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Credit for initiating this project goes to the three Major Communities of the Holy Sepulchre, namely to His Beatitude Theophilos III, Greek Orthodox Patriarch of Jerusalem, to Fr. Pierbattista Pizzaballa, OFM, former Custos of the Holy Land, and to Archbishop Yohanna Moukaddam, the Late Armenian Patriarch of Jerusalem. The Coptic Church of Jerusalem, the Ethiopian Church of Jerusalem, and the Syrian Orthodox Community provided invaluable support, enabling the spaces under their authority to be surveyed and studied. In particular, we are grateful to Archimandrite – now Bishop – Jouda Fakitas, to Fr. Fergus Clarke OFM, and to Fr. Samuel Aghoyan for supporting us in all the field operations, and facilitating access to the various parts of the buildings. We fondly remember the many cups of coffee we shared during the hours of the night in the company of Fr. Samuel, when the silence and the stones of the Holy Sepulchre were our only fellow adventurers, and the delicious sweets offered by Archimandrite Isidoros as he accompanied us to the inaccessible rooms around Golgotha. We thank Don Gabriele for his care and attention, especially after our working vigils, and Brs. Andrew and John who happily opened the doors of the Franciscan Monastery to us, during our measuring work. Also, we no longer remember all the names of the people who, over the years, gave us direct and indirect support, as we conducted our operations, and so our heartfelt thanks go to all the members of the Holy Sepulchre Communities, for their hospitality and willingness to help.

Sincere thanks to Fr. Athanasius Macora, for his wisdom and guidance in our dealings with the Communities. Over the years, as the project progressed, he was unfailingly helpful. A special thanks to Fr. Eugenio Attale, teacher of Christian Archeology, who acted as our guide, and often went over and above the strict confines of his work as historical archivist. He is indeed a first-class scholar, and his engaging modesty only serves to make his contribution that much more valuable. We also thank the architect Theo Mitropulos, who generously gave his time and shared his knowledge, especially with regard to the more recent interventions, that he followed first-hand.

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Foreword

It's truly a great pleasure to write a few lines of preface to this wonderful book on "Jerusalem. The Holy Sepulchre. Research and Investigations (2007-2011)". The pleasure doesn't arise only due to the beauty of the content and the scientific value, but also to my friendship with Piergiorgio Malesani. I perfectly remember when Piergiorgio told me about this project: his enthusiasm, his devotion to Father Piccirillo, his exceptional knowledge and skills in the field of petrography and its application to cultural heritage conservation, were the perfect ingredients to produce such extraordinary work, that the readers are finally able to look at.

I remember also that the work was born during the glorious years when at the University of Florence a Centre for Cultural Heritage constituted a marvelous experience where architects, geologists, chemists – as I am –, biologists, physicists, art historians, informatic scholars could dialogue and carry out true inter- and pluri-disciplinary projects. Indeed, the project to which this book deals with has all the peculiarities of a multi-disciplinary approach to a complex conservation and restoration case study.

I am very grateful to Grazia Tucci who succeeded after a long and intense work to end this beautiful story with this publication: it's a deserved prize to the memory of two great men, Piergiorgio Malesani and Father Piccirillo, two persons that I had the luck to meet and with whom I collaborated receiving much more than I was able to do. I hope scholars in all the world, and namely young researchers, can have interesting food for thought allowing new projects and improving their knowledge and skills.

Luigi Dei
Rector of the University of Florence

Acknowledgments

Grazia Tucci

her meticulous attention to detail. This book is densely illustrated, with a very disparate range of types of content. Her graphic skills helped to give a sense of continuity to the text as a whole, and made the result a pleasure also from the point of view of page layout. The 3D meshes used in the book are the work of Liliba Finzi, my tireless collaborator who, despite not having taken part in the actual work, devoted a lot of time, with her customary passion, to embellishing the volume with illustrations that convey an idea of the huge potential of all the data that was acquired. To her go my fond thanks.

Interpreting a language other than one's own can often be an unsatisfactory compromise; accordingly, special thanks to our translator, Gavin Williamson, who always sought to do more than slavishly translate mere words, to render the true meaning of the content. We also pay special tribute, with hope in our hearts, to Roberto Sabelli who, having been there at the start of the project, is right now fighting his own, difficult battle for life.

Our affectionate thoughts go to the two wonderful people who first set this undertaking in motion: Father Michele Piccirillo and Prof. Piergiorgio Malesani. To these scholars, to whom this book is dedicated, goes our great esteem and gratitude. Our conversations together were always full of new thoughts and ideas, accompanied by their exemplary lives, and by unforgettable experiences. Their contribution, both as people and academics, will be an inexhaustible source of inspiration.

My personal debt is owed to my loving husband, Giuseppe, without whose academic and moral support this book would never have been completed. Finally, grateful thanks to all those who, although perhaps not mentioned by name, took pains to ensure the success of this volume.

Grazia Tucci
The Holy Sepulchre Church is the most important Christian Shrine in the world; its rich history, though, and the fact that it is governed by an internationally recognised complex sharing system known as the Status Quo, have deeply influenced its architecture.

In 2006 the Heads of the Three Major Communities at the Holy Sepulchre, concerned about the stability of the Holy Sepulchre Church in the event of a major earthquake, engaged, through their representatives, in a series of consultations concerning the need for an appropriate evaluation, starting with a preliminary investigation as to what would be required to conduct a complete study. The late Fr. Michele Piccirillo, OFM suggested inviting the Architectural research team of the University of Florence (CABEC) to Jerusalem in order to carry out the seismic study. The proposal to commission the team from Florence required the common agreement of the Three major Communities, given that it would need to extend to all parts of the structure. The Communities did indeed agree to commission and enable CABEC to undertake the study, whereupon the team carried out the first phase of the study from the 16th to the 23rd of April, 2007.

