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Digital Archaeology: From Interdisciplinarity to the 'Fusion' of Core Competences Towards the Consolidation of New Research Areas

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Abstract The aim of this article is to explore the interdisciplinary turn observed in the development of humanities computing, in terms of integration and fusion of expertise. The debate started with the Seminar on *Discipline umanistiche e informatica. Il problema dell'integrazione*, held in 1991 at the Accademia Nazionale dei Lincei. Moving backwards in time, already from the 1960s the role of 'integration' was at the heart of many interdisciplinary initiatives supported by the National Research Council of Italy and the Accademia Nazionale dei Lincei as part of their coordinated efforts to promote scientific progress. Through a number of archaeological case studies pivoting around the Etruscan civilisation, it will be shown how over time archaeological computing, and its evolution towards digital archaeology, has found in GIS and multimedia systems a unitary platform on which methods and practice of data acquisition, analysis, interpretation, and communication can converge. The concept of 'fusion', however, is much more recent and responds to a global resource management model, which combines the methods of archaeology with the objectives of Heritage Science, along the research path that goes from field and laboratory investigation to the protection, enhancement and communication of cultural heritage.

Keywords Archaeology. Archaeological computing. Digital archaeology. Digital cultural heritage. Heritage science.

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1 Introduction

In 1991 Tito Orlandi organised the seminar *Discipline umanistiche e informatica. Il problema dell'integrazione* at the Accademia Nazionale dei Lincei (Orlandi 1993), where the scene was set for a debate on how the humanities community could embrace computing and technological innovation, balancing scholarly tradition against conceptual and methodological renewal. Promoted by the Centro Linceo Interdisciplinare "Beniamino Segre", the seminar set out to address the specific theme of 'integration' with the aim of finding some common ground between information science and humanities scholarship, in order to outline a cross-disciplinary approach.

Before examining the evolution of this process over time – drawing particular attention to archaeology and cultural heritage studies – it will be worth briefly tracing back the history of the 'interdisciplinary' turn of events in Italy, by following the initiatives supported by the National Research Council (CNR) and the Accademia Nazionale dei Lincei as part of their coordinated efforts to promote scientific progress.

2 From 'Symmetry' to Interdisciplinarity

In 1969, Beniamino Segre, the renowned mathematician, chaired the Steering Committee of a symposium on 'symmetries' held at the Academy (*Simmetrie* 1970). The conference gave the opportunity to discuss how symmetries could act as a propelling and unifying force: as Segre said, much of the progress that had taken place in several research areas hinged on symmetry-related phenomena, which led to uniform patterns and procedures and, at the same time, interconnections. Such thrust effectively was opposing the disruptive trend stemming from the necessary, but controversially harmful, specialisation of knowledge (Segre 1970).

At the end of the symposium, after Ugo Spirito's concluding lecture on the concept of symmetry from a philosophical perspective, Giovanni Battista Bonino was invited to present a draft proposal, which the Assembly approved by acclamation. In fact, drawing on the success of the symposium as an interdisciplinary event addressing a wide spectrum of scientific domains, the project of establishing a centre for mathematical and physical studies at the Academy was brought forward with the idea of fostering collaborative development between scientists from different research backgrounds.

As Tito Orlandi has recently pointed out,[1] the Centro Linceo Interdisciplinare di Scienze Matematiche e loro Applicazioni was established two years later, chaired by Beniamino Segre, with the mandate of promoting innovative projects to encourage interaction between individual disciplines with particular reference to mathematical thought and its applications. Among these projects, the humanities were soon brought to the forefront of research priorities, also in terms of the training needed for young scholars through the awarding of fellowships.

The series *Contributi* promoted by the Centre, which started with the publication of series of lectures and seminars, soon witnessed a growing interest in transversal issues on the part of humanities scientists in a wide array of research fields, ranging from linguistics to scientific documentation and data automation. The volumes related to archaeological research, which were inaugurated by Amilcare Bietti's lectures on applied mathematical and statistical methods (Bietti 1979; 1982), are now available online on the website of the Virtual Museum of Archaeological Computing, a joint initiative of the CNR and the Accademia Nazionale dei Lincei designed to retrace the main theoretical and methodological landmarks of the evolution of computer applications in archaeology, starting from the fifties up to the new millennium (Moscati, Orlandi 2019).[2]

3 Archaeology 'Ancillary' Sciences

At the end of the sixties, chaired by Vincenzo Caglioti, the CNR too promoted and coordinated scientific initiatives on the application of science and technologies to archaeological research, which in those years was undergoing a thorough interdisciplinary methodological review. The progressive acclamation of 'ancillary' sciences is upheld by the establishment, in 1967, of a special CNR Commission. Chaired by Paolo Graziosi and coordinated by Giuseppe Donato as its Secretary, in 1970 the Commission launched the Servizio per le scienze sussidiarie dell'archeologia, under the direction of Donato himself, with a specific focus on developing new scientific methods in the field of data acquisition, data analysis and dating techniques (Donato 1969).

