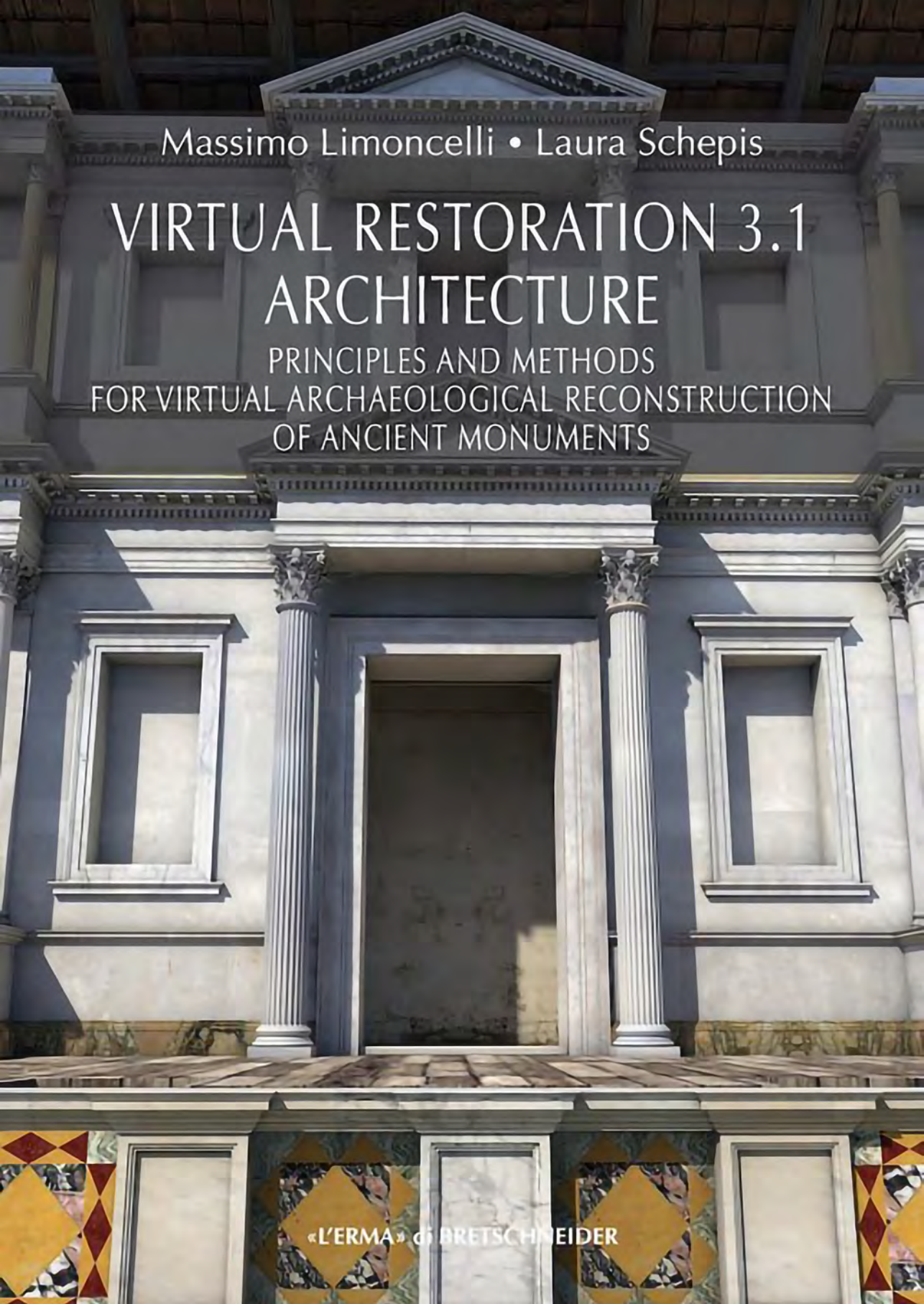

Massimo Limoncelli • Laura Schepis
VIRTUAL RESTORATION 3.1
ARCHITECTURE
PRINCIPLES AND METHODS
FOR VIRTUAL ARCHAEOLOGICAL RECONSTRUCTION
OF ANCIENT MONUMENTS
«L'ERMA» di BRETSCHNEIDER

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Massimo Limoncelli, Laura Schepis

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PRINCIPLES AND METHODS FOR VIRTUAL ARCHAEOLOGICAL RECONSTRUCTION OF ANCIENT MONUMENTS

«L'ERMA» di BRETSCHNEIDER (USA)

Virtual Restoration 3.1. Architecture

Principles and methods for virtual archaeological reconstruction of ancient monuments

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Massimo Limoncelli (Augusta Bagiennorum. Bene Vagienna (Italy), Roman Theatre, 3D reconstruction of *scaenae frons*)

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On the Cover: Massimo Limoncelli (Augusta Bagiennorum. Bene Vagienna (Italy), Roman Theatre, 3D reconstruction of *scaenae frons*)

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To
Noemi, Martina, Grazia Rita, Claudia, Marco
and all the students of the Virtual Archaeology course at the University of Palermo,
this book was written for you, but above all, thanks to you.

FOREWORD

Il Virtual Restoration is a «recent and constantly evolving discipline that promotes the development of formalized investigation procedures for acquiring, representing, processing, and communicating data, while simultaneously producing new information and tools for research that go beyond traditional forms and contribute to the advancement of archaeological practice. Therefore, archaeology has embraced scientific and technical investigation methods, initially derived from other sciences, and then adapted them to the specific needs of its own research».

In the field of archaeology, the increasingly widespread use of ICT (Information and Communication Technologies) has opened up new research possibilities, mainly thanks to the transition of computer science from a tool for data management and documentation to a tool for data production and analysis. Consequently, the development of computer technologies in recent decades has led to the emergence of new disciplines characterized by the combination of activities and research methodologies typical of hard sciences with those of more traditional humanistic extraction, including Virtual Restoration.

Following the uncontrolled proliferation of virtual and three-dimensional reconstructions from the mid-1990s onwards, some issues emerged, including the lack of scientific transparency of the reconstructions and hyperrealism. In the first case, virtual reconstructions were presented as a product to be accepted without the possibility of critical analysis and without explicitly explaining their principles and formative methods. In the second case, virtual reconstructions were presented as the unique and undisputed representation of the past, rather than as virtual hypotheses that could be supplemented by many others. There was therefore an awareness of the need to critically analyze the impact of the rapidly spreading virtual reconstructions within the scientific community.