The team, under the direction of the late Prof. Giorgio Malesani, included numerous experts of disciplines relating to architecture and geology. The Communities gave their full cooperation to the team, which carried out one investigative campaign in 2007 and two campaigns in 2008, as well as various other on-site visits required to complete the research.

The study required extensive access to the structure as well as to adjacent spaces. Under the Status Quo regime, access to the common areas was by the consent of the Three Major Communities, whereas access to the areas belonging specifically to one of the Communities, including the many areas not accessible to the public, was by specific invitation of the respective Community. The Communities cooperated fully and harmoniously with the entire research process, thus making for its successful completion.

The final report of CABEC was presented to the Three Major Communities in October, 2009, with the title (as here translated from Italian): Analysis of the Seismic Vulnerability of the Church of the Holy Sepulchre in Jerusalem. The final report was presented in three volumes: I - Geotechnical and geophysical characteristics; II - Three-dimensional relief mapping; III - Structural evaluation of seismic vulnerability.

This book is the fruit of the research done during the seismic analysis. The purpose of this publication is to share these results with a wider public. We, the undersigned, are happy to present it to this public, for the purpose of furthering knowledge and understanding of the Holy Sepulchre. We thank all the experts who were involved in any and all the stages of the field studies, and in analysing the data thus produced, and that have thereby made the present volume possible. That the study was carried out by our common initiative and agreement give us great satisfaction. Obviously though, we do not necessarily endorse any technical choices and judgements, which are the responsibility of the respective experts, and still less do we mean to approve any comments in this book regarding the Status Quo regime in the Holy Sepulchre, on which we alone are competent to make any statement.

With the publication of this volume, another of the projects of Michele Piccirillo that were left unfinished with his demise, 11 years ago now, is seeing the light of day, albeit in a partial form. The plan for a renewed study of the Basilica complex, setting out from up-to-date findings acquired using the most modern technology, had taken shape more and more in the thoughts of Piccirillo, who, throughout his life as a scholar of Palestine studies, and also as a Franciscan, gave a lot of space, and attached much importance, to the Basilica of the Anastasis in Jerusalem. Indeed, while already ill, he was working with his friend Franco Scaglia, and the director Luca ArmiMagi, on the documentary of the Holy Sepulchre: it’s even less surprising that the last volume he published – under the title: La Nuova Gerusalemme. Antropo-storia palestinese al servizio del Luiho Santo – dealt especially with the models of the Holy Sepulchre, made of olive tree wood and mother-of-pearl. These models were made thanks to the plans and sections carefully drawn up by Fra Bernardino Amico between the 16th and 17th centuries. It was the idea of bringing Amico’s work up-to-date, using the tools and knowledge accumulated over four centuries, that led Michele Piccirillo to entrust Prof. Malesani and a group of academics from Florence University with the task of carrying out the complete 3D survey, conducting geological and seismic investigations, and compiling an analysis of the Basilica’s seismic vulnerability. It sometimes happens that a person and a particular part of the world are deeply interconnected, so much so that when one of the two happens perchance to succumb, the other is often also at no small risk. This is the case with Father Michele Piccirillo and the Holy Land. “His” monuments are no longer the extraordinary place that they had become as long as Father Piccirillo made them so alive, and extraordinarily welcoming. When the monuments become laboratories, magical places in which the coexistence of different cultural experiences was made possible, in the interests of a more open vision, with a view to areas of common ground, and broader horizons for collective growth. Father Piccirillo lived in a borderland that «makes the road captivating» (Debray, 2010), the place where differing experiences meet, and are exchanged, providing concrete answers at certain times to the real and urgent problems we were called upon to face. In his actions the figure of the professional emerged with extreme clarity. Piergiorgio was in fact a university professor who had matured much of his knowledge directly in the field, dealing with a large number of objectively complex situations within very varied contexts. In short, he was one of those problem-solvers that the best companies constantly contend for. For this reason, he was also an esteemed consultant to various authorities, institutions and companies and has worked, on their behalf, both nationally (with contributions ranging from interventions to secure power lines to the optimization of industrial cycles in the production of cement and brick) and abroad (with interventions for the construction of tunnels, dams, road and rail tracks). In short, having shared such an extraordinary experience with Piergiorgio - the important results of which are contained in this book - we were able to fully appreciate the qualities of the scholar who is always ready to face the complex situations and the exceptional qualities of the man and of the sincere friend, whom he was able to express also on that occasion.

In 2007 Prof. Piergiorgio Malesani, as Director of the Centre for Cultural Heritage of the University of Florence, was commissioned by the Custody of the Holy Land to conduct a study on the Basilica of the Holy Sepulchre in Jerusalem with the main aim of assessing the seismic vulnerability of the entire architectural complex. At the same time he was also asked to carry out a survey of the Grotto of the Annunciation in Nazareth to determine the state of conservation. The task was certainly arduous and delicate but Piergiorgio was the most suitable man to deal with that type of task. First of all because he had the valid experience and competence that is required in such circumstances and then because he had already given proof of his extraordinary ability to develop interdisciplinary projects and collaborations with all the wide range of professionals (engineers, architects, geologists, geophysicists) that was necessary to deal with such a complex project. So, if on the one hand the more than 250 scientific contributions, published in national and international journals, certified the quality of the scientist, on the other hand, the numerous institutional assignments received during his career (President of the degree course in Geological Sciences from 1990 to 1996; Director of the Department of Earth Sciences for the three-year period 1989-1992 and for the three-year period 2000-2003; Dean of the Faculty of Mathematical, Physical and Natural Sciences of the University of Firenze for the three-year period 1996-1999) testified to his undoubted management skills. From the very first operational meetings, Piergiorgio - who in his work always combined the courage of the man of science with the pragmatism of the brilliant professional - immediately clarified his intentions and expectations. In essence, he frankly asked all of us who were part of the working group to provide concrete answers at certain times to the real and urgent problems we were called upon to face.
To this end, the wall elevations to be analysed were defined, and subdivided by level (main storey and upper gallery). On these, both the Architectural Elements (EA), displaying homogeneity of construction characteristics, and the Wall Stratigraphical Units (USM)25, were later evidenced, following a separate numbered sequence for each wall elevation.