Massimo Pallottino's opinion on this new scientific direction could be summarised as follows: if the whole history of archaeology is featured by the ingenious implementation of new tools and techniques

1 *Il Centro linceo interdisciplinare "Beniamino Segre": origini, sviluppo, prospettive*, conference held at the Academy in 2016.

2 http://archaeologicalcomputing.lincei.it/. The volumes are freely available in the section "Institutions" dedicated to the Centro Linceo.

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to support investigation activities, technology progress has now culminated in an 'explosive' climax. The novelty lies in that some tools and techniques are specifically devised for archaeology and applications extend over the entire archaeological research 'cycle', with a massive impact on four fundamental sectors: 1) exploration techniques; 2) data analysis techniques; 3) dating techniques; 4) conservation and restoration techniques (Pallottino 1963, 114-15).

Among the earliest application areas, geophysical surveys captured the interest of archaeologists since its inception in the fifties, especially thanks to the projects led by the Lerici Foundation. The archaeological prospecting unit, inaugurated by the Foundation in 1954, was soon involved in the activities promoted by the CNR and an unprecedented, uniquely Italian, chapter in the history of technology and information science applied to archaeology began. The impressive results obtained in the discovery of Etruscan tombs brought fame and fortune to the Foundation, which cooperated with some of the world's most renowned research centres[3] and soon became the focus of media attention, with important implications for the fight against the plague of illegal excavations (Lerici 1962; 1975).

Geophysical surveys also marked the introduction of computers into archaeological research. As Lucia Cavagnaro Vanoni pointed out, the results of the fieldwork conducted in the ancient city of Tarquinia, in an area of 4.5 hectares, were processed by an IBM 7090 in one and a half hour's work, distributed over a week (Cavagnaro Vanoni 1967). Without a computer, data interpolation, mathematical processing and representation would have required at least 18 months.

4 Multiple and Complementary Aspects of an Interdisciplinary Research Approach

Since the seventies, the emergence and evolution of an interdisciplinary approach were conceived as a unifying view of science and culture, often advocated by the humanities side of the scientific research. The term interdisciplinarity did not refer only to the competition between different disciplines, but also to their integration through the identification of common elements, interconnections, and methodological affinities. According to the suggestive definition by Willard McCarty, a "true *interdiscipline* [...] is an entity that exists in the interstices of the existing fields, dealing with some, many

3 The Museum Applied Science Center for Archaeology (MASCA) at the University of Pennsylvania, the Research Laboratory for Archaeology and the History of Art in Oxford, the Centre de Recherches Géophysiques of the CNRS in Garchy, and the Rheinisches Landesmuseum in Bonn.

or all of them. It is the Phoenician trader among the settled nations" (McCarty 1999).

Archaeology, with its solid scholarly legacy, managed to find in the application of the most modern technologies a huge potential for development in each investigation fields pertaining to its knowledge chain. At the same time, it succeeded in remaining faithful to its most intimate purposes – and concerns – consisting precisely in the systematic pursuit of knowledge as a prerequisite for the preservation of those assets that are at the heart of its study (Ferrari 1996).

Beyond any doubt, technologies facilitated and enhanced the nature of archaeological scholarship, which, while retaining its autonomy, moved step by step with the interdisciplinary shift in cultural heritage studies.

4.1 Tradition and Innovation in Archaeology and Cultural Heritage Studies at the CNR

As early as the 1970s, the Servizio per le scienze sussidiarie dell'archeologia expanded its name to include the conservation and enhancement of cultural heritage. Giuseppe Donato, together with Mario Fornaseri, Sebastiano Sciuti and Sergio Terrani, carried out a feasibility study for the setting up of a special project targeting knowledge, safeguarding and enhancing of the artistic heritage through a nationwide coordination activity.[4]

This was the beginning of a long journey the CNR was to embark upon. The timeline represented in the website of the new-born Institute of Heritage Science (ISPC),[5] inaugurated in 2019, helps to visualise, in a nutshell, the key milestones of this journey, one of which is the launch of the special project on the safeguard of cultural heritage in the nineties (*Progetto Finalizzato* 1996; Guarino 1998). Today, ISPC is the last offspring of the CNR institutional merging policy that has brought together the Institutes with the longest tradition in the fields of archaeological research, technologies applied to cultural heritage, and conservation and enhancement of cultural heritage.

In 2006, during the workshop-exhibition *Multi-quality Approach to Cultural Heritage*, organised by the CNR Cultural Heritage Department,[6]

4 *Studio di fattibilità del Progetto Finalizzato Scienze sussidiarie dell'archeologia e delle attività per la valorizzazione e la conservazione del patrimonio artistico*. Roma: CNR, n.d.

5 https://www.ispc.cnr.it/en/istituto/storia/.