Therefore, it was considered appropriate to create the first volume of the two books dedicated to architecture, the third volume of the "Virtual Restoration" series, which addresses the "Principles and methods" for the virtual reconstruction of an ancient monument through a methodological process that follows a well-defined sequence of operations: from acquisition to processing, up to the presentation of the data. Virtual restoration of an ancient monument should not be understood as a mere ideal restitution of an architectural artifact, but rather as a method for verifying archaeological data.

The use of methodologies and ICT technologies applied to ancient architecture represents an advancement of traditional studies aimed at reconstructing partially preserved or, in some cases, no longer existing monuments through three-dimensional models. These models provide

information that is not always easily deducible from traditional methods of studying ancient architecture.

Within the broader discipline, virtual restoration of ancient buildings is certainly the most complex field of application, as it encompasses all sectors of virtual restoration. This includes the pictorial aspects (frescoes, painted plaster, and stucco), the stonework (for any sculptures or plastic works in architectural decorations), woodwork, mosaic, and ceramics (roof tiles and tiles for the covering, etc.). Each of these areas has its own autonomous intervention methodologies, which are combined to create the complete 3D reconstruction of the building.

This book illustrates all aspects and issues related to virtual reconstructions of ancient buildings through 28 specific case studies. The aim is to propose a correct use of digital visualization of an ancient monument, showcasing the sources used for 3D reconstruction. It explicates the logical process followed in reconstructing various hypotheses, and in the most controversial case studies, it proposes different reconstruction hypotheses or one for each chronological phase of the ancient object under study for reconstruction.

Palermo, april 2024

PART 1

ARCHITECTURE AND VIRTUAL RESTORATION

I
PRINCIPLES AND METHODS FOR VIRTUAL ARCHAEOLOGICAL RECONSTRUCTION OF ANCIENT MONUMENTS

1. Introduction

The word "architecture" encompasses a broad and multifaceted meaning. It derives from two ancient Greek linguistic roots: the first, "Arch-," expresses the concept of foundation, while the second, "Tekton-," alludes to the activity of inventing, creating, consolidating, and building[1].

Gottfried Semper (1803-1879) defines architecture as «"pure art of invention," since its forms have no defined prototypes in nature; they are free creations of the imagination and human reason. Therefore, architecture could be considered the freest among the visual arts, were it not for its absolute dependence on the general laws of nature and the mechanical laws of materials. This is because, no matter what the object of architectural art we consider, its initial conception always arises from the necessity to satisfy some material need, especially the need for shelter and protection from the adversities of climate, elements, or other hostile forces; and since we can achieve this protection only through the solid combination of materials provided by nature, we are compelled to strictly observe the static and mechanical laws for our constructions. This material dependence on the laws and constraints of nature, which remain the same at all times and in all places, gives architectural works a certain character of necessity and allows them to appear as works of nature itself. However, they are such as nature can create through the medium of a being with reason and free will»[2].

Architecture, understood as the expression of the built environment, manifests itself as an artistic expression in its broadest sense. It encompasses a complex activity that involves a wide range of fields such as political, economic, legal, technical, scientific, artistic, and social

realms. Its objective is the human settlement in a specific space, more or less extensive, according to the peculiar characteristics of the geographic area affected by the settlement itself, such as geographical location, hydrogeological layout, and climate.

Therefore, architecture constitutes the operational aspect, which translates into constructive reality, of the organization of the territory encompassing human settlements in their overall structure, known as urban planning. Urban planning is identified in various types and functions of built objects, including religious, private, and public buildings, as well as infrastructure such as roads, bridges, ports, etc.

Today, virtual reality techniques applied to archaeology and ancient architecture have been an update to traditional studies aimed at reconstructing partially preserved monuments for many years. This has led to two main research strands: the scientific verification of archaeological data and the preparation of materials used as a basis for dissemination works across various media platforms.

In the first case, reference is made to the virtual reconstruction of an ancient monument, understood as the set of operations aimed at recovering, through a digital model, the original conditions of the building, respecting the spirit of the era by reconstructing the presumed original, degraded, or missing parts. Therefore, virtual archaeological reconstruction of a building indicates the methodological process that, starting from a heterogeneous quantity of data (the sources)[3], leads to the production of a 3D model. Such methodological process, linked to the interpretation of data and their representation within the reconstruction, can be defined as "digital anastylosis," which occurs through a true action of "virtual redesign" of a building.

In the second case, however, current trends in research in the field of Virtual Archaeology, particularly in scientific visualization, aim to deepen the understanding of the visualization process in order to use knowledge of perception psychology along with graphic design techniques to intervene in the design of increasingly effective visualization systems. Indeed, the availability of increasingly advanced computer tools has shifted attention to digital communication, new learning modalities in VR, shared consumption, and even the current universe of Extended Reality (XR)[4].

Within the discipline of Virtual Restoration, the virtual reconstruction of buildings represents the most complex field of application, as it encompasses all sectors of virtual restoration: in addition to architectural restoration, it includes stone restoration, such as sculptures and plastic works, as well as mosaics, frescoes, painted plaster, and stucco, extending to wooden restoration. Each of these areas has its own

autonomous intervention methodologies that add to the actual 3D restitution of the building.

Similarly to what has been observed in the history of physical restoration of a monument, within the field of Virtual Archaeology and Restoration, there has been a theoretical evolution of the methodology to be applied to a virtual archaeological reconstruction of an ancient building based on the philological method[5]. This evolution channels towards greater scientific transparency within rigorous methodological boundaries. Indeed, one of the main issues related to the reconstructive study of an ancient monument, among the most debated and controversial, is certainly attributable to the reliability of the results in a 3D reconstruction of an ancient building[6].

In scientific circles[7], one of the major criticisms leveled against virtual reconstructions is that they often represent mere technological exercises where the effect of spectacularization is entirely detached from the context of research and data analysis. The most glaring deficiency lies in the fact that the proposed models fail to answer certain questions, such as "what data were used as a basis?" Furthermore, "unique reconstructions" are proposed, meaning they lack opportunities for critique by observers, without offering alternative models or any explanation of the reconstruction choices.

In scientific circles, a second criticism concerns digital communication, particularly the use (or perhaps better, the overuse) of computer technologies that may "empty out" the contents of the disciplines to which they are applied: there is a risk of reversing the relationship in which technologies no longer remain merely tools, or means, but become the end of research. Furthermore, there is the additional inconvenience that these technologies take control of the discipline with which they come into contact, becoming in some measure the predominant element.

