The Archeology Field in the Mobile Era: A Roadmap to Catch-up

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Abstract—The field of archeology is undoubtedly left behind in the mobile era compared to other scientific domains. The deployment of mobile technology solutions is of meagre contribution to the field. In fact, almost no mobile apps are designed as per archeologists' work requirements in the excavation site. This study aims to tackle this dilemma through a roadmap to pave the way for the community to recover this digital divide. The roadmap encompasses a comprehensive methodology on how to develop mobile apps that meet the requirements of its respective audience. The development of two apps is introduced to illustrate the implementation of the methodology. The result of adopting this 'roadmap' study improves the data collection, processing and usage. It enhances information accuracy and sharing. Besides, it reduces the 'destructive' aspect of the archeology investigations and provides archeologists with handy solutions that they can use ubiquitously. The refinement of the first versions of mobile apps for archeology will make the measurements more accurate and improve the level of maturity of the field vis-à-vis the mobile technology sector. Most significantly, this study opens the door, eventually, for a new era wherein the community starts by deploying mobile technology solutions to ultimately go beyond the current dating techniques, such as the radiocarbon dating method. An ultimate future work could be the exploration of developing mobile apps, in an interdisciplinary context, that measure the age of archeological items by few clicks and prepare the field for the forthcoming post-device era.

Keywords—Archeology Field, Mobile Applications, Radiocarbon

1 Introduction

Archaeology is the exploration of the history of humanity through the retrieval and study of human and material relics, artefacts, ruins, habitat data and cultural landscapes to understand who we are and where we came from. "Archeology is more than a rear-view mirror: the lessons of the past are critical to inform wise choices for the future" D. Peebles said. It is the main source of information for prehistory. "Prehistory includes the whole time-span of human existence, and addresses fundamental questions about human evolution and the emergence of human society. It is within prehistory that archaeologists play the key role, developing ways of interpreting the material record without reference to written texts" [1]. The archeology field includes site surveying and excavation, as well as data analyses to further know our past. To attribute to an artefact a date in the past, archeologists use the process of chronological dating, which often involves what is usually called dating methods. These methods have mainly two categories: relative dating and absolute dating.

Relative dating assumes the age of an object by comparison and in relation with other artefacts found in the same excavation site. With respect to the last century, relative dating was the main method to determine the age of an archeological artefact. Archeologists inspected the artefact's connection to the layers of deposits in the site, and then they compared it to other objects at that site. Although still vigorously utilized, relative dating is presently enhanced by few current dating techniques. The likely blemishes in relative dating are self-evident. Basically, accepting that an object is older because it was found at lower layers in the site is just a superficial personal interpretation. For instance, geographic phenomena, such as earthquakes and avalanches can totally change the geology of an archeological site covering the top layer by an older one, which consequently turns around the strata layers. Absolute dating is a more novel and accurate dating method than relative dating. In most cases, it can define a specific date for an archeological item. Since last century, archeologists have witnessed a radical change in the dating techniques thanks to this method. Absolute dating depends highly on laboratory analysis. As the Arabic proverb goes "The calamities of some people, to others are blessings", the nuclear research efforts in the Second World War triggered several dating techniques in the archeology field that are categorized under two main ways of measuring the items' age: relative dating and absolute dating. One of the most adopted archeological dating techniques is the radiocarbon dating method. Renfrew named it 'the radiocarbon revolution' to describe its influence on human sciences "Radiocarbon dating has been one of the most significant discoveries in 20th century science" [2]. Oakley [3] suggested that its invention implied a nearly entire re-writing of human being evolution and ethnic appearance. In Clark's [4] statement about radiocarbon, "we would still be foundering in a sea of imprecisions sometime bred of inspired guesswork but more often of imaginative speculation".

In the same as all human being activities, the usage of computers and software has invaded the domain of Archeology. As the saying goes, "Software is everywhere". No wonder today archeologists are using computers in every phase of archeological activities; however, compared with other sectors such as the health sector, the deployment of computers and software in the archeology sector is erratic, missing standards and lacking industrial and academic publications. Adding fuel to fire, despite the massive penetration of the mobile phone and its application in human being life as shown in the figures below, unfortunately, the development of mobile apps as per archeologists' needs is of a meager nature. There are almost no Apps that tackle properly the archeological site activities. Ironically, there is no concept called "mArcheology" such as "mHealth"; mHealth or m-health is an abbreviation for mobile health, a term used for the practice of medicine and public health supported by mobile devices" [5]. Figure .1 below is an interesting illustration of the importance of mobile users and mobile connections worldwide, which can be great media for archeologists to share their information among the community and to disseminate the field achievements.

Mobile Applications or mobile apps are setting off an essential move in the way individuals deal with information processing and cell phone usage. A few decades ago, people used mobile phones just for calling. Today, cell phones provide remarkable computing power ubiquitously. Figure 2 presents Statista's forecast for the mobile apps downloads number, in billions, worldwide for 2016, 2017 and 2021 [7].