In the case of the Holy Sepulchre, the stratigraphical diagram (matrix) recording the sequence of construction, and the physical relations between the parts that were identified, presents no few problems, owing above all to the huge mass of data that would weaken their interpretation. To this end, a further simplification was effected in the numbering of those Architectural Elements which, despite being formed from differing parts that can be defined separately, can clearly be referred to a single phase with homogeneity of construction characteristics. This operation is possible above all with the Crusader period elements, which reveal an easily legible construction intention, that is clear in each of its parts. Obviously the features with special architectural or structural importance, and the parts replaced in a different era, were numbered as individual Cuts, USMs and EA26 (see Tables 2, 3 and 4).

The matrix was then processed to create several diagrams relating to each of the elevations analysed, and also organized as a tool for structural investigation, with an information content that is different from that usually defined.

All of the work of identifying Stratigraphical Units and Architectural Elements is thus based on an interpretation of the stratigraphical relationships that are still observable in the North Transept, highlighting, as a first draft, a relative sequence limited to the main construction events that can be dated clearly, as outlined below in the absolute chronology of the construction phases of the complex, identified by V. Corbo27 (see Figure 14).

**TABLE 2** Wall stratigraphy, sample elevation A-A' (drawing by Alessandra Angeloni, based on the original survey courtesy of National Techni- cal University of Athens. This survey was used to produce Tables 2, 3 and 4).

**TABLE 3** Wall stratigraphy sample at the lower level (from 2011 surveys).

**TABLE 4** Wall stratigraphy sample at the upper level (from 2016 surveys) and key to stratigraphic symbols (left).

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26 For example, as clearly visible in Table 3, the stratigraphical relationships have been shown between an EA comprising an entire Crusader-period pillar that was cut (Cut: negative Stratigraphical Unit) for the creation of a restoration stone element (USM), in turn numbered and placed in a physical (relative) relationship with EA and T (Taglio = Cut).

27 V. Corbo, 1981, Table 1.
It is interesting to note that both the Crusader masons and the 11th century Byzantine masons reused numerous capitals, column bases and column drums from the 4th century Basilica. The sequence of the construction and destruction phases which characterize this extraordinary architectural context can be seen in it, in a clear and orderly form (see Tables 1, 2 and 3).

1.2.2. The stratigraphical sequence

The stratigraphical sequence of the North Transept of the Holy Sepulchre has been subdivided, for a better interpretation of the macro-phases, into construction and destruction activities, which can be related to actions which are chronologically homogeneous, as documented so far. As mentioned above, this work is only an initial draft based largely on the observations and periodization of the parameters of the context under investigation, using the chronological indicators derived from the extensive bibliography on the subject.