6 The aim of the workshop was to present the latest technologies developed in Italy in the cultural heritage sector, to be then proposed to Japanese companies and institutions during the *Italian Spring in Japan* exhibition organised by the Italian Embassy in Tokyo. The success of the event was repeated shortly afterwards through the *TECHA 2008* workshop (Di Marcello, Cessari 2008).

over fifty projects, subdivided into seven specific subsets,[7] set out to illustrate the various aspects of the study and preservation of the archaeological, art historical, and documentary heritage. Convergence of purposes and originality of applications strengthened both the harmonious relationship between methodological assumptions and operational practice and the overall involvement of research institutes, universities, public administration and businesses. The 'multi-quality' approach gained wide success also from a terminological point of view: in each presentation, the words multidisciplinary, multi-objective, multimodal, multi-scale, multi-state, multi-criteria, multi-user, multi-channel, besides the well-known multimedia, were widely recurrent.

This was a clear sign of the success achieved by integration and cooperation. In this respect, new methodological trends and investigation strategies were emerging in close connection with the role played by information technology. Its function was to act as a catalyst for interdisciplinary innovation, with a significant impact on traditional research methodologies. The growing nexus of cultural heritage with the history and economy of individual countries was looking at ICT both as a point of reference and a source of innovation in order to amplify its echo in the modern industrialised world.

By the first decade of the new millennium, the interdisciplinary approach was therefore oriented towards the construction of integrated information systems: databases for inventory and cataloguing purposes; geographical information systems for archaeological site location and spatial patterning; network systems as an environment for reference and knowledge sharing; multimedia systems for the communication of research results, using visual and sound information; and visualisation and immersive systems for simulating and representing the lost heritage, allowing a wide community of users to fully enjoy it. Therefore, the digital model – applied both to data acquisition and structuring, and to the formalisation of the analytical processes that allow data to be interpreted – turned into a dynamic representation of a complex reality as opposed to a static procedure of data recording.

4.2 The Centro Linceo and the Formalisation of Knowledge

The Accademia Nazionale dei Lincei played a leading role, along with the CNR, in the dissemination of natural science disciplines, such as biology, chemistry and physics, in the study and preservation of cultural heritage. The international congress *Applicazione dei metodi*

7 Knowledge, Diagnosis, Conservation, Enhancement, Management, Enjoyment, and Training. The boundaries between all these sectors were often blurred thanks to the consolidation of integrated and complementary research paths.

nucleari nel campo delle opere d'arte (1976), convened between Rome and Venice in 1973, was the first of its kind throughout the world. As evidence of the attention paid to the constructive dialogue between the members of the scientific and the art historical communities, the event started off with the keynote speech of Beniamino Segre and ended with the concluding remarks of Cesare Brandi. More than a decade later, the memories of that event were still vivid among the interdisciplinary study group that in 1989 published a report on the use of scientific methods in the analysis and preservation of works of art in Italy, with the aim of conducting a fact-finding survey.[8]

The series *Atti dei Convegni Lincei* (and even before the series *Problemi attuali di scienza e di cultura*) are teeming with interdisciplinary initiatives. Of particular note for the archaeological sector are those projects first embracing archaeometry and then archaeoastronomy,[9] two research fields that have capitalised on the strategic investment in science and technology. Alongside the commitment of the Academy, the Centro Linceo gradually focused on the crucial role of computer science in the academic and social domains, particularly on issues related to computer systems, programming languages, and data models. In this regard, it is worth mentioning the series of seminars on systems science, followed by the conferences on classification techniques and their application in linguistics, computer systems for scientific documentation, automatic information retrieval systems, and expert systems. In 1982, moving from this theoretical and methodological framework, Tito Orlandi held a conference focused on computer science and textual scholarship (Orlandi 1982).

Ten years later, the seminar *Discipline umanistiche e informatica. Il problema dell'integrazione*, which was mentioned before, gathered a distinguished group of scientists who, while recognising the technical aspects of humanities computing as largely established, gave rise to a cutting-edge debate on the need for developing an embedded scholarly knowledge.[10] Can integration develop further towards

8 *La diffusione in Italia delle metodologie scientifiche* 1989. The study group consisted of E. Amaldi, V. Caglioti, G. Careri, S. Carrà, U. Colombo, M. Fornaseri, A. Mottana, S. Sciuti and R. Ugo.

9 For the first conferences on these topics, see respectively *Archeometria* 1985 and *Archeologia e Astronomia* 1995.

10 A lively debate on the meaning of interdisciplinarity has characterised the development of Humanities Computing/Digital Humanities (see e.g. Klein 2015). As part of the long-standing activity of the Humanist Discussion Group, founded in 1987, it is worth quoting, for example, the recent comment by Dino Buzzetti, which summarises efficiently the approach that informs this article: "By necessity, there would be no 'interdisciplinarity' without disciplines. Moreover, interdisciplinarity is NOT 'multidisciplinarity', for that would be just a juxtaposition of disciplines with no interaction, NOR 'transdisciplinarity', for there won't be disciplines and specific disciplinary competencies anymore" (https://dhhumanist.org/volume/35/43/).

unprecedented forms of humanities research? Can knowledge formalisation and mathematical modelling be instrumental in prioritising the interaction and interconnection of different system components?