Equipped with a variety of sensors, strong computing performance, and carried with people everywhere they go, mobile phones promise to transform the Archeology field. These handheld devices can store tremendous amounts of data. When processed, these pieces of information can possibly open new windows of knowledge for more investigation into archeological sites.

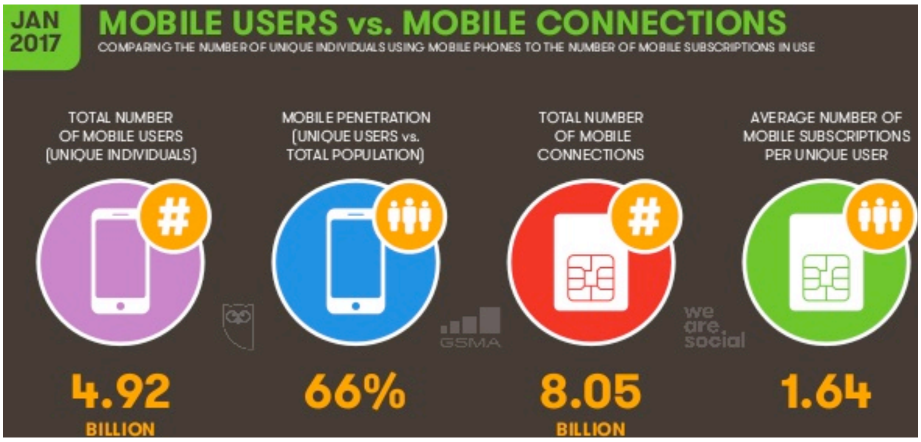

Fig. 1. Mobile Users versus Mobile Connections [6]

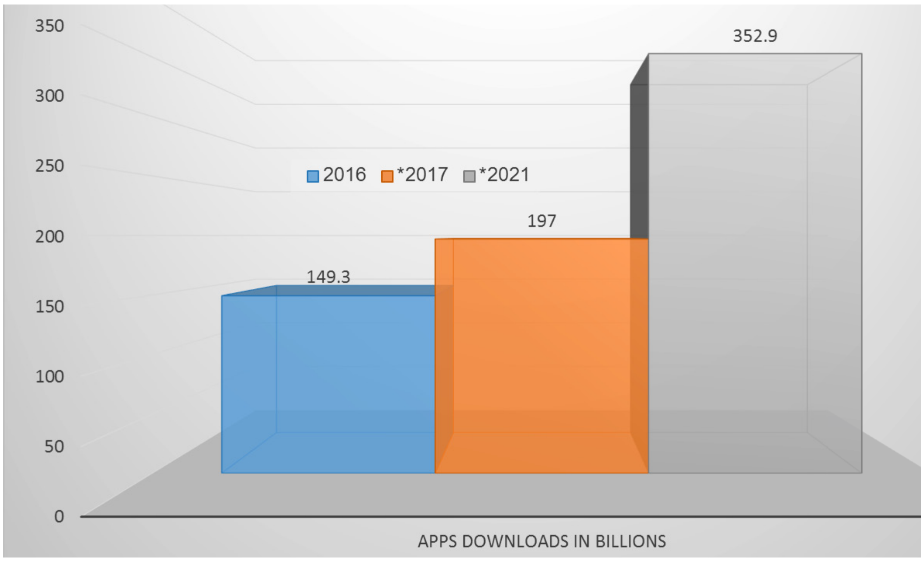

Fig. 2. Mobile App download number, in billions, worldwide for 2016, 2017 and 2021 [7]

The main contribution of this paper is to explore the possibility of drawing a roadmap for developing mobile apps to facilitate archeologists' activities during their sites' visits. The rest of this paper is organized as follows: The second section presents the previous literature related to the problem of statement. The paper demonstrates the methodology adopted in section 3. The results and discussions of this study are presented in section 4. Section 5 briefs the conclusion and highlights future work directions.

2 Literature review

This section discusses the previous literature that is related to the use of computers and mobile apps in the Archeology arena, as well as a standout amongst the most widely used methods in archaeology, which is radiocarbon dating.

2.1 Archeology and Information Technology

Archaeologists are surrounded by an extensively diversified information technology infrastructure. This context has created the notion of computational archaeology. It calls for analytical methods using computer solutions to study long-term humans' comportment and the evolution of their behavior. It is called Archeological Informatics, as well. Since Burenhult and Göran said in 2002 "Being an emerging field of research, Archeological Informatics science is currently a rather dispersed discipline in need of stronger, well-funded and institutionalized embedding" [8], frivolous progress has been recorded in this discipline. It is still suffering from erratic deployment of computer solutions. For the last three decades, archeologists have been using computers mainly for data management. In the beginning, computers were used for conventional database management and numerical analysis. With the dawn of microcomputers, their application has extended. Nowadays, scientists use computers in each phase of archeological undertakings to perform three noteworthy activities: data gathering, data analysis and data presentation.

Computer-based data gathering techniques comprise the usage of digital calipers and apparatus to measure artefacts' sizes, video imaging solutions to quantify surface territory and shape, and different information technology communication (ICT) devices that can record site information directly for further analysis.