These risks have been effectively defined as the "Star Wars Syndrome," which occurs when the developmental potential of a technique takes precedence over the content, and the "Cinecittà Syndrome" when a virtual reconstruction risks imposing itself solely for its suggestive capacity[8]. In addition, «it is worth noting that the majority of Virtual Archaeology applications developed to date lack significant archaeological content and, as would be appropriate, do not answer precise questions. Instead, they float in a generally informative and multimedia environment, or with specific intentions of technological exercise and spectacularization, completely detached from the context of research and data exegesis»[9].

The same criticism was already expressed over five centuries ago, in 1475, by Leon Battista Alberti who wrote: «I would like to add a recom-

mendation that seems very appropriate: displaying colored models or making them attractive with paintings indicates that the architect does not simply intend to represent his project, but rather, driven by ambition, seeks to attract attention with the exterior appearance to captivate the eye of the beholder, distracting the mind from a thoughtful examination of the various parts of the model to fill it with wonder. Therefore, it is better not to make models that are impeccably finished, polished, and shiny, but rather naked and plain, in order to highlight the acuity of the architectural conception, not the accuracy of the model's execution»[10].

Today, technologies have progressively moved in a specific direction: representing an architectural artifact in the form of a synthesis of collected data and as the final result of a critical re-evaluation of the information gathered through a 3D digital model. Therefore, the editing of a virtual reconstruction must highlight the knowledge data contained therein through forms of scientific visualization that allow reading, recognizing, and verifying the informational and knowledge content of the model itself. Scientific visualization is precisely the transformation of information into a perceivable form that should assist the researcher in understanding the analyzed building and help the user perceive the nature of the information present in the analyzed data[11].

The need to constrain a virtual reconstruction within strict boundaries has therefore become even more pressing, as expectations are high and the available tools are powerful. Therefore, the objective of this book is to emphasize the level of final reliability, which should always occupy the center of every reconstructive process and rigorously formalize every interpretative solution with scientific rigor[12].

2. From the London Charter to the Principles of Seville

The general methodological principles underpinning a correct archaeological reconstruction were set out in the early XXI[th] century, first in the *London Charter for the Use of 3D Visualisation in the Research and Communication of Cultural Heritage* (2006)[13] and subsequently in *Principles of Sevilla. International Principles of Virtual Archaeology* (2011)[14]. Indeed, these documents establish the principles and methods that need to be adopted in order for the virtual reconstruction of an ancient monument to be considered scientifically correct. In other words, they present a coherent set of methods characterised by a precise sequence of measures, operations and analyses to be performed in accordance with a pre-established order centred on the acquisition, processing and presentation of data[15].

The need to draft a "charter," a term usually reserved for documents that enunciate principles of very broad generality, such as the well-

known Venice Charter on Conservation and Restoration[16], It originated from the necessity to articulate rigorous methodological principles for communities of researchers and technical experts in the field. The most challenging aspect involved providing answers to some of the questions regarding the applications of Virtual Reality (VR) in the archaeological domain. In particular, the credibility and validity of the reconstructive models of objects, monuments, sites, or landscapes, partially or completely modified or destroyed, and virtually reconstructed based on archaeological interpretation[17].

Following the uncontrolled proliferation of virtual reconstructions in the archaeological field from the mid-1990s onwards, several issues emerged, including the lack of *transparency in the reconstructions*[18] and *hyperrealism*[19]. In the first case, virtual reconstructions were presented as a product to be accepted without the possibility of critical analysis and without explicating their formative principles and methods. In the second case, virtual reconstructions were presented as the unique and unquestionable representation of the past, rather than as virtual hypotheses alongside which many others could be considered.

There was therefore awareness of the need to critically analyze the impact of the virtual reconstructions that were rapidly spreading in the scientific community[20].

Thus, in 2006, following the Symposium and Expert Seminar "Making 3D Visual Research Outcomes Transparent," organized between February 23rd and 25th by The British Academy of London and The Centre for Computing in the Humanities at King's College London, concerning various aspects of the issue of intellectual transparency in virtual reconstructions, it was proposed that the community could draft a Charter outlining the principles that should underlie the use of three-dimensional visualization technologies in cultural heritage research and dissemination[21].

In March 2006, the first draft of the London Charter for the *Use of 3D Visualization in the Research and Communication of Cultural Heritage* was presented. It included the fundamental principles agreed upon at the Symposium and added new principles. Finally, in 2009, the final version was published on www.londoncharter.org. The initiative of the Charter did not aim to propose radical new proposals but rather to consolidate principles that had been published by numerous authors, yet not fully embraced by the scientific community.

The Charter aims to define the basic objectives and principles of the use of 3D visualisation methods in relation to intellectual integrity, reliability,transparency, documentation, standards, sustainability and access.

The Charter therefore does not seek to prescribe specific aims or methods, but rather seeks to establish those broad principles for the

use, in research and communication of cultural heritage, of 3D visualisation upon which the intellectual integrity of such methods and outcomes depend.

Although the objectives and principles of this Charter may equally apply to the use of 3D visualisation in other contexts, such as in the creation of mass entertainment products, its main focus is upon research into cultural heritage and the communication of such research.

The Charter seeks to enhance the rigour with which 3D visualisation methods and outcomes are used and evaluated in the research and communication of cultural heritage, thereby promoting understanding of such methods and outcomes.

The objectives of the London Charter seeks to establish principles for the use of computerbased visualisation methods and outcomes in the research and communication of cultural heritage in order to: Provide a benchmark having widespread recognition among stakeholders; promote intellectual and technical rigour in digital heritage visualisation; ensure that computer-based visualisation processes and outcomes can be properly understood and evaluated by users; enable computer-based visualisation authoritatively to contribute to the study, interpretation and management of cultural heritage assets; ensure access and sustainability strategies are determined and applied; offer a obust foundation upon which communities of practice can build detailed London Charter Implementation Guidelines.

In the London Charter, 6 methodological principles are outlined which are necessary for digital visualization of cultural heritage to be intellectually and technically rigorous, like all other research activities related to archaeological heritage.

Principle 1: Implementation. The principles of the London Charter are valid wherever computer-based visualisation is applied to the research or dissemination of cultural heritage.

Principle 2: Aims and Methods. A computer-based visualisation method should normally be used only when it is the most appropriate available method for that purpose.

Principle 3: Research Sources. In order to ensure the intellectual integrity of computer-based visualisation methods and outcomes, relevant research sources should be identified and evaluated in a structured and documented way.

