDF documents account for security issues and protects the copyright of digital models. Electronic publication in the archaeological field is a highly disputed topic within the profession. J. Richard argues that a change in publication practice "has partly been driven by problems with traditional media, but partly it is led by the anticipated advantages of new technologies" (2006, p. 214). While books traditionally provide the reader with a linear and coherent narrative, electronic information systems contain information which is linked and interconnected. Electronic publications also allow the combination of a greater variety of material when compared to paper-based publications. It provides "the reader with a level of access to data which will allow them to test interpretations and to develop rival theories, thereby contributing to a process of democratisation of archaeological knowledge" (Richards, 2006, p. 215).

Critics of electronic publication in archaeology and other disciplines claim that the nonlinear approach of electronic publications might confuse or disorient the reader, but also "allows the author to present the dumping of raw undigested field data as a virtue, rather than as an opt out from the professional responsibility of adequate post-excavation analysis" (Richards, 2006, p. 214).

The shift from linear media like books or videos towards electronic publications and non-linear media is not a one-on-one transformation of the same information and content. In traditional media, "the structure and order of the information contained within the document is the same as the structure and order of the user's acquisition of information" (Lock, 2006, p. 230). In non-linear media, however, these structures are not necessarily related. This should be noted but at the same time taken as a chance to use the advantages which are specific and unique to digital forms of publications.

4.1.3. Teaching and Learning

> *"… knowledge is not an external reality waiting to be handed on by a teacher but is the personal construction of new perspectives."*
> *(Lock, 2006, p. 227)*

Digital computer-based information sources account for both teachers' and students' changing attitudes towards teaching and learning today. 3D PDF provides a powerful computer based learning (CBL) tool which encourages students to actively explore and get involved with the presented information. G. Lock mentions independence, control, and active engagement as principles for effective learning and argues that learning is more about "interacting vigorously and critically with the content material rather than just accepting information and ideas passively" (2006, p. 227).

Interactive 3D PDF models can be applied in academic teaching to illustrate spatial connections and to provide students with an interactive learning tool. "Accepting that learning is about enquiry, it is important to realise that everyday modes of enquiry are rapidly changing and to assess how these changes have and will impact on university learning and teaching" (Lock, 2006, p. 226).

4.1.4. Interactive Museum

Cultural heritage exhibitions play an important role in creating interest and in communicating archaeological matters to the general public. Interactive digital visualisations could help to convey the exhibition's information by asking visitors to get actively involved with the contents. "In museums […] interactive displays are often effectively used to engage visitors in a dialogue with information so that the pace and direction of accessing a mix of text, images and sound is user-controlled and, perhaps most importantly, enjoyable"

(Lock, 2006, p. 226). Possible implementations are interactive terminals or large screen projections.

Unity provides a rich interactive environment for information visualisation and information conveyance. Due to Unity's original background as a game development tool, it is particularly qualified for standalone applications which function independently. Also to account for its high adaptability and flexibility for both input controller (navigation) and output devices (large projections), it is suitable for applications addressing a wide audience. Using sophisticated and fast rendering, Unity specifically qualifies for applications with high visual demands. The "approach of interactive virtual representations can provide a strong motivator for the general public and scholars alike" (Roussou & Drettakis, 2003, p. 56).

Likewise, Google Earth can be a powerful tool to convey information to museum visitors by enhancing exhibitions with interactive visualisations. Google Earth can be used to provide the geographical context and to make a connection between the artefact in a museum and the site's settings. Interactive virtual tours can give the visitor a guided experience and visualise further information of exhibited objects. Digital visualisations can also help to visually communicate processes like an object's changes over time or different variations of a reconstruction.

4.1.5. Web Integration

The web evolved to a powerful communication medium which allows users to not only passively receive but to interact with information or even create content online. Increases in bandwidth support larger data set transfers including rich media. The web has far-reaching potential to a wide audience and to disseminate information which is instantly available.