Despite having referred in depth in the previous paragraphs to the studies on the Holy Sepulchre in Jerusalem, it is opportune here to cite the works used for the study of the construction phases. The monograph on the city by H. Vincent and J. M. Abel, Jérusalem Nouvelle, vol. 2 (Paris, 1914), the story of the building summarized in R. Oosthoek, “Rebuilding the Temple: Constantine Monomachus and the Holy Sepulchre”, JSAH 48 (mar. 1989), 66-78 and, by the same author, in 2003, “Architecture as a Relic, and the Construction of Sanctity: the Stones of the Holy Sepulchre”, JSAH 62 (mar. 2003), 4-23; V. Corbo, II Santo Sepolcro di Gerusalemme, 3 vols. (Jerusalem, 1981), a work which, as mentioned several times, superseded all previous publications on the subject, and which also documents part of the restorations carried out in the second half of the 20th century. A perhaps slightly less detailed account, in terms of richness of graphic documentation, is provided by C. Cousens, The Church of Holy Sepulchre in Jerusalem (London, 1974). Finally, S. Gasson and J. Teague, Under the Church of Holy Sepulchre (London, 1994), made important observations regarding the Constantinian building, while Michael Biddle’s The Tomb of Christ (Sutton, 1999) remains the most significant work, after Corbo’s own studies, and before the fundamental text on Crusader architecture by D. Pringle, The Churches of the Crusader Kingdom of Jerusalem: A Corpus. III the City of Jerusalem (2007). Important observations on the building’s chronology are made in J. Fould, Art of the Crusaders in the Holy Land. 1089-1187 (1995).
sader work site began. Saewulfus told that the Anastasis was a large church with an open roof so that the rain fell on the Arches of the Tomb82 (Figure 22). Abbot Daniel gave a more detailed description of this ceiling shaped like a pseudo-co- polis and observed that it was made of wood. He specified that the building was circular and was supported by twelve monolithic columns and by six pillars made of stone83 on the gallery level; finally, the flooring was in marble, it was decorated with frescoes and mosaics, and it had six entrance doors85. Two chapels leaned against the Anastasis northern and southern sides, dedicated to Saint Mary and Saint John the Evangelist, who had witnessed the Passion of the Christ86. On the left side of the latter oratory, there was a beautiful chapel dedicated to the Holy Trinity («monasterium in quo est locus baptisterii»), which in turn shared the southern wall with another chapel dedicated to Saint James the Less, first Bishop of Jerusalem87. Abbot Daniel stressed that on the Chapel of Saint Mary lum atrii Templi» by Mary of Egypt, to whom Mary directed her gaze after retiring to the porticoed courtyard. Some of them were already built by Byzantines. On the northern corner there was the ancient chapel of the Prison of the Christ91, although not in the same chapel92. On the... Saewulfus mentioned some chapels located on the western side of the porticoed courtyard. Some of them were already part of the High Medieval complex, others were built by Byzantines. On the northern corner there was the ancient chapel of the Prison of the Christ93 and, on the opposite corner, the church of the Calvary. The latter had probably been rebuilt, since it was one of the buildings that had been destroyed by Muslims thirty years before (Figure 24). The pilgrim noted that this sanctuary was made of two superimposed arcades: the one above brought to mind the Location of the Crucifixe and where Abraham had built his altar; the one below where, according to tradition, there is Adam’s Tomb94. Abbot Daniel also specified that the Holy Rock was surrounded by walls and covered by vaults, both entirely covered in mosaics. This envi- ronment, which must have been the church of the Calvary, had two entrance doors with steps95, perhaps connected to the porticoes in the atrium. The High Medieval church of «Saint Constantine», which had been built on the Martyrium crypt and then destroyed under the command of Hakim, was no longer restored. After the Byzantine works the whole area was simply called «the place where queen Helena had built the great basilica that celebrated the finding of the True Cross». Walking through the ruins of the old crypt, it was possible to climb down to the Sanctuary of the invento, which was still serving as an oratory and sanctuary96. Using the volume of the Martyrium97 former vestibule, the Byzantines built three oratories between the Calvary and the Prison of the Christ. They were dedicated to three episodes of the Passion of the Christ: the Chapel of the Division of the Robe, the Chapel of the Crown of Thorns, and the Chapel of the Denial, reminding of the soldiers who derided Christ and dressed him in purple. In the crusader reconstruction, the latter would be dedicated to the Flagellation, but at that time the columns associated with the torture was still located inside the former vestibule together with other sanctuaries (among which the Altar of Abraham and the Place where the Christ was hit in the face), although not in the same chapel98. On the southern side of the Calvary, there were the remains of the High Medieval church of Saint Mary, described by Saewulfus. The ruins lay on the Holy Place where the body of the Christ, taken down from the cross, would have been anointed with perfumed oils and wrapped in a clean linen cloth99. In the internal porticoed courtyard, right below the Anastasis apse wall (Figure 23), there is a particular object named Com- pia that symbolizes the Omphalos or Center of the World. Saewulfus defined this holy place as an altar100. Abbot Daniel described a small construction covering it, similar to a choran, with a vault decorated by rich mosaics. On the vault there is the following inscription: «the sole of my foot serves as a measure for the heaven and for the earth»101.
On July 15th, 1099, Jerusalem was conquered by crusaders, who maintained control until October 2, 1187. During these eighty-eight years of Latin governance the Holy Sepulchre was restored in the Romanic form that is still visible (Figure 23). For the first time after many centuries a new consistent renovation project for the whole sanctuary was conceived, instead of the several projects for partial reconstructions or adaptations that had been carried out before. Thus, they created a new magnificent architecture, formally, stylistically, and volumetrically homogeneous. The construction was supported by relevant financial resources. The Crusaders intervention in the Holy Sepulchre, after the completion of the Crusaders bell tower (Figure 27) [M. Biddle, 2000, p. 52], may have disappeared during the reign of Almuko (1163-1174), when the apse was demolished to connect the Basilica of the Resurrection to the Crusaders Decanum. It is therefore plausible that only at that time the crusader construction site came to an end (Figure 27) [M. Biddle, 2000, p. 52].

What we see nowadays of the Holy Sepulchre (Figure 28) is the result of the archaeological process thus far illustrated, to which uncontrollable restoration works done between the beginning of the XIX century and the end of the XXI century add on. This is the monument that the past centuries have given to us: an extraordinary historical document made of stone, which witnesses religious and military events as well as natural catastrophes. A sacred place that people have been using for more than one thousand six hundreds years, almost always an object of dispute. It has been defined as «a majestic metaphor of the human condition and of the History of Christianity in Middle East» [M. Acanfora Torrefranca, F. Ardito, C. Gambard, 2000, p. 90]. Such is today, and such will be for who knows how long the Holy Sepulchre of Jerusalem.
1.3.4. The quarry and its transformations

Simonetta Fiamminghi

1.3.4.1. The ancient cave

It is possible to have an idea of the quarry as it appeared in the past thanks to the discovery of two ancient quarries dated to the end of the Second Temple period, which were excavated by the Israel Antiquities Authority. These caves were opened in the area north of the Holy Sepulchre, outside the ancient walls, and allow a more precise visualization of the quarry morphology on the site of the Basilica (Figure 50).

The first quarry was found during an excavation in Shmuel HaNavi Street, in the neighbourhood of Mount Zion, Jerusalem. It was at least 5 dunams (1 dunam = 1000 square meters)\(^1\). The quarry dates back to Second Temple period, in the first century AD. Here, they found 6 meters long blocks, similar to the ones that were used in the lower parts of the Temple Mount\(^2\) (Figure 51a).