Data Analysis relies upon developing and managing intricate databases for archeological information. Data from various stages of an excavation and from several sources are integrated together to draw insightful conclusions. For instance, information of an archeological site can be stored in a database that contains information about articles, which have been treated, to uncover patterns of distribution of comparable articles. The ability to enter and oversee more types of data allows progressively to introduce new theories and to test them. In addition, with the advent of digital devices that allow entering data on site, performing data analysis on the archeological sites is currently enabled to promptly guide scientists in the subsequent digging task.

Data presentation can likewise supply clear pictures of the findings as visualization instruments. Graphic programs determine perplexing stratigraphic areas directly from digital measurements carried in the site. Images can be treated and color-coded to focus on specific attributes. Artefacts' patterns distribution turned out to be quickly detected, which can suggest how artefacts were saved, or how they may have been utilized.

The benefits of digital systems for the archeology arena are countless. Computers automate a great part of the conventional procedure of recording site information, increase the usage of data accumulated and drastically reduce mistakes. Conventional strategies for recording artefact areas include manual measuring. Using a computer, archeologists can rapidly perform numerous measurements to build an outline of every substantial item in situ. The precision of measurement, position and alignment calculated with computers, is unachievable manually. The characteristic of exposing error by emphasizing anomalous aspects is another strength of digital systems in addition to the access within seconds to relevant information in detail. The ability to analyze each day's work immediately, combined with previous conclusions, allows the archeologists to draw a more holistic view of the findings, which appear most promising.

Integration is the key to take full advantage of mobile technology. Integrating data from different phases of a project, from several archeological sites and many scientists is the potential of mobile technology systems that can carry fast and accurate measurements. Manual measurements reduce the number of parameters people can record and limit the analysis they can do on. Mobile solutions can alleviate this limitation by restoring collected potsherds, putting together data about remains of flint tool, as well as the site's environment where they were excavated. In the archeology field, even nowadays, these tasks are carried through manual experimentations over long periods.

The procedure for interpretation needs cautious examination of excavation records; the settings of the items are as imperative to a clear discernment as the items themselves. The significance of setting for an archeologist highlights the significance of accurate records. Those records are vital for the field, and the exceptional effectiveness of mobile technology for that recordkeeping is clear today. Thus, if mobile can be used to store and process a lot of data on which archeologists shape their comprehension of the past, all experts should at last have the capacity to use mobile devices to access those data. Information technology skills, namely, are required for all archeologists if a considerable part of the archeological information is kept in digital format.

The pace of the creation of new technology is speedy. Here are few technologies that can be largely used in the archeology discipline: the key potential of computer-assisted design (CAD) is its aptitude to store and process 3-D data. Deployed through mobile apps, it can generate onsite 3-D drawings based on the geometry of location. With the advent of mobile technology and modern surveying instruments, CAD can now model more complex 3-D representations for archeological records onsite.

Virtual reality and augmented reality are computer-based techniques capable to provide a more realistic view of archeological sites where users can navigate through, while working in the site.

The most used concept of information technology in archeology is the website. Several websites display different information about archeology and related disciplines. Few of them, present large-scale developed datasets, such as, the Archeological Settlements of Turkey (TAY) Project: http://tayproject.org/ [9]. It was "set up to build a chronological inventory of findings for the cultural heritage of Turkey - an important component of World Heritage sites - and to share this information with the international community" [9]. The National Archaeological Database is another useful website. It is an electronic communications network for the community of historic and archeological preservation. It was built up to enhance the access to archeological activities information across the country. The Archeology Program National Park Service in the United States has developed this project.

The Archeological Resource Guide for Europe (AGRE: http://odur.let.rug.nl/arge), which is a "database contains links to evaluated Internet resources concerning European archaeology" [10] and the OASIS form is a "data capture form through which archeological and heritage practitioners can provide information about their investigations to local Historic Environment Records (HERs) and respective National Heritage Bodies" [11] are fruitful examples of successful assistances for researchers since they permit access to various pieces of information over a joint main point, however, without forcing impractical novel standards.

The OxCal program, from Oxford Radiocarbon Accelerator Unit Research Laboratory for Archaeology, is a computer program available online at: https://c14.arch.ox.ac.uk/login/login.php?Location=%2Foxcal%2FOxCal.html. It can also be downloaded at https://c14.arch.ox.ac.uk/oxcal.html. "It is intended to provide radiocarbon calibration and analysis of archeological and environmental chronological information" [12].

Nevertheless, there is almost no single mobile app tailored according to the archeologists' requirements. Archaeologists have used many computer solutions to mainly record data. Indeed, this is the greatest essential advantage computers have offered to archeology – the capacity to manage more information, more efficiently. Obviously, dealing with the information efficiently means getting to the information adequately, too. The Internet importance is usually overlooked when the information technology paradigm is evoked; it is taken for granted that we fail to recall. Furthermore, adding mobile apps capabilities to the Internet is a gold mine waiting for excavators. Archeology, by definition, is an international endeavor, thus, scholars are regularly collaborating on ventures while living in different countries. In this context, emails are crucial tools for communication. To reach the great public, obviously, the Web has effectively changed the degree to which researchers can and will offer their information to a wider audience.