In close analogy with the spiral approach promoted years earlier by Jean-Claude Gardin (1980), the systems theory, which fits well into the basic principles of cybernetics, describes the interaction between individual components of a system as a filter (typical computer procedure) for which the information extracted or represented by one of the components (output) becomes the input of a subsequent component (see also Orlandi 1999). Comparison and integration are implemented through the evaluation of the methodological renewal of each discipline. Consequently, an epistemological approach to the development of methods and their interaction prevails, in the framework of open systems in which to encode data irrespective of further uses and organise the exchange and interactive use of application tools to be provided in a single environment in which the resources of a 'global library' can be shared.

During the meeting, a novel challenge came into play. While Tito Orlandi made explicit the difference between the two levels of research and data dissemination, Anne-Marie Guimier-Sorbets (1993) introduced the theme of communicating archaeological knowledge. The scholar focused on the need to define and implement standard policies and procedures for information transfer that allow researchers to access and retrieve data from large archives in which information gathered throughout their work is recorded. Following the documentary perspective of databases and focusing on the public aspect of research, Anne-Marie Guimier-Sorbets deemed it necessary to combine the instruments specifically designed for scientific research and those aimed at disseminating knowledge across a much wider audience.

In the same years, in conjunction with the approval of Law 28 March 1991, no. 113 on the dissemination of scientific culture, the Academy was assigned to the coordination of the *Settimana della Cultura Scientifica*.[11] Many insightful subjects were on the agenda: the thirst for knowledge, the unification of all branches of knowledge beyond the borders between nations and between generations, European cooperation, the social role of science, the quality control of knowledge dissemination, the use of models to face the challenge of cultural complexity, and the role of museums as an inspiring research environment.

11 *La diffusione della cultura scientifica* 1994; *La diffusione della cultura scientifica* 1996; *La cooperazione europea per la diffusione della cultura scientifica* 1997

5 Computational Models in Archaeology: A Forty-Years Research Path

The research projects I have been carrying out since the eighties at the CNR in the field of computer applications to archaeology are intertwined with the activities undertaken by the Centro Linceo, where their original design took shape. The illustration of some case studies concerning the Etruscan civilisation will help to examine the research evolution in an attempt to unravel its complex unfolding, in which advances in theory and technology are two indivisible facets of the same interdisciplinary approach. Similarly, I will rely on the thirty-year publication of the international journal *Archeologia e Calcolatori* and in particular on a number of special issues focused on scientific and cultural achievements against the background of archaeology and computer science joint evolution.[12]

5.1 Integration as a Multidimensional Approach: The Classification of Archaeological Artefacts

In the eighties in Italy statistical techniques had increasingly gained ground in prehistoric studies, but hardly in classical archaeology. The quantitative approach mostly focused on the typological classification of artefacts and the analysis of their spatial distribution. Inspired by the teaching of Amilcare Bietti and François Djindjian, in the early eighties the research project on the computerised analysis of Etruscan mirrors started out at the Centro Linceo laboratory. In the basement of the Palazzina dell'Auditorio, in the Villa Farnesina complex, an interdisciplinary group of research fellows, working through remote terminals connected to a Sperry UNIVAC 1100 mainframe computer at the data processing centre of Sapienza University of Rome, was involved in a programme focused on the use of computers in the scientific research.

The project soon found recognition in the research line Automatisation of Etruscan corpora at the CNR Centro di Studi per l'Archeologia Etrusco-Italica, under the direction of Mauro Cristofani,[13] who also

12 All issues, special issues, conference proceedings, and the supplements series cited in this paper are freely available in the Journal's website: http://www.archcalc.cnr.it/. See in particular: http://www.archcalc.cnr.it/journal/year_list.php; http://www.archcalc.cnr.it/pages/special_issues.php; http://www.archcalc.cnr.it/supplements/year_list_sup.php.

13 At the time, Mauro Cristofani was deeply involved in the founding committee of the new Faculty of Cultural Heritage Conservation of Tuscia University (Viterbo) and in the fostering of academic policies aimed at training new skilled professional profiles in the cultural heritage domain. On these university-related issues, which go be-

promoted the publication of the first Italian handbook of computing and archaeology (Moscati 1987). The research purpose was to test a computer-based method in order to investigate and classify homogeneous groups of artefacts belonging to the Etruscan civilisation. By using SPSS (Statistical Package for the Social Sciences) and SPAD (Système Portable pour l'Analyse des Données) packages, the research started with the analysis of about 1,000 Etruscan bronze mirrors and continued, in the following years, with the stone cinerary urns produced in Volterra in the Hellenistic period (the *Volaterrae* project). Descriptive statistical techniques helped to sift and provide a detailed picture of each variable, whereas exploratory data analysis techniques were oriented to study patterns and relationships in a heuristic process within which new information on the most distinctive features of each class of artefacts could be inferred.