Both Unity and Google Earth support web implementations. [12] This allows interactive 3D content to be embedded in websites which can be applied to many purposes. Possible applications could be to communicate researchers' work to the public or to give archaeological students virtual access to excavations sites. Interactive websites also address potentials visitors or customers by providing insight into the work of museums, universities, or companies.

[12] Requires a free browser plugin which can be downloaded from the developer's website.

Tab. 4.1 Possible applications, software requirements, and encountered issues.

Technology	**Adobe 3D PDF**	**Google Earth**	**Google Earth Web API**	**Unity**	**Unity Web Player**
Areas of application	- electronic publication - teaching & learning - exchange of 3D information	- documenting excavations - scientific exchange - presentations	- web presence (museums, universities, companies etc.)	- archaeological & cultural heritage exhibitions - teaching & learning	- web presence (museums, universities, companies etc.)
Required software [13]	Adobe Reader	Google Earth	Web browser, Google Earth Plugin	Unity	Web browser, Unity Web Player
Supported platforms and browsers	Windows, Mac OS, Linux, Solaris	Windows, Mac OS, Linux	Windows: Internet Explorer, Firefox, Chrome, Flock Mac OS: Firefox, Safari, Chrome	Windows, Mac OS	Windows: Internet Explorer, Firefox, Safari, Chrome, Opera, Mozilla, Netscape Mac OS: Firefox, Safari, Mozilla, Netscape, Camino
Encountered issues and weak points	- workflow (U3D file format) - restricted adaptability - minute navigation (e.g. inside of rooms)	- navigation (close to ground) - "editor" view only - limited texture size (due to performance) - limited number of polygons (due to performance)	- navigation (close to ground) - bugs with web browsers - limited texture size (due to performance) - limited number of polygons (due to performance)	- non-photorealistic rendering difficult to achieve - programming skills required (professional application)	- non-photorealistic rendering difficult to achieve - programming skills required (professional application) - performance (web)

[13] All required software for viewing Adobe PDF, Google Earth, and Unity files are free to download.

4.2. Summary

Digital Archaeology uses documentation and visualisation methods to explore new technologies for scientific archaeological work. Today, excavation and documentation is massively supported by digital technologies which are used both on site and in post excavation work to generate digital 3D models of objects or buildings. Moreover, virtual reconstructions are modelled based on archaeological research work. Besides deriving 2D representations (plans, sections, renderings, etc.) from these digital models, spatial information systems are able to communicate the model's information in its full dimension. Situated in the rich and challenging field of archaeology, the project's case study shows that virtual spaces can be utilised for interactive information visualisations. There is evidence that interactive visualisations create interest, increase understanding, and help to communicate archaeological matters to scientists, scholars, and the general public.

The case study presents possible technologies and implementations for exchanging spatial information in digital documents, visualising information in its spatial, geographical and historical contexts, and providing a walkthrough of virtual spaces. Digital visualisations in archaeology often strive for intriguing photorealism. The case study deliberately deviates from this trend and uses non-photorealistic rendering to shift focus on visualising spatial relations and conveying specific information.
The visualisation using Adobe 3D PDF shows how the common PDF can be used to view and exchange spatial models within a standard document including spatial navigation, embedded metadata, and other interactive functions via JavaScript. The technology is suitable for embedding 3D information in electronic publications, or as an interactive teaching and learning tool.
Google Earth accounts for the growing significance of interactive geovisualisation of archaeological work, and allows 3D information and other multimedia to be visualised in its spatial, geographical, and historical contexts. It can help to document different media from archaeological excavations and to provide a comprehensive view of a subject. Web-based versions enable Google Earth to communicate research results to a wider audience.
The visualisation example in Unity shows that game engines could be used for serious applications to communicate archaeological information and spatial experience to a broader audience. Possible implementations are walkthrough simulations in archaeological museums or for scholastic purposes.
Besides the technologies' different foci, the implemented functions aim at navigation and orientation issues, enhancing the understanding of archaeological inscriptions with translations, and implementing additional information about objects (metadata, audio, external linking, etc.). However, each reviewed technology is opened for further functionalities and other uses which have not been applied in this project's case study but could suit other visualisation projects.