In addition, the mobile apps have a main advantage on websites as Paley reported in 2014 "Apps can also leverage phone features that responsive websites cannot, such as location services, the phone's camera, and phone vibrations. Using these features allows an app to be more connected to a user's everyday experience with their phone in ways that a responsive website cannot" [13]. Figure 3 illustrates the comparison between websites and apps.

Fig. 3. Comparison between websites and apps [13]

A smartphone camera can supply a walking gamma ray detector. No need for extra devices, smartphones now can warn people if they are approaching a gamma radiation zone. Researchers at Idaho National Laboratory developed an Android app called CellRAD [14]. The App turns mobile phones' camera into radiation detectors. It is tested with four mobile devices: Samsung Nexus S, Samsung SIII, Samsung Galaxy Nexus and LG Nexus 4.

Therefore, with their integrated cameras, smartphones can discover gamma radiation and even measure its level of radiation. The advent of web services has allowed the app to detect the radiation and send the information to a remote server. The server performs the required processing to determine which kind of radioactive substance could emit the radiation. This mobile app is chiefly a pocket radiation detector [15]. Mobile phones can detect infrared radiation, as well, which is an invisible part of the electromagnetic spectrum. In addition, Mobile phones can display the physics of electromagnetic waves and process them.

Beta Analytic launched mobile app "BETA App users can now consult their carbon-14 results and quality assurance reports, access sample collection and submittal advice, and contact the company's global team for prices and technical support directly from the app" [16]. This free mobile app is developed for Android 4.0 and iOS 7.0 and higher. The mobile device should have a PDF viewer to open the App reports. However, the worldwide community of archeology has only one international organization in relation with the computing field, which is the Computer Applications and Quantitative Methods in Archaeology (CAA) that brings "together archaeologists, mathematicians and computer scientists. Its aims are to encourage communication between these disciplines, to provide a survey of present work in the field and to stimulate discussion and future progress" [17] and three International Journals in the Field of Archaeology and Information Technology, which are "Internet Archaeology", "Digital Applications in Archaeology and Cultural Heritage" and "Archeologia E Calcolatori" [18]. Thus, the archeology has specific and noticeable impediments to relish the power of mobile apps.

2.2 Unique Obstacles for Deploying Digital Solutions in the Archeology Field

Alike archaeologists operate in the same areas, they do not use the exact terminology, methods and processes. Thus, consolidating information from many projects continues to be an elusive objective. Endeavors to force normalization among different groups of researchers have done small achievements. The difference between the necessities of the archeological groups and those of history experts has exacerbated the difficulties with standard terms and information structures.

Archaeologists and the museum conservators who eventually collect the excavated items register their data about those items in diverse approaches, the former use the excavation milieu and the latter exhibit the cultural categorization aspect. Hence, the two groups' databases are differently organized, which renders collaboration more problematic.

The gap is an issue of learning rather than of age; young researchers have ample computer skills. However, those who appear computer shrewd unequivocally need the aptitudes most required for archeological computing such as mobile apps development for the archeological sites. Although computers are now used in all archeology phases, the project managers may lack the required proficiency to use the available technology. No guarantee that future archeologists will have the capacity to use the computerized information currently available in the field. Unluckily, proficient individuals in information technology are frequently self-educated, even though any concepts are well taught by specialists who comprehend the issues and difficulties that are probably going to be experienced.

The issue of self-educated or untrained people in mobile technology is rarely perceived or recognized in the archeology discipline. To an extent, archeologists have not understood that they require at least the knowledge to query databases, computer aided design models or datasets from a mobile app. The lack of professional training represents a genuine obstacle to both, practical use of mobile technology and the re-use of information stored in digital devices.

Regardless of the remarkable changes that information technology has introduced to the field, the change from paper-based to computerized processing is yet fragmented. The field has not completely digested the need to ensure access to mobile era for future researchers around the world. It has not yet figured out a powerful and moderately standard approach to introduce mobile technology as a major aspect to be ready for the coming era, which the post-device era. Its academic establishments have not acknowledged the need to demystify the mobile technology to all archeologists and to highlight the mobile era opportunities to their communities. To some extent, these issues mirror the discipline's status towards the mobile technology, a particularly divided one comprising professionals who may have started as historians, specialists in early languages or socialists – yet not as researchers relying on a convention of quick and complete information sharing. These issues reflect, furthermore, the interesting autonomy of archeologists, who must have a solid entrepreneurial approach with a specific end goal to subsidize and work complex activities. Until these issues are resolved, a consolidated effort to develop and implement a roadmap to catch-up in the mobile era is a must. Otherwise, the archeology field will not only be left-behind in the mobile era, but also require double efforts to cope with the post-device era. "We are entering a Post-Device, Service-led era. The future of computing seems to be about a set of platform and device-independent services", as stated by O'Donnell [19].