Principle 4: Documentation. Sufficient information should be documented and disseminated to allow computer-based visualisation methods and outcomes to be understood and evaluated in relation to the contexts and purposes for which they are deployed.

Principle 5: Sustainability: Strategies should be planned and implemented to ensure the long-term sustainability of cultural heritage-relat-

ed computer-based visualisation outcomes and documentation, in order to avoid loss of this growing part of human intellectual, social, economic and cultural heritage.

Principle 6: Access. The creation and dissemination of computer-based visualisation should be planned in such a way as to ensure that maximum possible benefits are achieved for the study, understanding, interpretation, preservation and management of cultural heritage.

The London Charter recommends the creation of specific implementation guidelines for each community of experts (London Charter Preamble and Article 1.1). The International Forum of Virtual Archaeology has agreed to take up this challenge by drafting an international document governing the implementation of best practice in computer-based archaeological visualisation. The new document, written in 2011, is called *Principles of Sevilla. International Principles of Virtual Archaeology,* shortened to The Sevilla Charter.

Since the theoretical framework for the Seville Principles is the London Charter, this document would adopt all the objectives approved by the Advisory Board of the London Charter. These general objectives should be accompanied by some new objectives, namely: generate easily understandable and applicable criteria for the whole community of experts; including indistinctly computer experts, archaeologists, architects, engineers, general managers or specialists in the field; establish guidelines aimed at giving the public a greater understanding and better appreciation of the ongoing work of archaeology; establish principles and criteria for measuring the quality of projects carried out in the field of virtual archaeology; promote the responsible use of new technologies for the comprehensive management of archaeological heritage; Improve current archaeological heritage research, conservation and dissemination processes using new technologies; open new doors for the application of digital methods and techniques in archaeological research, conservation and dissemination; Raise awareness of the international scientific community of the prevailing need to make concerted efforts worldwide in the growing field of virtual archaeology.

The Seville Charter presents 8 methodological principles:

Principle 1: Interdisciplinarity. Any project involving the use of new technologies, linked to computer-based visualisation in the field of archaeological heritage, whether for research, documentation, conservation or dissemination, must be supported by a team of professionals from different branches of knowledge.

Principle 2: Purpose. Prior to the development of any computer-based visualisation, the ultimate purpose or goal of our work must always be completely clear. Therefore, different levels of detail, resolutions and accuracies might be required.

Principle 3: Complementarity. The application of computer-based visualisation for the comprehensive management of archaeological heritage must be treated as a complementary and not alternative tool to other more traditional but equally effective management instruments.

Principle 4: Authenticity. Computer-based visualisation normally reconstructs or recreates historical buildings, artifacts and environments as we believe they were in the past. For that reason, it should always be possible to distinguish what is real, genuine or authentic from what is not. In this sense, authenticity must be a permanent operational concept in any virtual archaeology project.

Principle 5: Historical rigour. To achieve optimum levels of historical rigour and veracity, any form of computer-based visualisation of the past must be supported by solid research, and historical and archaeological documentation.

Principle 6: Efficiency. The concept of efficiency applied to the field of virtual archaeology depends inexorably on achieving appropriate economic and technological sustainability. Using fewer resources to achieve steadily more and better results is the key to efficiency.

Principle 7: Scientific transparency. All computer-based visualisation must be essentially transparent, i.e. testable by other researchers or professionals, since the validity, and therefore the scope, of the conclusions produced by such visualisation will depend largely on the ability of others to confirm or refute the results obtained.

Principle 8: Training and evaluation. Virtual archaeology is a scientific discipline related to the comprehensive management of archaeological heritage that has its own specific language and techniques. Like any other academic discipline, it requires specific training and evaluation programmes.

The general methodological principles defined by the London Charter and the Principles of Seville represent the theoretical reference point for a correct virtual reconstruction, which must now be translated into an accurate 3D visualization.

3. The Construction Process: the Virtual Redesign of a Building

The virtual reconstruction of an ancient building involves the use of a digital model «to visually recover a building or object made by humans at a given moment in the past from available physical evidence of these buildings or objects, scientifically-reasonable comparative inferences and in general all studies carried out by archaeologists and other experts in relation to archaeological and historical science»[22]. Such action is defined as Virtual Restoration in which the digital model is used to «to reor-

der available material remains in order to visually recreate something that existed in the past. Virtual restoration includes virtual anastylosis»[23].

Indeed, in archaeology, the building is often reduced to the level of ruins, resulting in the loss of volumes, lights, cladding decorations, and the context in which it was constructed. The interaction between the real monument, with its spaces and paths albeit mutilated, and virtual reality, with its reconstructive effects, offers a concrete opportunity for understanding, otherwise very difficult, the relationships between volumes, spaces, paths, and lights/shadows of the internal environments of which we often have no awareness. In order to reconstruct these relationships, the virtual reconstruction of an ancient monument aims to study the so-called "construction process," a true action of "virtual redesign" of the building.

Architecture, indeed, is a set of creative activities mainly composed of two phases, *design*, and *construction*, which together constitute the "construction process" indicating «the way in which construction activities are carried out and organized both intellectually and materially, resulting in one or more architectural artifacts»[24] it consists of three main aspects: the protagonists, the operations, and the materials.

The *protagonists* of the construction process represent a multitude of individuals. Firstly, there are the clients of the architectural work, i.e., those who finance the building asset; secondly, there are the users (who sometimes coincide with the clients themselves), i.e., those who individually or collectively benefit from the building asset; the technicians and professionals, i.e., those who operate in closely related fields, such as architects, engineers, surveyors, etc., who determine the architectural design; finally, there are the workers, those who physically construct the building asset.

The operations, on the other hand, are further divided into program, architectural design, and construction activities.

The *program* is the stage where the goals and dimensions of the project are generally defined by the customers, in accordance with the economic constraints imposed, which limit the possibilities for the execution of an architectural work[25]. The *architectural design*, instead, is the process of theoretical and methodological elaboration conducted by technicians and professionals, which precedes the execution of an architectural work and provides «the order of spaces and construction elements coherent with the assumed program»[26]. The architectural design is influenced by two parallel processes: *ideation*, which represents the translation of the program into space and volumes, and the *construction solution*, that is, the study of suitable construction methods through the choice among available building materials and their utilization based on the laws of nature[27]. The relationship between ideation

and construction solution thus gives rise to architectural design, which in turn precedes the *construction activity*.