Statistical analyses on bronze mirrors (Moscati 1984; 1986) yielded interesting results on the frequency and distribution of mythological figures and episodes (the Judgment of Paris, Helen's loves, amorous abductions), as well as on daily life scenes associated with the *mundus muliebris*. In addition, they were conducive to demonstrating the significant relationship between figures coming from both the Greek and Etruscan civilisations, through the participation of typical Etruscan mythological figures in scenes of Greek origin or the transposition of typical Greek deities in local Etruscan myths. By regrouping the mirrors in a series of homogeneous clusters, some suggestions on the spatial and chronological distribution of workshops were also proposed.

In the *Volaterrae* project, descriptive and multidimensional analyses were conducted on about 1,200 cinerary urns (Moscati 1998; 2004). As for the repertory of scenes carved on the front of the chests, both the interrelationship between morphology and iconography and the chronological dissemination of mythological or funerary themes were investigated. The formal description of architectural mouldings – considered in the literature as distinctive trademarks of single workshops – helped to detect some manufacturing techniques relying on the stone-carving of local craftsmen. Quantitative analysis revealed some characteristic elements of the standard production as opposed to the high quality production embellished with framing decorations that bear witness to the will of the deceased to celebrate his/her social and civil function.

This interdisciplinary approach was well suited to giving substance to the theoretical and methodological reflections on the im-

yond the scope of this paper, see in particular the momentous conference organised in Naples in 1991 by Mauro Cristofani himself (Cristofani 1994), in which some topics on computer applications were also addressed.

portance of the individual phases of the archaeological research – the 'statistical cycle', as Clive Orton (1980) defined it – and on the need for their formalisation. This scientific ferment resulted, in 1994, in the publication of the first special issue of the journal *Archeologia e Calcolatori* devoted to *Choice, Representation and Structuring of Archaeological Information*, which opened up an international debate on the identification and structuring of archaeological information and on the definition of a logical model according to which data can be formally represented.

In the same year, Tito Orlandi convened a second cycle of seminars at the Centro Linceo under the heading of *Informatica e discipline umanistiche: il problema della formalizzazione* (Orlandi 1997), with the aim of exploring whether and to which extent formalisation was conceivable within individual humanities disciplines, also before and irrespective of the emergence of computers and information technology.[14] On that occasion, the statistical classification of archaeological artefacts was pointed out, with specific reference to data sampling and numerical encoding (Moscati 1997). While, according to the traditional approach, the classification of archaeological artefacts relies on comparative procedures, the quantitative approach relies on statistical association and correlation mechanisms. In such a way, integration means that several dynamic models are set in motion, the subsequent stages of which are the endpoints of validation actions culminating in archaeological interpretation. Alongside a first descriptive level of analysis, the use of multidimensional statistical techniques gives rise to an inferential process designed to extract new information and to identify a logical structure that could meet specific criteria, such as those required by the classification and seriation of archaeological artefacts.

14 In this regard, it is interesting to refer to some letters from the unpublished correspondence between Jean-Claude Gardin and René Ginouvès, in which the first of the two scholars insisted on prioritising the method and its theoretical implications, regardless of the underlying physical system (Moscati 2016).

5.2 Integration as the Merging of Archaeological Research Practices

Throughout the eighties, the CNR Institute carried out a series of field surveys and excavation campaigns on the urban plateau of the ancient Etruscan city of Cerveteri, bringing to light several archaeological phases, from the Villanovan to the Roman period. The systematic use of computers gave birth to the *Caere* project, which in the nineties received full approval as part of the CNR Cultural Heritage Special Project. In 1998, the results achieved thanks to an international survey, designed to gather information on the application of Geographical Information Systems (GIS) in archaeology, were published in a special issue of *Archeologia e Calcolatori*.[15] The aim was to illustrate trends and perspectives of this new and powerful information system that had just emerged in archaeology.[16]

Building on modern trends of contextual archaeology and relying on the technological challenge of transposing an advanced computer platform into a virtual environment in which to reproduce the archaeologists' work, GIS systems and the underlying georelational data model soon became the instrument to consolidate the central role of spatial data, both on settlement and regional scale. In the case of *Caere*, the GIS environment provided an opportunity to collect data resulting from geophysical and archaeological surveys and from excavation campaigns. Digital Terrain Models highlighted the unique morphology of the southern Etruscan landscape, characterised by isolated tufa plateaux bound by streams and deep ravines. Spatial Analysis techniques helped to study the distribution of finds and features, as well as to investigate spatial and visual relationships between the main buildings on the urban plateau. An archaeo-astronomical approach was also applied to study the quite exceptional north-western orientation of the Temple of Vigna Parrocchiale, dating back to the beginning of the fifth century BC, with respect to the monumental tumuli of the Banditaccia necropolis.