Digital information models provide the possibility to integrate and link to an almost infinite quantity of information. On account of this, reasonable choices regarding which information is visualised and how information is communicated must be made taking into account the purpose and sufficiency of the given visualisation. Using digital media to convey information requires a clear strategy of how the potential recipient uses and interacts with the system and the information at hand. It is particularly useful to apply methods and functions which are unique to the digital medium and have no or hardly any other analogue alternative. By far not all possible functions offered by a visualisation application should be implemented in one visualisation, and a clear visualisation concept is essential particularly because of the vast possibilities.

4.3. Outlook

The Giza Archives

By arrangement with Peter der Manuelian, Director of *The Giza Archives Project*, it is planned to integrate the visualisation in the *Giza Archives* which forms a comprehensive online research database on Giza. The goal is to realise a visual 3D search for the tombs of the Eastern Cemetery, and to provide a spatial experience and deeper understanding of the Mastaba of Queen Meresankh III.

Virtual Ancient Egypt Project

Together with other visualisations of Egyptian sites carried out by the Department Digital Architecture and Planning, Vienna University of Technology, the case study will be implemented in the web based, *Virtual Ancient Egypt* visualisation. The goal of the project is to provide an interactive and easy to use spatial information system about ancient Egypt. First tests have shown promising results.

Improvements to the 3D Model

The 3D model is constructed based upon the publications and the digital information at hand. Improvements to the 3D model could be made by embedding a terrain model of the Eastern Cemetery together with a high resolution aerial photograph. The rock-cut statues in the interiors of the tomb could also be 3D scanned to improve the quality of the model. A research trip would be required for photo documentation to fully texturize the model with colour images of the wall paintings.

Research Trip

In spite of good documentation about this tomb in various publications, some questions concerning the exact geometry remained open (entrance and shaft). There has also never been a systematic colour recording of the entire tomb. To fully answer all research questions, it would have been necessary to undertake a research trip to Giza to gather all required information. For this reason, a first research trip had been scheduled for April 2010 to visit the site, create complete colour photo documentation, and to perform a 3D-scan of the rock-cut statues in the tomb. Unfortunately, this trip was not possible.

As the mastaba's model will possibly find further use in future research projects, a second application for permission to document the site will be made. The required technical equipment and software solutions had already been evaluated in two test sessions in the Egyptian and Near Eastern Collection of the *Museum of Fine Arts in Vienna*.

Mobile Integration

Integrating 3D models and spatial information systems in mobile devices are not only neat gimmicks but have the potential to change the way of interacting with information in both the real and the virtual worlds. The game development tool, Unity already supports to publish builds (applications) for the iPhone, iPad, and others mobile devices. The case study's 3D model could already be successfully visualised on an iPhone using the 3D model viewer *3DVIA Mobile for iPhone (Dassault Systemes)* [14].