The construction activity represents the phase in which the architectural object is physically built, that is, the actual construction of an architectural work, according to various stages ranging from laying the foundations to the construction of the elevations (walls and partitions) to the roofing and ancillary works (floors, interior and exterior cladding, etc.). The design and construction activities thus determine a construction process through which an architectural artifact is shaped. In the project, the requirements of the construction program converge to give form to a spatial and organized organism, which, in turn, acquires a lasting and definitive appearance through the solutions adopted in the construction activity.

Archaeological research has mainly focused on studying the information contained in the construction activity. However, ancient buildings are often reduced to ruins, resulting in the loss of volumes, light, decorations, and the context in which they were built. The interaction between the real monument, with its spaces and paths albeit mutilated, and virtual reality, with its reconstructive effects, provides a concrete opportunity for understanding, otherwise quite difficult, the relationships between volumes, spaces, paths, and light-shadow dynamics of the internal environments of which we often lack awareness.

Different approaches and purposes have been adopted in the investigations conducted on structures, whether they have been found within an archaeological excavation or are still intact and functioning buildings. One initial approach is the *technical analysis* of a building, which aims to study its structural and functional logic through an understanding of the construction solutions adopted[28]. In this case, the Science of Construction Materials is crucial, a discipline that deals with the static and dynamic behavior of the structures of an architectural artifact and the equilibrium of its structural components under the effect of permanent or accidental loads[29].

Furthermore, a building is determined by a sequence of construction actions, but over its lifespan, it may have undergone various manipulations and transformation activities that could have led to the modification of its original "static equilibriums" over time.[30].

The transformations can be of various kinds, either dictated by traumatic events such as earthquakes, fires, or abandonment, or by changes introduced in its balance by humans, such as expansions of the structure, reorganization of interior spaces, different roofing systems, or changes in function. Therefore, even the constructive-structural aspect assumes an important value for the understanding of a building, especially if envisaged for a possible restoration intervention, both real and virtual.

In this research area, the study of the "degradation sequence"[31], also falls within, which is a post-depositional "passive" or "transformative"[32] process caused by the physical and chemical action on building materials. The agents of deterioration can have various origins: they can come from the soil, such as water; they can result from slow and continuous anthropogenic actions (surface wear) or traumatic events (warfare, abandonment, etc.); finally, they can be natural, such as actions from vegetation or climate. Aging and degradation of building materials should not be understood in an "anthropocentric" manner but depend solely on external causes: no material, including wood, changes its characteristics over time due to its own causes[33]. Understanding the agents of deterioration has always been an essential component in the practice of construction, similar to knowledge about maintenance, conservation, and restoration of buildings.

Materials for construction do not refer only to stone materials but also to all those used in the construction of a building, such as clay materials, wood, metals, glass, binders, plaster, and stucco.

In architecture or civil engineering, the study of materials is linked to understanding their workability and mechanical resistance characteristics[34]. Conversely, in the field of archaeology and restoration, analyses are conducted using tools specific to the natural sciences, such as Archaeometry[35]. This discipline is used to determine the mineral-petrographic nature and chemical composition of materials, as well as their chemical, physical, or technological characteristics, and their behavior under various types of degradation.

Archaeometric analyses can be used to determine the origin of the raw materials used. This information is useful not only for understanding the construction history but also for actual restoration efforts on a building. Furthermore, certain materials serve as chronological indicators, and their dating can be obtained through scientific methods such as radiocarbon dating and dendrochronology for wood, thermoluminescence and archaeomagnetism for bricks, terracottas, kilns, and hearths, just to name a few examples.

A second approach involves studying masonry techniques and their evolution over time, which can provide not only chronological indications but also information regarding the production cycle of construction materials[36]. In nature, there are no construction materials ready for use but rather natural resources that can be transformed into raw materials through simple or complex processes. The study of production cycles, which until the pre-industrial age indicated all «the sequences of operations that allow transforming one good into another different from the first»[37], means understanding all the steps that transform natural resources into finished building products. The "natural resource" is

"a portion of the environment capable of providing raw materials and energy," while the "raw material" is «a portion of a natural resource, free from defects, with dimensions and shapes suitable for the construction elements to be produced»[38]. The cycle of construction materials continues with the identification and extraction, or "cultivation," a term analogous to that used in human primary production, of the building material with the use of specialized workers who carry out the selection, fundamental for the successful outcome of the entire production sequence. Finally, transportation occurs to the construction site where the material, which has been partially worked so far, is finished and installed according to specific procedures and techniques.

An additional approach to the study of masonry is ethno-anthropological analysis[39], which identifies masonry with what anthropologists define as the "technical objective" of the builder. With this term, the aim is indeed to define the purpose of one or more individuals who, coordinated by a series of operations, envisage the construction of a structure as the final act[40].

From this, it is inferred that none of the actions are the result of a random choice, but each operation directly reflects the technical knowledge of the builders and the cultural and economic context of the clients in relation to the availability of construction materials. Ethno-anthropological analysis therefore seeks to understand «the relationship between masonry evidence and the dynamics of technological-cognitive processes, as well as the mechanisms of transmission of such knowledge, and their connection with the cultural environment and the political-social organization of the time»[41].

In conclusion, the archaeological approach to architecture starts from the assumption that any architectural artifact represents a container of data which, once analyzed, can allow, through the study of materials and construction techniques, a reconstruction of the economic and social microhistory of the building.

The fundamental limitation of studying construction activity is that it alone is not sufficient for understanding and interpreting the structural and functional logic of the building. To achieve this result, it is necessary to try to trace back to the original architectural design. This analysis is realized through the creation of architectural models using computer technologies, particularly virtual reality applications.

Architectural design refers to the phase in which «the visualization of the formal idea is defined through a series of directly visual or conventional means, representing a progressive transition from a hypothetical and purely mental space to a specific and concrete space. In this sense, it can be considered a transition from a hypothesis to an actual possibility of form, as evidenced by the fact that an architectural project always starts from a graphic

delineation to reach a chiaroscuro representation and sometimes a plastic or colored one. This gradual transition of the mental image into a real or practicable space is clearly exemplified by the progressive development of the design aimed at prearranging the construction phases; the plan considers the building in relation to the horizontal or laying plane, the elevations in relation to the vertical planes, the axonometries extend the two dimensions into a stereometric view, and finally, the models consider the unity of the building in real space. The accuracy of the translation is ensured by what we could call the technique of design and related instrumentation: of fundamental importance are perspective projections and metric scales, which allow the ideal form to be situated in a space structurally similar to real space and to precisely determine the relationship between the dimensions of the graphic design and the actual dimensions of the building»[42].