Integration is the true novelty introduced by GIS systems. Not only did they act as a repository for methods and models already tested in archaeological computing, but they were expected to perform an interdisciplinary design task, fully responding to the needs of archaeologists, geographers, architects, geologists, and geophysicists. It was the first time in the history of archaeological computing that technol-

15 "Methodological Problems and Future Perspectives in the Application of GIS in Archaeology", special issue, *Archeologia e Calcolatori*, 9, 1998.

16 A systematic bibliographic survey, conducted in the following years as a further check, allowed us to closely analyse GIS developments in archaeology (Moscati, Tagliamonte 2002).

ogy succeeded in breaking new ground, introducing an unprecedented theoretical model inspired by global archaeology, combining all available research practices for a thorough investigation of the past.

For these reasons, the architecture of the *Caere* project[17] was presented at the international conference *I modelli nella ricerca archeologica* (2003), which was organised in 2000 by the Centro Linceo and inaugurated by Jean-Claude Gardin's brilliant remarks (Gardin 2003). Our intent was to illustrate the tripartite model we had embraced as a conceptual paradigm: the 'data model', aimed at outlining the structure of archaeological data; the 'theoretical model', aimed at processing the data in order to interpret them; and finally, the 'digital model', aimed at formalising traditional research processes through the interaction of the two above-mentioned models (Moscati 2003).

In addition, the *Caere* project provided a new model for excavation data recording, based on the encoding of the yearly excavation diaries in a hypertext format and aimed at recreating the main phases of the archaeologist's field 'readings' in a digital environment and in an interactive manner, in order to associate both data documentation and data interpretation to the archaeological stratigraphic sequence. The transformation of excavation reports into electronic documents, thanks to the use of markup languages, led to a process capable of semantically encoding the entire excavation activity that had been described in a natural language: the daily account of the excavation process, specific problems to be solved, and suggestions proposed by the archaeologists. After all, it was a formalised experience of storytelling, in which the system had the capacity to recover not only words but also stratigraphic records and conceptual interpretations.

The adoption of the Standard Generalized Markup Language (SGML) and the relevant Document Type Definition (DTD) brings us back, once more, to Orlandi's words in the 1991 conference: a semantic tagging system for data structuring and description, generally applied to text analysis, was the only one capable of exploiting data in highly differentiated research areas. During the conference, for example, a similar approach was illustrated by Manfred Thaller in the historical research sphere (Thaller 1993).

17 For the methodological and technical aspects of the project, see the insert published in vol. 12 (2001) of the journal *Archeologia e Calcolatori*, with an introduction by P. Moscati (2001) and contributions by I. Bonincontro, C. Barchesi, S. Mariotti and L. Ceccarelli: `http://www.archcalc.cnr.it/journal/idyear.php?IDyear=2001-01-01`.

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5.3 Integration as a Way to Interactivity, Hyper-mediality, and Connectivity: The Dissemination of Archaeological Knowledge

The *Caere* project opened up a new research season fostering and enhancing the relationship between archaeology and the 'information society'. In the annual research conference jointly organised by the Academy and the CNR in 1996, one of the roundtables addressed the theme of *Multimedialità, tecnologia, società* (Orlandi 1998), fostering a new concept of multimedia systems, as an unprecedented environment where computer science did play a central role not only in media integration, but also in scholarship integration.

In archaeology, multimedia systems were reported as being mainly oriented towards document integration, encouraging cross-reference reading, establishing information interconnection, as well as enhancing the audio-visual experience. Hypertext representation provided an intellectual innovative niche in the context of interactive technologies: dynamic models for data storage and retrieval were fostered, and interactive visualisation techniques, capable of creating and animating real-time 3D environments, were soon deployed in an interdisciplinary endeavour, supported by specialists in neuroscience and cognitive science alike.

The concept of languages, as formal models designed to represent archaeological data, was consolidated and its relevance became self-evident in all sectors of computer applications. In the information society, languages used in cultural communication should embrace three key concepts: interactivity, hyper-mediality, and connectivity. In addition, web-based technologies should be directed towards a process of integration into a global system of data representation and knowledge 'socialisation'. In 2004, the research team of *Archeologia e Calcolatori* launched a call for papers for a new special issue with a self-revealing title: "New Frontiers of Archaeological Research: Languages, Communication, Information Technology". The call, which was widely recognised within the international scientific community, read as follows:

> The problem of language, together with that of descriptive standards, which characterised the pioneering work of scholars who approached the computer recording and classification of archaeological data, is significantly back under discussion in light of today's consolidated growth of multimedia communication, which takes full advantage of the web as a transmission tool and makes use of international standards for data encoding, thus solving old problems in innovative ways.