The second quarry was opened in Shmuel HaNavi Street and also dates back to first-century AD. Extracted blocks measured 5x2x2m. Evidence suggests that many miners used to work in this quarry.

These two quarries produced blocks of various sizes, which were quarried by creating wide detachment channels. The blocks were then marked by means of a chisel that weighed approximately 2.5 kg\(^3\) (Figures 52-53). Methods of quarrying the stone remained largely unvaried until the introduction of modern techniques.

The Romans refined the techniques used in the ancient times standardizing the various methods of quarrying throughout their Empire.

In the first phase of the extractive process the smaller blocks were quarried, in order to level the surface. Then, the bigger blocks were extracted, creating wide detachment channels. The channels, marked by means of chisels too, were cut all around the blocks except for their bottom, probably because of a natural discontinuity in the rock stratification. To facilitate the extraction, wooden wedges would be placed inside the channels and then soaked with water. The pressure generated by the wood natural enlargement would have helped to detach the block. Finally, the wedges would have been beaten until the complete detachment of the block (Figure 51b).

The quarrymen would use first the natural discontinuities of the rock to insert wedges, therefore blocks were usually extracted along their natural stratification.

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\(1\) The excavation has been realized before the construction of residential buildings, under the direction of Dr. Ofer Sion and Yehuda Rapuano of the Israel Antiquities Authority.

\(2\) According to the Bible, the Temple of Solomon or First Temple was built by King Solomon in the tenth century BC. It was completely destroyed by Nebuchadnezzar II in 586 BC. The works for the Second Temple started in 536 BC. It was completed on March 12, 515 BC. It was then destroyed in 70 AD by the Emperor Titus. Today only its western wall remains, known as the Wailing Wall.

\(3\) http://www.antiquities.org.il/article_eng.asp?secid=25&subjid=240&id=1586&module_id=##as
1.4.1. The “Status Quo” in the Holy Sepulchre Church

The Holy Sepulchre Church in Jerusalem, the Nativity Church in Bethlehem and the Tomb of the Virgin in Gethsemane are unique in that they are the only Christian shrines in the world that are shared by different Christian Communities. In the Holy Sepulchre we find six Christian Communities who share the Church complex in complete agreement as to the importance of the Holy Place. Here we find different Christian Communities often worshipping the same God under the same roof at the same time. However, this sharing of the Church, which is one of its most fascinating aspects, is also something that generates incomprehension and negative publicity. This sharing is known as the Status Quo. Almost everything concerning operations in the Church is regulated by this reality. Therefore, defining what the Status Quo means is important.

1.4.2. The “Status Quo”

In February of 1852 the Sultan of the Ottoman Empire, Abdul Majid, issued an imperial decree (Firman) by which he obliged the Ottoman Governor of Jerusalem and other members of the Ottoman government in Jerusalem, as well as the Christian Communities, to «maintain things in their actual state» and «to introduce no changes» in the holy places that were held in common. The decree is very short – translated into English it counts about 1,000 words – and it contains very few details. The decree affirms that the Church of the Holy Sepulchre, the Basilica of the Nativity, the Tomb of the Virgin and the Dome of the Ascension should remain in their existing state, as they were in February 1852. Of the four above-mentioned shrines, only the Dome of the Ascension is not possessed by Christians, but rather by Muslims. This concept that «there is to be no change» is repeated six times in reference to the shrines mentioned in the decree. The substance of the decree was later called the «Status Quo» in the Treaty of Berlin in 1878.

The Status Quo therefore imposed on all the Communities present in these four above-mentioned shrines that they remain as they were, with no changes of possession or use in the widest sense of the term. Hence, it is interpreted to mean that there would be no changes in possession, prayer schedules, cleaning, repairs, and so forth.
Chapter V

Part one

FIGURE 1

Land (VII century).

The original building was built over an abandoned quarry, around the year 100 BC. It was appointed by Pope Sixtus II to build the church (1591-97), and an interim report on the surveys and the works under way at the time was published by Coüasnon in La magazia de la Corte Santi (15, 1964, pp. 264-294), followed two years later by his report "Les travaux de restauration du Saint-Sépulcre" to the Académie des Inscriptions et Belles-Lettres (Comptes-rendus des Séances...). In Cah. C., 2, 1966, pp. 205-206. Regarding the ups and downs in the history of this work, see J.C. Cusa, Santi, il Santissimo Sepolcro (Rome, 1978), and the excavations by Father Corbo (1960-80), the accurate photogrammetry and measuring campaigns and laser 3D scans carried out (2007-2010), under my own supervision, by the GeoLab of the University of Florence for diagnosis of the seismic security of the monument, as commissioned by the Custodianship of the Holy Land from the C.A.B.C., directed by Prof. Makris.

In choosing the surveys, consideration was given to their accuracy, and whether information about measurements is given in the plates and/or in the text, omitting studies on the topography of Jerusalem and the resultant city maps, starting with the famous one by Antonio De Angelis (1581), and the more sketchy illustrations, or those taken from previous works, and renderings of supposed original layouts, including those outlined by Vincent and Abel (1949), Kenneth J. Conant (1956) and Terry Ball, a collaborator of Coüasnon. Nor was consideration given to diagrams in essays and volumes by architectural historians (C.A. Delio, A. Gruber, E. Byggre, etc.), and the suppositions advanced regarding the Holy Sepulchre site in the mid-1800s by Edward Robinson, James Ferguson and Charles Wilkin, which at the time were the subject of fierce controversies, that disputed the location of the Tomb of Christ and the site of the original building.