As evident from this definition by Giulio Carlo Argan, in no artistic activity are the stages of conception and realization as distinct as in architecture. Vincenzo Scamozzi, in his work *L'idea dell'architettura universale* of 1615, clarifies the relationship between conception, design, and execution, defining the building as «a scientific habit that resides in the mind of the architect»[43], attributing to the design alone the entire value of the concept of architecture. Indeed, according to Scamozzi, architectural design is the logical moment of the compositional operation, which does not need to be prolonged in the construction of the building.

The same concept was revisited three centuries later by Luigi Grassi in *Storia del disegno* (History of Drawing). According to the architect, «only the project is pure architecture, in which the phenomenon of architectural creation is accomplished and exhausted, precisely in the project and through the project»[44]. On the other hand, according to Giulio Carlo Argan, speaking about the concept of architectural design, he says that «the distinction between the ideational phase and the executive phase is artificial, no less than the identity that is often established between ideation and design»[45]. Architecture, therefore, does not end in the architectural design, which precisely represents only one of the phases for the complete realization of a building.

Each building, as an expression of an architectural design, is therefore characterized as a "built volume in space"[46]. The built volume is determined by its limitations: surfaces and partial volumes joined together, additions and penetrations of surfaces and volumes, simple and composite volumes, smooth and plastic volumes, open and closed. Architecture is thus conceived in the architectural design as a relationship between volume and space that determines a wide range of possibilities for defined spaces within an open space.

This relationship is well expressed by two definitions. The first definition, by architect Wilhem Pinder, states that «all spaces artificially creat-

ed by humans are delimited by volumes. Without determined volumes, there is no determined space»[47].

The second definition, on the other hand, comes from the Swiss architect Le Corbusier, who stated that «architecture is the wise, strict, and magnificent play of volumes assembled in light: our eyes are made to see forms in light: shadows and lights reveal forms; cubes, cones, spheres and cylinders or pyramids are the great primary forms that light enhances; the image appears clear and tangible, without ambiguity»[48]. Finally, a similar concept is summarized by the german architect Walter Gropius: «the primary means of expression in architecture, beyond any technical aspect, is space»[49].

This relationship determines the definition of "interior spaces" within buildings, and "exterior spaces" located between different buildings, parts of buildings, or groups of buildings[50]. Critical to the form and configuration of space are the so-called "boundaries," which are solid volumes such as walls, ceilings, supports, beams, roofs, arches, and vaults; in the case of exterior space, buildings or parts thereof[51]. The relationship between space and volumes is identified in architectural composition, which finds its expression in the preliminary study of floor plans, elevations, and cross-sections where the internal and external aspects of a building are geometrically delineated[52].

Subsequently, after studying the relationship between space and volume, the architectural design must define a primary objective of every construction: "stability"[53]. Every building is composed of matter constantly subject to the force of gravity, which acts as a downward push towards the Earth's surface and must be balanced by opposing forces. Buildings, structural elements, and constructions that are not in a state of equilibrium are destined to collapse[54]. Stability is also determined by the materials used and the techniques of processing and installation, and it is subject to the laws of *Structural Mechanics* (construction science) and *Statics*, disciplines that study the equilibrium of bodies under the actions of specific loads.

From an archaeological perspective, understanding the design process is an important goal for gaining a deep knowledge of an architectural work. Understanding the design intentions means comprehending the mental processes and cultural influences that have shaped the construction of a building. Indeed, building programs, building types, and construction forms are based on influences imposed by the climate, construction materials, economic structure, and religious, political, and economic concepts prevalent in the territory.

Therefore, archaeological investigation should aim to understand all the different elements that interact with the work of the designer, such as the role of the costumers, construction techniques, and the context

in which the work is situated. This perspective is now well-established in the field of architectural criticism, achieved through the analysis of evidence related to construction activities, which represent the completed form of an executive project.

In summary, just as in architecture the model serves as a verification of the construction solutions adopted in the architectural project, in virtual restoration, the 3D model represents the scientific verification of available archaeological data (the sources of research)[55], their interpretation, and their framing. Virtual reconstruction is like the final link in a chain of investigations that document the evidence of construction activity, leading up to the study of the architectural project and technical analysis.

NOTES

[1] Muller, Vogel 2000, p. 5
[2] Semper 1852, p.79 (our translation)
[3] *Infra* Part 2
[4] Gownder *et al* 2016
[5] Casiello 2005; Serafini 2018
[6] Niccolucci 1999, pp. 101-118; Goodrick, Gillings 2000, pp. 41-58
[7] Frischer, Niccolucci, Ryan, Barceló, 2002, pp. 7-18
[8] Guzzo, Liverani 2007. p. 12
[9] Forte, Beltrami 2000, p. 277
[10] «Aggiungo qui una raccomandazione che mi sembra molto a proposito: l'esibire modelli colorati o resi attraenti da pitture, indica che l'architetto non intende già rappresentare semplicemente il suo progetto, bensì per ambizione cerca di attrarre l'attenzione con l'esteriorità dell'occhio di chi guarda distraendo la mente che da una ponderata disamina delle varie parti del modello per riempirla di meraviglia. Meglio, quindi, che non si facciano modelli non già rifiniti impeccabilmente, forbiti e lucenti, ma nudi e schietti, sì da mettere in luce l'acutezza della concezione architettonica, non l'accuratezza dell'esecuzione del modello». Alberti 1475, (II, III) (our translation)
[11] Barcelò 2001, pp. 221-244; Trizio, Demetrescu, Ferdani 2023
[12] Frischer, Niccolucci, Ryan, Barceló, 2002, pp. 7-18
[13] London Charter 2009
[14] Principles of Sevilla 2011
[15] Frischer, Niccolucci, Ryan, Barceló, 2002, pp. 7-18
[16] Carta di Venezia1964
[17] Barcélo, Forte, Sanders 2003
[18] Ryan 1996, pp.95-108
[19] Roussou, Drettakis 2003, pp. 51-60
[20] Niccolucci 1999, pp. 101-118
[21] Beacham, Denard, Niccolucci 2006, pp. 263-269; Denard 2012, pp. 57-72
[22] Principles of Sevilla 2011, p. 3
[23] Principles of Sevilla 2011, p. 3
[24] VV.AA. 1996, pp. 335-336 (our translation)
[25] Argan 1958, p. 60
[26] Samonà 1968, p. 11 (our translation)
[27] Muller, Vogel 2000; De Rubertis 2000, pp. 475-481
[28] Giuliani 1989