2.3 Radiocarbon Dating

A standout amongst the most used and well-known methods to date organic remains is called the radiocarbon dating technique. In 1949, Libby developed this method. It rapidly ended up noticeably a standout amongst the most generally utilized techniques in archeological studies. It has profoundly affected the archeology field, frequently portrayed as the radiocarbon shift. Taylor said [20] "14C data made a world prehistory possible by contributing a time scale that transcends local, regional and continental boundaries". Space radiation generates neutrons that penetrate the atmosphere of our planet. They react with nitrogen to deliver the carbon isotope C14 [21-24]. Figure 4 below illustrates how the method "14C is produced in the atmosphere by cosmic neutrons colliding with Nitrogen atoms. The newly formed 14C is oxidized to 14CO2 where it then penetrates the biosphere. Following an organism death, radioactive decay occurs converting the 14C back to 14N" [25]. The purpose of this paper does not allow a thorough explanation of the radiocarbon dating technique; however, a comprehensive review of the technique was issued by Ramsey [26].

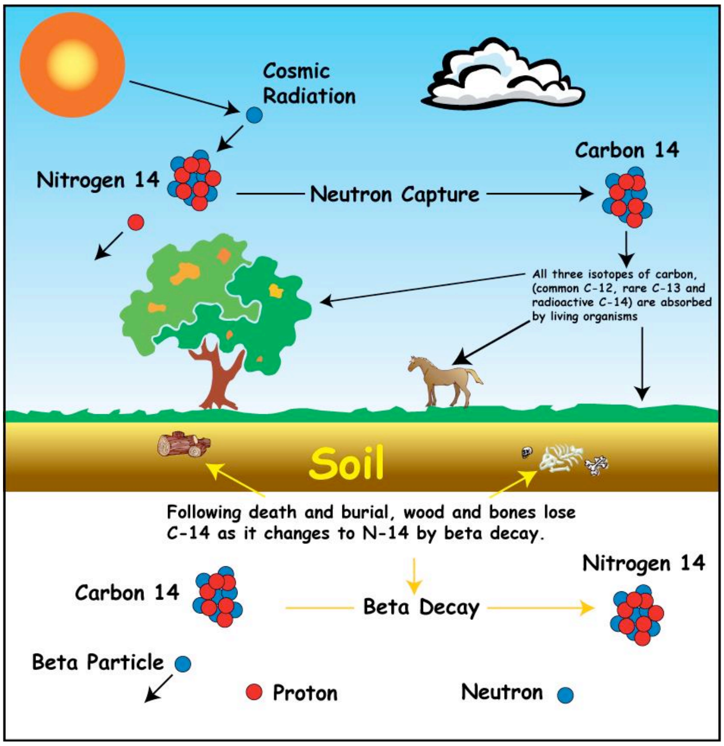

Fig. 4. The process of C14 production and decay [25].

To measure the quantity of C14 in an archeological item, three main methods can carry this task: accelerator mass spectrometry, liquid scintillation counting and gas proportional counting.

Gas proportional counting is a "conventional radiometric dating technique that counts the beta particles emitted by a given sample. Beta particles are products of radiocarbon decay" [27]. In the liquid scintillation method "the sample is in liquid form and a scintillator is added. This scintillator produces a flash of light when it interacts with a beta particle. A vial with a sample is passed between two photomultipliers, and only when both devices register the flash of light that a count is made" [27]. The accelerator mass spectrometer (AMS) is an innovative method of radiocarbon dating that scientists have developed recently. AMS is a "modern radiocarbon dating method that is considered to be the most efficient way to measure radiocarbon content of a sample. In this method, the carbon 14 content is directly measured relative to the carbon 12 and carbon 13 present. The method does not count beta particles but counts the number of carbon atoms present in the sample and the proportion of the isotopes" [28]. This method can measure the ages of archeological items as tiny as a small piece of a tooth or a fragment of metal inside a human carcass. It may estimate artefacts' ages up to a thousand of centuries old. Since AMS can measure the age of tiny and confined items, its results can be more precise than other radiocarbon dating methods. Scientists worldwide agree that radiocarbon methods provide ages' approximations with error margins. The margins increase with the artefacts' ages. However, for a few thousand years old artefacts, the radiocarbon dates can be more accurate with the usage of dates from tree rings' analysis. Since archeologists depend on the radiocarbon dating method, it is important to comprehend its restrictions and how the findings can be misinterpreted. The radiocarbon method is not an age teller; it is an approximation of artefacts' ages using the radioactive carbon concept in a deceased body.

The greatest limitation of radiocarbon is "the simple fact that the amount of radiocarbon in the atmosphere fluctuates through time" [29]. In addition, conducting the radiocarbon method in laboratories has its costs and consumes time.

Moreover, scientists must make sure that the radiocarbon dating results can answer the questions raised at the beginning of the entire process. The relationship between the archeological artefacts and their digging site is not very forthright. For instance, it is unprecise to link wood samples, which have already stopped interacting with the biosphere, with the age of their archeological site. There are additional situations wherein the relationship between the specimen and the excavation site is not evident or effortlessly caught on. Researchers must pay great attention when they link an archeological artefact context to an event context of the same site using the radiocarbon dating method.