This chapter presents an overview, in chronological order, of the most important surveys of the Church of the Holy Sepulchre since the latter part of the 16th century. Beginning with those by Jean Zuallart (1586) and Bernardino Amico (1591-97), and ending – after a list of works, almost none of which are first-hand studies, published before the fundamental Jérusalem Nouvelle (1914) by Vincent and Abel – with an examination of new contributions in the 20th century.

Among the later works, much space is given to the reports by W. Harvey (1935) and the supplementary checks by L. Marzogari (1937) on the building's structural stability after the 1927 earthquake, and the associated dissections over the risks of collapse, also in view of the excess load of the stone dome that was planned to erect over the Anastasis, and the forces that would thereby be transmitted to the adjacent structures (the masonry and the arches). Of more recent work, the list includes, after the investigations by C. Cossigny and the excavations by Father Corbo (1960-1980), the accurate photogrammetry surveys by M. Biddle (1989-1991), restricted only to the Aedicule, and the work of A. Georgopoulos and G. Lawas, before finally covering the topographical measuring campaigns and laser 3D scans carried out (2007-2010), under my own supervision, by the GeoLab of the University of Florence for diagnosis of the seismic security of the monument, as commissioned by the Custodianship of the Holy Land from the C.A.B.C., directed by Prof. Makris.

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Joseph John Scoles (1798-1862) was an English Gothic Revival architect, who designed several Roman Catholic churches. He was apprenticed in 1812 for seven years to his kinsman, Joseph Ireland, an architect largely employed by the Earl of Hillsborough, the Roman Catholic bishop. In 1822, Scoles left England and devoted himself to architectural and archaeological research in Rome, Greece, Egypt, and Syria. He published in 1829 an engraved "Map of Nuba", and a map of the city of Jerusalem. In 1826, he returned home and resumed his practice. Scoles was elected a Fellow of the Royal Institute of British Architects in 1832, was honorary secretary, and vice-president in 1857-8. To the society's proceedings, he contributed papers principally on the monuments of Egypt and the Holy Land; the outcome of his early travels. His measured map (1825) of the church of the Holy Sepulchre, Jerusalem, with his drawings of the Jewish tombs in the valley of Jehoshaphat, was used by Robert Willis as the basis for his book, "The architectural history of the Church of the Holy Sepulchre at Jerusalem" (London 1849).

In note C, in the appendix, R. Willis gives some history of the materials from which he compiled the plans and sections in his book. He cites the work of Father Moreau for its known characteristics of completeness, and because it was accompanied by detailed descriptions and measurements. However, while he regards the plan as reliable because it is accurately drawn, and because it was not significantly altered after the reconstruction after the fire of 1808, the same cannot be said for the elevations, as he believes them to be wrongly surveyed and, in part, the product of a classical interpretation. So ends his account of Willis's observations made on the scene, for the layout of the vaults.

A section of the church from east to west, meets a section through part of the north wall, of the Church of the Holy Sepulchre, as written "from the pen of Professor Willis", who so fully established the identity of the present site with that of the original Sepulchre.


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JOSEPH J. SCOLES


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1
Subproject: ROTUNDA
N. scans: 34

2
Subproject: SQUARE AND FACADE
N. scans: 3

3
Subproject: APSE
N. scans: 10

4
Subproject: CHAPEL OF ST. HELENA
N. scans: 21
Subproject: ENTRANCE AND GOLGOTA
N. scans: 14+5

Subproject: ARMENIAN CHAPEL
N. scans: 8

Subproject: CATHOLICON
N. scans: 15

Subproject: ARCHES OF THE VIRGIN
N. scans: 9
FIGURE 42: 2D plan of the ground floor of the Complex of the Holy Sepulchre, including the Chapels of St. Helena, the Invention of the Cross and St. Vartan, extracted from the 3D point cloud (Tucci-Bonora surveys 2007-2009).
Figure 43: Superimposition of the 3D point cloud of the roof of the Complex of the Holy Sepulchre with the plan of the ground floor (Tucci-Bonora surveys 2007-2009).
FIGURE 44 Superimposition of the longitudinal section of the complex of the Holy Sepulchre, extracted from the 3D point cloud, with the orthophoto of the elevations (Tucci-Bonora surveys 2007-2009).
FIGURE 46 Superimposition of the longitudinal section of St. Irene’s Chapel, extracted from the 3D point cloud, with the orthoimage of the elevations (Tucci-Bonora surveys 2007-2009).

FIGURE 47 Superimposition of the plan of the 1st floor of the Golgotha, extracted from the 3D point cloud, with the orthoimage of the floor (Tucci-Bonora surveys 2007-2009).

In the previous page:

FIGURE 45 Superimposition of the plan of the Rotunda, extracted from the 3D point cloud, with the 3D mesh of the floor (Lidia Fiorini from Tucci-Bonora surveys 2007-2009).
2.3.3. State of progress in modelling and future prospects

Over the three survey campaigns, the three-dimensional data acquisition extended to the whole of the Holy Sepulchre complex. Thanks to the technical characteristics of the tools used, at the same time we were able to survey buildings and structures not directly concerned by the studies underway. Thus we were able, for example, to survey the whole width of the street marking the western edge of the complex, the surrounding buildings and the roofs in a large area around the church, up to the minaret on the Omar mosque. Hence, we acquired an enormous database, which at first was just used for the structures analysis considered in the seismic risk vulnerability analysis (see the Survey Chapter).