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The organisation of the special issue into six sections reflected a new scholarship systematisation: i) writing or rewriting archaeology; ii) languages, standards and metadata; iii) data encoding, formalisation and analysis; iv) between time and space; v) from reality to virtuality; vi) communicating archaeology through the web. Formal languages and metalanguages were undoubtedly the predominant theme upon which contributions were centred. Thanks to the publication of over thirty papers, the debate evolved in parallel: the interaction between theoretical thinking and data processing techniques; the relationship between natural and formal languages in the analysis of archaeological data; the role of languages to simultaneously provide for the encoding, interaction, exchange, transmission and exploitation of archaeological data, as a vehicle for transforming documents into a source of structured and integrated information.

At the onset of the new millennium, the end results of the *Caere* project – in particular the cognitive aspects of electronic text processing and the impact of interactive multimedia strategies – led us to closely investigate two separate research foci: the role of digital repositories in the cultural heritage setting and the impact of archaeological data dissemination and sharing. Once again, the first focus was intertwined with the activities carried out by the Centro Linceo. In the framework of the international conference *Archivi informatici per il patrimonio culturale* (2006), the information recording of and extraction from unstructured or semi-structured archaeological texts (Moscati 2006) answered well the question on the difference between born-digital record collections and documents that need a smooth transition from the 'identification of the document' – i.e. the recognition of its nature – to its storage in digital form (Orlandi 2006).

As for the use of interactive multimedia techniques, not only for research purposes but also for data dissemination in virtual environments, in 1997 the journal *Archeologia e Calcolatori* inaugurated the supplement series with a specific research theme on "Virtual Museums and Archaeology", in order to evaluate and test the effects of Virtual Reality techniques on cultural transmission and education. As part of the CNR activity, and as a sign of our genuine commitment towards virtual musealisation, a project dedicated to reunification and recontextualisation of the grave goods found in a princely tomb of the Sabine necropolis of Colle del Forno was illustrated (Emiliozzi, Moscati, Santoro 2007).

The tomb was excavated in the early seventies and shamefully was found already looted. The grave goods – at the time exhibited in two different Museums, the Ny Carlsberg Glyptotek in Copenhagen and the Fara in Sabina archaeological museum, and now returned to Italy – were fully recontextualised. Moreover, the virtual restoration and the 3D representation of the princely cart, with its magnificent bronze sheets, allowed us to work in a virtual laboratory, replicating the workshop of an ancient craftsman, and to show the

beauty of this masterpiece, dating back to the end of the seventh century BC. This working environment fulfilled both scientific enquiry and dissemination purposes, taking into account expert scholars and visitors' requirements alike.

6 Digital Archaeology and Heritage Science

The application of standards, metadata and markup languages to managing, preserving, and giving continuous access to electronic resources drew our attention to the cyberspace, where contents can be re-conceived in accordance with communication and education strategies. As a consequence, two broader projects were launched with the idea to fully integrate them with key research policies and development areas that feature the future progress of digital archaeology.

6.1 The Open Science Paradigm

In 2005 *Archeologia e Calcolatori* joined the Open Archives Initiative (Barchesi 2019). Over time, the choice to provide a scholarly forum for promoting Open Science has allowed the journal to offer a better insight into the nature of data and its interoperability and to foster the sharing of archaeological open data collections in a digital environment. Today, the Journal is an active protagonist in the debate on FAIR and LOD principles, cooperating in initiatives aimed at aggregating cultural and scientific digital contents, such as CulturaItalia and Europeana. Since December 2020, the Journal is also data provider of OpenAIRE, the Open Access Infrastructure for Research in Europe (Piergrossi, Rossi 2019).

This approach, currently supported by the CNR-ISPC research group supervising the Open Data, Open Knowledge, Open Science Laboratory,[18] blends with the recent trend of merging digital archaeology into the broader scope of Digital Cultural Heritage and Heritage Science,[19] with the general aim of creating common platforms – or infrastructures – in which to share data, digital tools and services. Archaeology is thus moving towards embracing the solutions envisaged at national and European level for the digitisation of cultural heritage, with the aim of achieving common objectives and planning a census and preservation programme.

18 https://www.ispc.cnr.it/it_it/2020/05/14/gruppo-open-data/.

19 The term was first introduced in 2006: Science and Heritage, 9th Report of Session 2005-06, House of Lords, Science and Technology Committee, HL Paper 256 (https://publications.parliament.uk/pa/ld200506/ldselect/ldsctech/256/256.pdf).

In order to facilitate interoperability between existing open digital repositories, European e-infrastructures are designed to intensify the dissemination and sharing of large integrated datasets – in essence the 'big data movement' – recorded over a long period of time and stored in ad hoc digital repositories. Open Science, therefore, is a 'multidimensional' challenge, whose goal is to unify, or merge, diversified resources by employing integrated approaches and competencies, in accordance with some research priorities that are often set out at governmental level with a keen eye on the stakeholders' needs and financial priorities.