[29] Cagnana 2000
[30] Corradi 1996, pp. 101-107
[31] Carbonara 2003; Carbonara 2004
[32] Brogiolo 1996, p. 14; Brogiolo 1997, pp. 181-184; Brogiolo 2007, pp. 7-38
[33] Mannoni 1996, p. 97-106
[34] Rockwell 1989
[35] Castellano 1992; Martini, Sibilia, Castellano 2007; Siano 2012
[36] Giannichedda, Mannoni 1996
[37] Giannichedda 1998 (our translation)
[38] Mannoni 2000, pp.9-15 (our translation)
[39] Vidale 1992
[40] Bianchi 1997, pp. 53-64
[41] Bianchi 1997, p. 54 (our translation)
[42] Parenti 1997, pp. 175 (our translation)
[43] Scamozzi 1838 (our translation).
[44] Grassi 1947, p.21 (our translation)
[45] Argan 1958, p.58 (our translation)
[46] Muller, Vogel 2000, p.7
[47] Pinder 1970, pp. 431-452 (our translation)
[48] Le Corbusier 1950, p. 21 (our translation)
[49] Argan 1988, p.18 (our translation)
[50] Muller, Vogel 2000, p. 681
[51] Muller, Vogel 2000, p. 681
[52] Giovannoni 1946, p. 77
[53] Pevsner, Fleming, Honour 1996, p. 623
[54] VV.AA. 1996, p. 335
[55] *Infra* Part 2

PART 2

ACQUISITION OF DATA:
RESEARCH SOURCES FOR THE RECONSTRUCTIVE STUDY OF ANCIENT MONUMENT

II
THE DIRECT SOURCES

The general methodological principles underpinning a correct archaeological reconstruction were set out in the early XXI[th] century, first in the *London Charter for the Use of 3D Visualisation in the Research and Communication of Cultural Heritage*[1] (2006) and subsequently in *the Seville Principles*[2] (2011) on Virtual Archaeology. Indeed, these documents establish the principles and methods that need to be adopted in order for the virtual reconstruction of an ancient monument to be considered scientifically correct. In other words, they present a coherent set of methods characterised by a precise sequence of measures, operations and analyses to be performed in accordance with a pre-established order centred on the acquisition, processing and presentation of data[3].

Therefore, before starting to create a virtual reconstruction of an ancient monument, it is necessary to acquire all possible data to have a preliminary in-depth knowledge of the building on which the research is to be concentrated: or the so-called "research sources".

Principle n°3 of the London Charter, "Research Sources", stresses the notion that «In order to ensure the intellectual integrity of computer-based visualisation methods and outcomes, relevant research sources should be identified and evaluated in a structured and documented way»[4]. "Research Sources" refers to the retrieval of «All information, digital and non-digital, considered during, or directly influencing, the creation of the computer-based visualisation outcomes. Research sources should be selected, analysed and evaluated with reference to current understandings and best practice within communities of practice. Particular attention should be given to the way in which visual sources may be affected by ideological, historical, social, religious and aesthetic and other such factors»[5]. Indeed, this information serves to ensure the intellectual integrity of the methods and results of the digital visualisation and it must be identified and assessed in a documented and structured way.

Principle n°4, pertaining to "Documentation", paragraph 4.5, on the Documentation of Research Sources, declares that «A complete list of research sources used and their provenance should be disseminated»[6],

while paragraph 4.6, regarding Documentation of Process (Paradata), states that «Documentation of the evaluative, analytical, deductive, interpretative and creative decisions made in the course of computer-based visualisation should be disseminated in such a way that the relationship between research sources, implicit knowledge, explicit reasoning, and visualisation-based outcomes can be understood»[7].

Lastly, the glossary specifies in greater detail the meaning of "paradata", i.e. «Information about human processes of understanding and interpretation of data objects. Examples of paradata include descriptions stored within a structured dataset of how evidence was used to interpret an artefact, or a comment on methodological premises within a research publication. It is closely related, but somewhat different in emphasis, to "contextual metadata", which tend to communicate interpretations of an artefact or collection, rather than the process through which one or more artefacts were processed or interpreted»[8].

On the basis of these considerations, the information to be gathered before the start of a reconstructive study of an ancient building can be divided into three types: direct, indirect and secondary . The sum of all the sources (direct, indirect and secondary) thus determines the degree of methodological reliability and any impact this may have on the general process of cataloguing and publishing the data, which is closely linked to the quantity of archaeological data available.

The *direct sources* indicates all the information that is still «available on the body of the monument or is immediately connected to it, especially physically, or can be deduced from it»[9]. It is therefore information that can be found and verified by direct analysis of the architectural artefact, based on its state of conservation, by means of a survey, the stratigraphic reading of the elevations and the data from the archaeological excavation.

1. State of conservation of a building

The conservation status of a building indicates information about the state of integrity and/or legibility, considered in relation to the original condition of an Architectural Monument or Archaeological Complex. The state of conservation of a building can vary depending on whether it is buried, having been discovered by means of stratigraphic excavation, or partially visible, either in a state of ruin or incorporated within subsequent constructions, in which case it is made legible by means of architectural drawing and stratigraphic examination of the standing structures, or finally, intact.

Assessing the conservation state of a building inevitably involves comparing the observable and analyzable current state with a presumed, previous condition in which the materials originally constituting