In a subsequent phase, we pinpointed 3D modelling as a tool that could be the basis for a complex communication project aimed at the variegated target of visitors to the monumental complex. The high resolution and accuracy of the data available has led us to try out different modelling approaches, test new software that has become available during the research, and, after various attempts, define the level of detail with which it seemed correct to represent the building. In this connection, it is important to underline our choice to model the Aedicula in a different manner to the rest of the monumental complex. We concentrated the first tests on the small sacellum, which is interesting owing to its rich decoration and the significant deformations caused by earthquakes and fires. Therefore, we decided to ignore the deformations of the stone cladding and render the geometry of the Aedicula with the 3D model after calculating a triangulated model from the surveyed points. The first illustrates the original building, at least in its last configuration, while the second documents its present state, with the numerous oil lamps that adorn it and the metal support structures surrounding it.

For the rest of the building, the non-negligible limits of managing the hardware for a high-resolution model meant we had to set a lower degree of detail, even though no geometrical schematization was introduced: the columns are not cylinders, the irregular layout and outline of the barrels of the cross vaults reflect the real configuration of the spaces, and the points of the arches correspond to reality. Instead, for the moment we have not modelled the bases, capitals and cornices which may, nevertheless, thanks to the approach followed, be detailed subsequently, or rendered with texturing techniques.

The model completed to date concerns the Rotunda, with the Aedicula in the centre, the Katholicon and the so-called transept of the Virgin. We hope that the significant experience gained to date may be useful in order to complete a model of the whole complex. In turn this could lead to the creation of new educational/entertainment tools to guide visitors and pilgrims, as well as virtual visitors and scholars, in finding out and understanding spaces that they can observe and explore and intuitively link to the enthralling historical events and religious tradition of the site.
on occasion of a seismic event will not only depend on the extent of the PGA (Kawamura, 1998), but also on its association with a frequency that is hazardous for the building (both relative to its natural modes of vibration) as well as the duration of the shaking itself, linked to the cubic root of the seismic moment. It needs to be noted that the durations proposed by Cozza & Kiemowitz (1977) have been criticized by some authors who prefer to refer to the durations found by Trifunac & Brager (1975). Above all, in light of the data collected in subsequent years, Novikova & Trifunac (1994) proposed rather accurate tables (Figure 2), in which the durations are related not only to the magnitude, but also to the distance from the epicentre, as well as the site conditions and geology of the area.

In earthquake engineering studies, particular significance is given to spectral acceleration, namely the amplitude of the response spectrum (spectral ordinates) obtained directly from the spectrum of acceleration. The importance of the response spectrum for assessing seismic vulnerability can also be deduced from the consideration that it is the regulation of many countries the project spectrum (generalized response spectrum, obtained from the envelope of many spectra, for calculating individual spectra we use a damping corresponding to 5% of the critical damping) is the basis for calculating the forces to apply when designing structures.

A decisive step consists of analysing the interactions that can be produced between the expected shaking – generally formulated starting from a “benchmark” earthquake while applying the “mark” earthquake while applying the various available attenuation relationships (Kawamura & Sennikov, 1997; McGuire, 2001; Boscardi & Seilmann, 2005) – and the morphological and litho-stratigraphic characteristics of a site that are able to improve the prediction at specific frequencies. Therefore, it is also necessary to obtain amplification spectra which refer specifically to the site, where the monumental complex of the Holy Sepulchre is situated (see the paragraphs on site effects and modal analysis). The dashed red lines represent the main faults, while the white ones show the linear direction of the drift of around 10 km, that the plates have undergone in the last 20 million years. (Taken from the DESIRE project).

TABLE 2

<table>
<thead>
<tr>
<th>MAGNITUDE</th>
<th>DURATION ON FIRM ROCK</th>
<th>DURATION ON GROUND</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>6.0</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>6.5</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>7.0</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>7.5</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td>8.0</td>
<td>31</td>
<td>62</td>
</tr>
</tbody>
</table>

Nonetheless, it is very difficult to establish the effects and damage caused by the historical earthquakes, especially in a region such as that under examination permeated by profound spirituality. Indeed, as some authors have already demonstrated with regard to the 1546 earthquakes (Ambraseys & Braile, 1992; Ambraseys, 2005), the effects were at times emphasized in order to give the natural events a theological or politico-moral meaning. If a city has a long history – with a relative long history of seismic events – this can create a false perception of extraordinary vulnerability. The consideration just set out have even led some authors to conclude that isolines of the duration (in sec) of the horizontal component of strong earthquake ground motions indicate the exact faults while the white areas show the directions of the drift of around 10 km, that the plates have undergone in the last 20 million years. (Taken from the DESIRE project).

FIGURE 2:Isochrones of the duration (in sec) of the horizontal component of strong earthquake ground motions. The dashed red lines represent the main faults while the white ones show the linear direction of the drift of around 10 km. The big earthquakes that happened from 1000 to 1900 are depicted as red circles with an associated magnitude. The general seismicity is also necessary to obtain amplification spectra which refer specifically to the site. The seismicity recorded in the 1984-2004 period is shown as small white circles. The dashed red lines represent the main faults. (Taken from the DESIRE project).

FIGURE 3: Isochrones of the probable seismic events with a M>5.5 [Kien-Tien & al., 2001]. Nevertheless, there is no doubt that, while no active faults have been discovered in the Jerusalem area (Bartov, 2002), the immediately adjacent areas display an elevated seismicity, with episodic concentration peaking in the proximity of the Dead Sea Transform (2015) just 25 km away; this very proximity makes it fundamental to calculate the extent of the hazard linked to the area. Indeed, both the seismogenic activity in the Dead Sea Fault System, and the presence of neotectonic faults indicate a state of activity with significant events concentrated in a thin strip along the DST (Coli, 2006; Bartov & al., 2001; Salamun & al., 2005). Therefore, the DST is not just the longest seismogenetic structure in the region but also the source of strong earthquakes closer to Jerusalem (Salamun & al., 2005).