6.2 Public Archaeology and the Education Strategies

Since 2010, we have concentrated on a research project dedicated to the History of Archaeological Computing. The idea behind this project took shape during the international symposium *La nascita dell'informatica archeologica*, held in Rome at the Accademia Nazionale dei Lincei in 2008 and published in the 20th issue of *Archeologia e Calcolatori*. The Virtual Museum of Archaeological Computing, jointly promoted by the CNR and the Accademia dei Lincei, is currently in progress with the specific aim of reflecting upon the history of archaeological computing, going back to the earliest applications and reassessing their theoretical basis, which had been overshadowed by the exponential growth of technology.

The aim of the Museum is to give access to published and unpublished resources (archival documents, bibliographies, specialised books and series, reports, interviews…) that can shed light on the association between computing and archaeology from an epistemological perspective. The project has already been widely illustrated, with all its theoretical and methodological implications and a special focus on the documents coming from the Fonds Jean-Claude Gardin kept in Nanterre at the Service des Archives of the Maison Archéologie et Ethnologie, René-Ginouvès, now Maison des Sciences de l'Homme Mondes (Moscati, Orlandi 2019).[20]

What we want to emphasise here is the educational function of the museum environment, in which we have been directly involved in an attempt to provide a new narrative, unfolding along interactive itineraries. Great importance is placed on educating young people on the systematic use of electronic resources freely accessible on-

20 The web pages dedicated to Jean-Claude Gardin in the virtual museum give access, among other documents, to the reports on the establishment at the end of the fifties of the Centre Mécanographique de Documentation Archéologique, then Centre d'Analyse documentaire pour l'archéologie (Moscati 2013).

line and on the critical assessment of current audience development strategies planned to enhance the relationship between cultural organisations and a wider public, being it defined as public archaeology, community archaeology, participatory archaeology or, more in general, citizen humanities.[21]

Some multimedia itineraries, all under the umbrella of a major container entitled *Engaging Young People: Social Media, Interactivity and Museums*, focus on their involvement in cultural activities.[22] Texts were written by students at classical high schools and by undergraduate students, who were asked to reflect upon the usefulness of interactive tools in museums (digital platforms, video applications, archaeogaming) and on the role of social media as a successful method for audience capture and development. This experiment has laid the foundations for a new research proposal, intended to create customised educational paths, supporting distance learning programmes and promoting knowledge sharing and enjoyment. By encouraging a dialogue between young people and the research community, specific attention has been paid not to stifle students' knowledge but to familiarise them with the Open Science paradigm.

7 Conclusion

Today, digital archaeology is strictly associated to the routine adoption of cutting-edge technologies and to the pervasiveness of digitisation strategies in all phases of archaeological investigation (Djindjian 2019). Therefore, it is primarily aligned with technological advances and fully in harmony with the European advisory policy to develop Digital Cultural Heritage initiatives and to improve STEM (Science, Technology, Engineering and Mathematics) skills in the cultural heritage domain.

As we have illustrated in the previous sections, the role of 'integration' was at the heart of archaeological computing, while the concept of 'fusion' has spread in recent years as a global resource management model, which combines the methods of archaeology with the objectives of Heritage Science and with a focus on digital and public humanities. Whenever the term fusion is used to reinforce the concept of complementarities between disciplines, archaeologists can be considered among the protagonists of this transformation that pro-

21 According to Heinisch 2020 "While the digital humanities provide the citizen humanities with data, tools, techniques and infrastructures […] the public humanities offer the means of communication and ways of engaging diverse publics in research activities" (144).

22 The itinerary is published in the following section: `http://archaeologicalcomputing.cnr.it/itineraries/category/techniques/`.

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motes a new 'infrastructure' philosophy, based on integrated systems that embody the responsible planning and management of common resources (Wright, Richards 2018).

Computational archaeologists, as other digital humanists, have a much more difficult task to perform than in the past as they are supposed to facilitate the dialogue between experts, to introduce new research objectives, to become software engineers, and to assume a preeminent role in society, with a careful eye on preservation and prevention. As a consequence, they will increasingly deal with new paradigms, in which Artificial Intelligence and Machine Learning algorithms are deployed within large-scale research infrastructures.

Overall, this process of blending disciplines is such that cultural and economic outcomes will likely be impressive. Nonetheless, the scholarly boundaries – whether they relate to archaeology or computational archaeology – are progressively blurring. Therefore, a careful attention should be drawn to the risk of creating an "impoverished uniformity of interdisciplinarity" (Liu 2008, 178) and, at the same time, a serious and misleading gap between archaeological research that is increasingly fine-tuning its own methods, and data storing, sharing and dissemination that are expanding the network of knowledge.

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