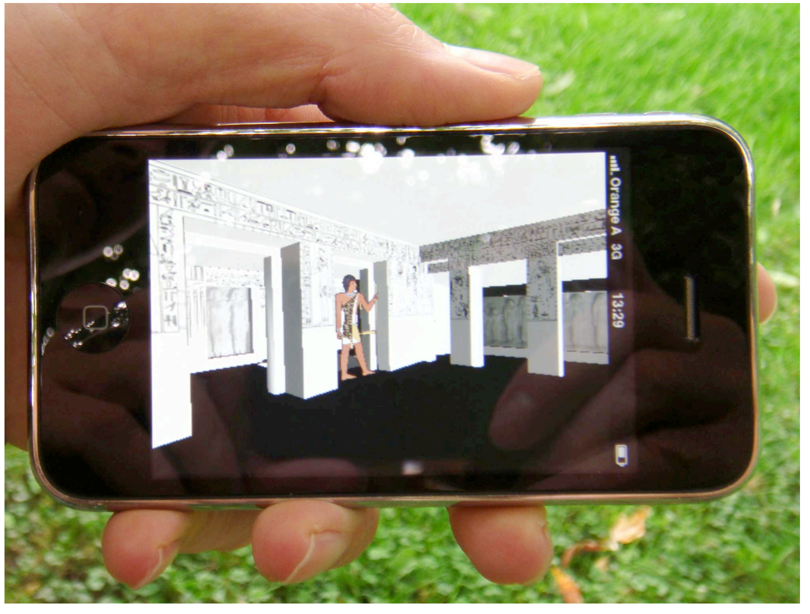

Fig. 4.1 Interactive 3D model on an iPhone (3DVIA Mobile for iPhone).

Mobile devices offer the combination of many potentially interesting features such as GPS, compass, camera, network connection, etc. Geovisualisation applications are able to use the GPS coordinates to filter information related to the user's current position. Object recognition techniques could use the camera of mobile devices to present further information about the surroundings.

As the performance, functionality, and reliability of mobile technologies improves, many new interesting and powerful applications will be developed in various fields.

[14] http://www.3dvia.com/products/3dvia-mobile/

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List of Figures & Tables

Abbreviations

API	Application Programming Interface
AR	Augmented Reality
CAD	Computer-Aided Design
CAVE	Computer-Aided Virtual Environment
CBL	Computer based learning
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human Computer Interaction
KML	Keyhole Markup Language
NPR	Non-photorealistic Rendering
OCR	Optical Character Recognition
QTVR	QuickTime Virtual Reality
SDK	Software Development Kit
URL	Uniform Resource Locator
VE	Virtual Environment
VR	Virtual Reality

Web Links

Archaeological visualisation projects

Theban Mapping Project
http://www.thebanmappingproject.com/

ISEE
http://isee.kitabi.eu/

The Giza Archives
http://www.gizapyramids.org/

Satet Temple 4D - Elephantine
http://www.iemar.tuwien.ac.at/content/elephantine.aspx

Visualisation technologies

Adobe Reader
http://get.adobe.com/de/reader/

Acrobat 3D Developer Center
http://www.adobe.com/devnet/acrobat3d/

Supported file format of Acrobat 3D
http://www.adobe.com/manufacturing/resources/3dformats/

Google Earth
http://earth.google.com/

Google Earth API
http://code.google.com/intl/en/apis/earth/

Google Earth KML reference
http://code.google.com/apis/kml/documentation/kmlreference.html

Google Earth Code Playground
http://code.google.com/apis/ajax/playground/?type=earth

Google Maps
http://maps.google.com/

Wikimapia
http://wikimapia.org/

Bing Maps
http://www.bing.com/maps/

OpenStreetMap
http://www.openstreetmap.org/

UNITY - Game Development Tool
http://unity3d.com/

Unity Web Player
http://unity3d.com/webplayer/

Unity Wiki
http://www.unifycommunity.com/wiki/

Unity web forum
http://forum.unity3d.com/

List of game engines
http://en.wikipedia.org/wiki/List_of_game_engines

3DVIA Mobile for iPhone (Dassault Systemes)
http://www.3dvia.com/products/3dvia-mobile/

Institutions

Institute of Architectural Sciences
IEMAR: Digital Architecture and Planning (E259.1)
Vienna University of Technology
http://www.iemar.tuwien.ac.at/

Institute for Egyptology, Vienna University
http://www.univie.ac.at/egyptology/

Egyptian and Near Eastern Collection, Museum of Fine Arts Vienna
http://www.khm.at/khm/sammlungen/aegyptisch-orientalische-sammlung/

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