Seismic activity in the areas subject to the study is attested by documents covering a period of over 5000 years (Rizzetti, 1985; Rin, Mugnaiou, 1991; Avni, 1991; Avni, 1995; Avni, 2005). Together the historical information and instrumental earthquake data clearly demonstrate that a conspicuous number of destructive earthquakes have taken place in recent centuries along the Dead Sea transform fault system (Figures 3 and 4). Palaeo-earthquake studies have always confirmed the elevated seismicity of the region, in particular, both the drilling carried out in order to investigate the late Neolithic settlements of Lake Saur (Dead Sea paleo-lake) – which highlighted a palaeoseismic sequence of 5,000 years (Dakri & al., 1996) – and the exposed section of the Zeilib Terraces identified a frequent recurrence (since every 100 years to every few thousand years) for seismic events with a M>5.5 [Kien-Tien & al., 2001].
2.6.3. Noise study

The first point of evaluation concerns the direction from which the seismic noise originates. As well as being necessary for methodological requirements, this analysis is also needed to attach a meaning to the most recurrent spectral characteristics. The method used is based on calculating the covariance matrix, which is linearized by calculating the eigenvalues and eigenvectors and applied to signals filtered on preset frequency bands. The result is shown in Figure 5 and demonstrates a substantial lack of polarization in the whole selected frequency band except between 1 and 2 Hz.

If we are to focus our attention between 1 and 2 Hz, it has been noted that at times in this range there is a recurrence of asymmetrical peaks centred around 1.6 and 1.9 Hz, with the second particularly polarized on the longitudinal component. This evidence shows exceptions in the eastern part of the building, in particular in the corridor area, the Chapels of St. Helena, and the cloister.
2.10.2.2. Scale of priorities for possible retrofitting interventions

The list of the sustainable accelerations for the different macroelements is ordered in terms of decreasing vulnerability and underlines the most vulnerable structures of the Monumental Complex of the Holy Sepulchre.

Table II allows an immediate comparison of the performances of the various structures with respect to a benchmark ground acceleration value (e.g. 0.13 g or a modified value).

As already underlined previously, the evaluation of the seismic vulnerability resulted from the analysis had to be framed within the sphere of validity of the analysis itself: this aspect is considered in the following paragraph, which deals with the sphere of validity of the results of the analysis and proposes guidelines for future developments.

2.10.2.3. Analysis summary

As for every structural analysis, the reliability of the results depends on two important aspects:

1) on the completeness (quantity) and on the quality of the available data;
2) on the fitness of the calculation procedures applied.

For point 1), the following sets of data were available:

- visual data taken from on-site surveys;
- data from previous studies;
- data from remote sensing techniques.

For point 2), the following calculation procedures were applied:

- finite element analysis;
- probabilistic seismic hazard analysis;
- macroelement analysis.

The results of the analysis were validated by comparing the calculated accelerations with the available data and by performing sensitivity analyses.

TABLE II - LIST OF THE MACROELEMENTS SET OUT IN ORDER OF DECREASING VULNERABILITY

<table>
<thead>
<tr>
<th>Macroelement</th>
<th>$a_{eq}$ N S</th>
<th>$a_{eq}$ E W</th>
<th>$a_{eq}$ F H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell tower</td>
<td>0.029</td>
<td>0.019</td>
<td>0.029</td>
</tr>
<tr>
<td>North transept</td>
<td>0.026</td>
<td>0.018</td>
<td>0.026</td>
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<tr>
<td>Greek Choir</td>
<td>0.032</td>
<td>0.024</td>
<td>0.032</td>
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<tr>
<td>Chapel of St. Helena</td>
<td>0.032</td>
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<tr>
<td>Entrance to the monumental complex</td>
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<td>0.032</td>
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<tr>
<td>The Calvary area</td>
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<tr>
<td>Bell tower</td>
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in-plane mechanism can in itself display a lower collapse multiplier. This prevents the analysis from being performed in ranges of strain that are unacceptable. Knowledge of the areas of damage of the structure in correspondence to the ultimate shear shall enable the hypothesis of breakage in an orthogonal direction to be integrated, providing exhaustive information on the expected damage. The two steel rings in the structure are also identified, positioned at a height of approximately 2.50 and 4.50 m above the 0.00 of the springer. The rings have a square section of 100x10 mm (Figure 19).

The illustration of the damage expected owing to membrane effects is shown in Figure 21.  

2.10.3.1.2. The Dome with drum underneath
A modal analysis was performed to define the period of vibration. A non-linear seismic analysis defines the collapse mechanism owing to the instability caused by the dislocation of the thrust line from the geometry of the structure. An additional model investigated the limit behaviour, with the kinematics hypothesized beforehand, with regard to the orthogonal collapse mechanism at the middle level of the structure (out of plane). The analysis was conducted on the portion of the structure relating to a 45° slice, comprising a pier2 of the drum and the two openings alongside it: it is hypothesized that the detachment would take place halfway along the architrave.  

A wall between two openings.
1) the restructured dome was subject to a specific in-depth study carried out with modern engineering tools and approaches;
2) the data processed and processed by the engineers, regarding the geometry, the state of strain of the single metal trusses, the physical and mechanical parameters of the materials (defined through experimental investigations) certainly featured a greater level of knowledge than can be reproduced in this chapter.

Instead, in this work, the analysis of the Rotunda supporting structure underneath the dome is of primary interest.