Archaeologists should likewise ensure that only suitable samples are collected and treated for radiocarbon dating, not each item found in the site. However, the ubiquitous mobile technology infrastructure can help a great deal to overcome several limitations in the archeology filed.

3 Methodology

Archeology nurtures the understanding of our origin through its study of the evolution of human beings. Archaeologists have a consensus, i.e. determining the age of an artefact is difficult. However, although it is intractable to dissect the details of one life, the task to find out fossils and artefacts' age is significantly improved by means of several dating methods. They have a wide range of chemical, radio-metric and electro-magnetic methods for dating that at hand to precisely date items that are only a couple of hundred years of age and artefacts that are a couple of million years of age with good precision in the right conditions. The advent of mobile technology can help carrying these methods more accurately, onsite and faster. Another issue with dating an item from an archeologic site is that almost each dating procedure requires the destruction of no less than a part of the item to conduct the study. Unfortunately, archeology is a destructive discipline; once the excavation started, the site is gone for good. In addition, lab experiments are part of any archeology study. As illustrated below, the post-excavation analysis is usually the most time-consuming part of an archeological investigation, which consists of lab experimentations. Hence, at this stage, the mobile app can play a real time-saver role, besides other previously mentioned advantages, namely being a non-destructive tool.

This section describes the steps of the methodology used to achieve the roadmap and reduce the digital divide that the archeology suffers from compared to other fields.

3.1 Step1: Determine the archeological study stage wherein the mobile app is deployed

An archeological exploration typically encompasses numerous different stages, each of which uses its own methods. Before starting any real-world work, archeologists must agree upon a clear objective for their exploration. Once a consensus has been approved, the following series of subsequent activities is initiated:

1. Remote sensing: to locate the sites for exploration.
2. Field survey: is a field of study to find archeological sites and gather data about them, as well as about the spreading and arrangement of ancient human civilizations within a vast zone.
3. Excavation: It is the digging, finding, preparing and recording of archeological items, and it is the origin of most of information recuperated in many on-site activities. On the other hand, it is the costliest stage of archeological exploration. Additionally, as a ruinous procedure, it brings ethical concerns.
4. Analysis: After the collection of the items from the excavation site, the analysis phase takes place. This phase is often the lengthiest part of an archeological study. The results of this phase may take years to be disseminated.
5. Virtual Archeology: Computer representations are currently used to assemble virtual 3D models to provide simulations of archeological sites. This is an area where the archeology field is using the power of computers and digital devices.

Unmanned Aerial Vehicle (UAV), called drone as well, is an aircraft system without a pilot on board. These days, archaeologists worldwide are using drones to expedite survey work and preserve sites from any work that may demolish them. By means of mobile apps, specialists can develop a virtual site on a mobile phone for prompt analysis. For instance, the Geographic Information Systems (GIS) help archeologists in making accurate surveys of main sites and in rebuilding the detailed plans of ruins down to complex architectural structure. One of the aspects of bringing computational data analysis is to introduce digital processing into it. Using digital technology like mobile apps in the archeology investigations can reveal interesting information with a least of excavating and a small number of people.

3.2 Step 2: Recommend the development of a mobile app for a specific dating method

Today, many archeologists work with dedicated groups of prepared excavators and with researchers from different sectors who have practical experience in ancient civilizations. Nevertheless, the cooperation between archeologists and mobile apps developers is unnoticeable. Thus, to bridge the gap between these two categories of professionals, below is a non-exhaustive list of the two primary dating methods where both categories of experts can talk to determine where the development of mobile apps can make a difference in the archeology field.

Table 1. Non-exhaustive list of two primary dating methods

Relative dating	Absolute dating
1. Cross-cutting relationships	1. Amino acid dating
2. Fluorine absorption dating	2. Archaeomagnetic dating
3. Harris matrix	3. Argon–argon dating
4. Law of included fragments	4. Cementochronology
5. Law of superposition	5. Datestone
6. Lead corrosion dating	6. Dendrochronology
7. Marine isotope	7. Fission track dating
8. Melt inclusions	8. Herbchronology
9. Morphology	9. Iodine-xenon dating
10. Nitrogen dating	10. Lead–lead dating
11. Paleomagnetism	11. Luminescence dating
12. Paleopalynology	12. Molecular clock
13. Palynology	13. Obsidian hydration dating
14. Principle of faunal succession	14. Optically stimulated luminescence
15. Principle of lateral continuity	15. Oxidizable carbon ratio dating
16. Principle of original horizontality	16. Potassium–argon dating
17. Sequence dating	17. Radiocarbon dating
18. Seriation	18. Rehydroxylation dating
19. Tephrochronology	19. Rubidium-strontium dating
20. Typology	20. Samarium-neodymium dating
21. Varnish microlamination	21. Tephrochronology
22. Vole clock	22. Thermoluminescence dating
	23. Uranium–lead dating
	24. Uranium-thorium dating
	25. Wiggle matching

The main contribution of this study is to pave the way for interdisciplinary activities between the archeology and the mobile technology fields to prepare the archeology for the next era of computing that is the post-device era.