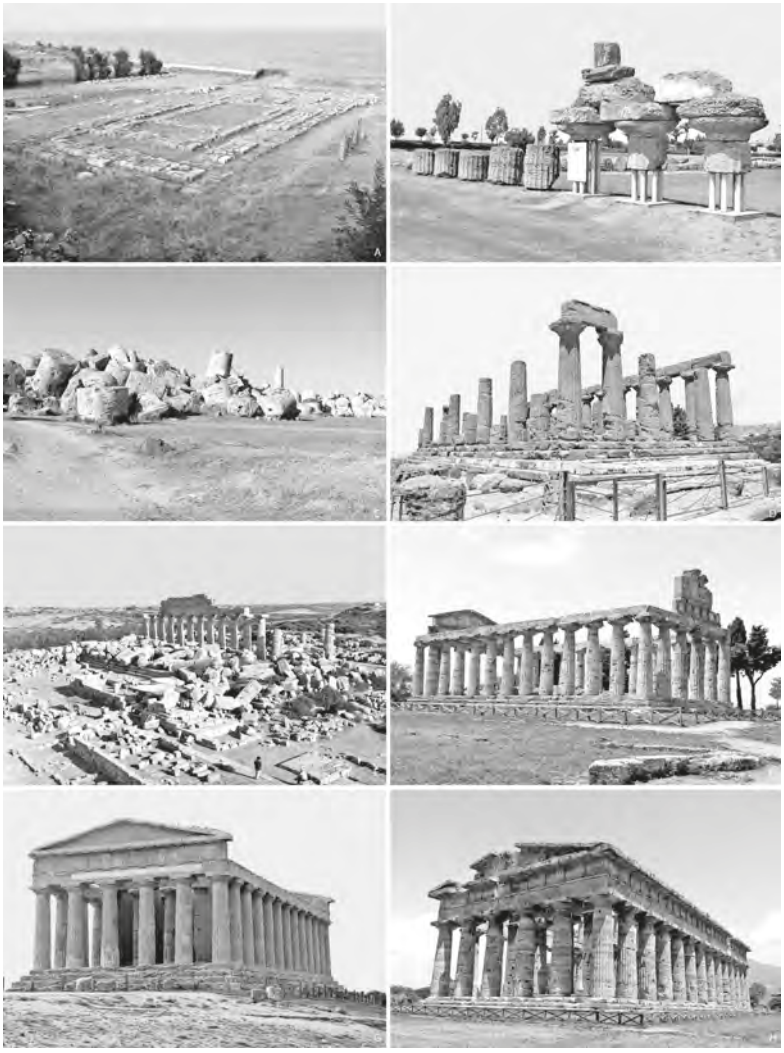


Fig. 1. examples of different states of conservation of temples: Kaulonia (A); temple of Apollo at Metaponto (B), Selinunte (C), Agrigento (D), Selinunte (E), Paestum (F), Akragas (G), Paestum (H). (photo M. Limoncelli).

it could be considered optimal because they fully met the functional, formal, and expressive requirements envisioned in the executive project and subsequently realized.

The conservation state can be classified using an ordinal scale of qualitative values that can be divided into: excellent, good, fair, poor, and very poor[10].

- Excellent: it is a building that is preserved almost intact, where all the compositional elements are still visible and documented in situ: foundations, elevations, roofs, architectural decoration, and finishing works (floors and wall decorations, etc.).

- *Good*: it indicates a state of preservation that allows for a complete readability of the building, although some parts may be missing in the structural elevations, roofs, architectural decoration, and finishing works.

- *Fair*: the building still has legible structures, although many of its preserved parts are missing in situ, but there are still many elements of architectural decoration in collapse (columns, capitals, elements of the entablature, etc.).

- *Poor*: the building is characterized by poor legibility of the structures due to the absence of significant parts, where only the foundations, floorings, limited portions of the elevations, and fragments of floors survive.

- *Very poor*: The conservation status is limited to the presence of only the foundations.

As evident from this classification, there is no absolute value for measuring the state of conservation of a building. It is, in fact, a scale of values that does not describe an objective, and therefore absolute, condition, but is expressed through qualitative parameters dictated by the subjective perception of the observer/researcher.[11].

Indeed, the degree of reliability of a virtual archaeological reconstruction of a building is not solely determined by its state of conservation. It is linked to the combination of all informations derived from various direct, indirect, and secondary sources.

2. Survey and rappresentation of architecture

The architectural drawing, instead, it must be understood as a preparatory action to any virtual reconstruction intervention of a building as it represents the metric basis for what will be the 3D reconstruction action that will happen later through digital modeling. Both are founded on the principles of descriptive geometry, with the difference that the drawing provides a two-dimensional representation, on one or more planes, of three-dimensional objects, while 3D modelling translates the same objects into surfaces or solids within a virtual space.

The complete survey of the monument is a necessary preliminary step in any act of restoration (including virtual) and should be understood as «an annotated edition of the monumental text»[12] by means of which it is possible to acquire, understand and interpret data, necessary for the correct execution of a 3D model for a virtual reconstruction of an archaeological monument.

Architectural surveying encompasses not only the simple task of measuring and graphically representing both two-dimensional and three-dimensional architectural structures but also a complex set of operations aimed at investigating all components of architecture. This includes geometric characteristics (stereotomy) as well as dimensional aspects (stereometry), structural and constructional features, and formal

and functional aspects, using appropriate systems of codes and graphical standards.[13].

From architectural surveying, various types of thematic elaborations can be obtained: *geometric surveying*, which provides measurements and perimeters of individual building elements, and *technological and structural surveying*[14], which highlights construction techniques for historical-technical analysis, and conditions of alteration and degradation for diagnostic analysis. this type of architectural surveying is a historical-critical representation of the artifact that takes place through thematic elaborations of graphic interpretation aimed at highlighting the maximum amount of information about the building.

Through the survey, an initial two-dimensional representation of the reconstructive study of the monument is carried out, with the verification entrusted to the 3D model. It is essential to produce the plan (*ichnographia*)[15], which is actually a section on a horizontal plane set at a predetermined elevation and represents the area below the section plane, including floors, windows, doors, pillars, walls, etc. Reconstructing the plan is fundamental: «The architectural conception materializes in the plan, which holds particular importance. From the plan, space unfolds according to absolute measures. These measures do not represent independent values: they are the result of differentiated research on the conditions of reality, investigated and related to human capacity to understand space»[16]. The elevations and cross-sections (*orthographia*)[17], on the other hand, are the graphic representation of the internal and external elevations of the building with which it is possible to reason about the levels to understand foundations, walls and partitions, floors, and roofs. Like the plan, the cross-sections, which cuts the building on a vertical plane, must convey as much information as possible and therefore pass through scales, doors, windows, etc. Finally, with axonometries and perspectives (*scaenographia*)[18], it is possible to visualize the building simultaneously on the three planes through a geometric projection on a projection plane along a projection line.

Depending on the state of conservation, position, size, and shape of the buildings under study, specific survey techniques can be applied, which can be classified into two main types: direct and indirect. Direct survey refers to a survey that occurs through "direct" contact with the artifact to be documented. It is carried out using simple instruments and results in graphic representations typical of geometric and architectural drawing: plans, elevations, and cross-sections using an appropriate system of codes or graphic standards.

Indirect survey (also known as "digital survey") encompasses all measurement operations that occur without direct contact but through the mediation of optical, mechanical, or computerized instruments.