3.3 Step 3: Decide on the Mobile Technology Platform

Mobile app developers are responsible for choosing the right mobile technology type and platform that meet the requirements of the audience and the archeological investigation. First, it is imperative to decide the type of App that fits best the context of the study: native or hybrid. A native mobile app is probably what comes to our mind when we think of mobile apps. It is developed to a platform such as Google's Android or Apple's iOS. The main benefit of this type of app lies in the optimization of the device resources and improvement of the user experience. It is more reliable and faster since it is developed for a specific platform. The main concern it is targeting the users of one platform only. A hybrid mobile app is developed using HTML5; accordingly, it is run on a web browser. It can serve all platforms. However, it is not reliable and fast as native mobile apps. There are four main mobile technology platforms: Google's Android or Apple's iOS, BlackBerry OS or Windows Phone. The scope of this study does not encompass benchmarking them. However, it is worth mentioning that Android is the only open source software mobile technology platform. As a matter of fact, it is the most used mobile technology platform [30-35].

3.4 Step 4: Select the appropriate software application

This step consists of the selection of the right software application that meets the expectations of users and developers. There is a large number of software applications where, software developers and archeologists should collaborate, to choose the right one for a particular context. Here are few examples of software applications that researchers can apply in the field:

1. Digital Image processing: the use of computing algorithms to process and improve digital images
2. Optical Character recognition: the recognition of printed or written text within an image to convert it into computer text. It uses optical scanner and software.
3. X-Ray Analysis: An application that processes an image, which is the result of a radiation technique.
4. Hyperspectral image analysis: An emerging division of computer vision to tackle the frequent applied applications and high data complexity.
5. Radiation detector: It is a computing application that measures the radiation level in a specific location.

3.5 Step 5: Implementation of the application requirements and testing of the final product

The last step in developing mobile apps for the archeology field is the implementation of the app functional and non-functional requirements per the users' needs. Testing is necessary to ensure the quality of the apps. There are two kinds of software testing: white-box testing and black-box testing. The white-box testing should be conducted by software developers since it examines the code of the app. Archeologists can conduct the black-box testing, because it is about testing the app's functions. It assesses the current output with the expected output according to a specific set of inputs. Figure 5 below consolidates the methodology of this study.

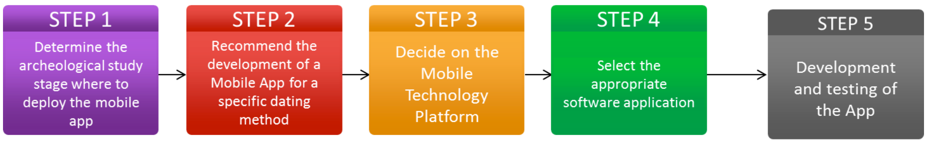

Fig. 5. The Methodology to develop a mobile app for the archeology field

4 Implementation and Results

To validate the methodology above, to participate in bringing the two communities of archeologists and developers closer, and to reduce the archeology filed digital divide, the author, with the collaboration of a group of interdisciplinary researchers, are developing two mobile apps. The two mobile apps, under development, are about Epigraphy (ultimately Paleography) and Dendrochronology. Epigraphy is "the discipline that investigates written documents inscribed on materials differing from those typically used in writing, materials that are durable and permanent, such as pottery, metal, stone and the like". Paleography is the study of ancient handwriting [36].

Dendrochronology is a science of dating using tree rings. A single tree ring is created each year in the stem of a tree in its whole life time. Through this approach each tree ring can be assigned to a specific calendar year. The inner most ring at the center corresponds to the first year while the last ring corresponds to the last growth year of the tree. A sample tree ring structure is shown in the Figure 6 as follows:

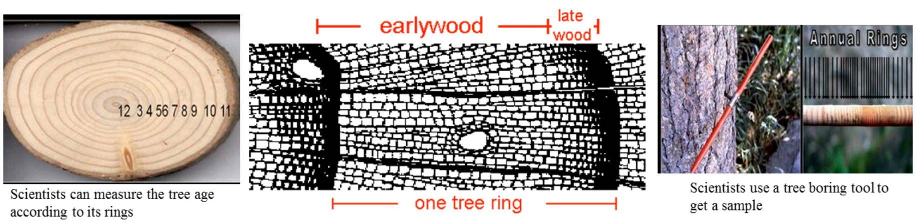

Fig. 6. Dendrochronology: The Tree-Ring Dating concept [37]

These methods involve specialized equipment and a set of calculations to measure the age of a sample. The reliability of the methods depends on the amount of time spent doing the experiments. Besides, archeologists incorporate tree rings dating to enhance their results for radiocarbon dating. This study highlights the implementation of the methodology above to develop the mobile apps. More comprehensive articles about the details of the two mobile apps' functions and their testing results are expected to be published soon. Then, more investigation can be carried out to refine the eventual issued versions of the Apps and gradually enhance them.

4.1 The Epigraphy mobile app

The Epigraphy mobile app is intended to read ancient documents using the Optical Character Recognition (OCR) software developed for mobile devices. After reading the ancient documents, the app provides a translation of the ancient text in English. Then, the user can translate it into other languages. The app is tested using the Musnad language, which is the Ancient South Arabian script. The OCR technology is available for computers. Unfortunately, no reliable OCR for mobile devices has emerged yet. In addition, the OCR engine needs will be enhanced to support multiple languages and to predict or suggest the words that are illegible on a document. Whenever needed, the app considers the paleography if the old document is handwritten. OCR technology allows a computer to look at a document, decipher the characters it detects, and transcribe them to the program to which it is associated. OCR technology can process a dense tome, like a book of records or legal jargon, and make it searchable. Developing an App for Epigraphy using OCR reduces the cross-referencing of massive source material in libraries. A quick search-and-find function will provide the exact needed part of any written material. Digitizing historical records using OCR within mobile technology makes searching through documents omnipresent, easier and faster, but it also democratizes these documents. Once a file has been digitized, it can be available online.

Without digitization of important, historical records, even timeless documents can be stained by the effects of time: Document spotting and quality compromise can negatively affect the imaging process, failing to keep documents and files from history in mint, view-able condition.

Reading ancient manuscripts which are not in good shape is another problem that could be faced. To digitally enhance the ancient copies and make them readable, it takes time to manually process each document and to get the results out of it. Translating documents is a second problem within this scope, i.e., a language expert is needed so they can correctly understand and translate them into native language if the documents are not originally in native language.

This problem can be solved by incorporating the OCR technology and using it to read the ancient manuscripts and convert them into digital information which can be interpreted later. This solution is beneficial for both archeologists and the research community related to it. People would use this handy tool to read the old manuscripts on the spot.

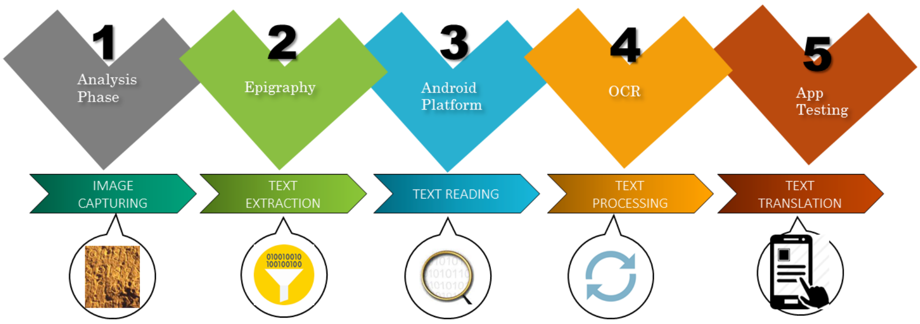

Fig. 7. Epigraphy app for Musnad language

Figure 7 displays the methodology implementation for the first version of the Epigraphy app.

4.2 The Dendroarchaeology mobile app

The Dendroarchaeology mobile app applies image processing techniques to read tree rings through a mobile application and provide an estimation of the tree age. Measuring the age of archeological items can only be calculated using specialized laboratory environment and equipment. Special training is required to carry out the experiment for date estimation. However, with the Mobile Technology, the measuring process can be faster and more precise. Reading tree rings via digital image processing would help for the calibration and cross check of the sample date. It is quite straightforward to determine the calibration of radiocarbon. Given radiocarbon estimation on a sample, scientists can look for a tree ring with a similar quantity of radiocarbon. As the tree rings' calendar age is known, this can reveal the sample's age. With extremely old trees, researchers can estimate the age of samples back to a thousand years ago. Currently, the tree ring reading is not properly available in digital format. Computer vision is a diverse area of research already acting as a base for other research areas. Dendrochronology, studying the tree rings, is one the areas that could benefit from image processing. Researchers at different research labs around the world would spend hours on examining the tree ring samples with a microscope, trying to measure ring boundaries and widths correlating this data with different other samples. This is not an easy task but it is a main source of data collection. Numerous methods are proposed to improve the tree ring detection but the accuracy is still evaluated by tree ring experts. Some of the aspects involve false rings, cracks in image, overlapping rings. Nature is a creative phenomenon and it produces different ring formations and thus there is no end to find and improve methods to detect tree rings. The computer vision-based technologies can identify the tree rings in an image to ease the data collection process.

In the dendroarchaeology app, to begin tree ring analysis, the image of a tree ring is analyzed and optimized for tree ring detection. A region of interest window traverses the image to find the proper region of rings. The image preprocessing helps in finding the rings. In this preprocessing, the image contrast is enhanced so that the lines are identified. Then, the orientation of the rings is identified and subjected to a ring detection algorithm. Rays in a tree cross-section may be confused with tree rings. The distinctive feature between rays and tree rings is that they are orthogonal to each other so that the orientation should be known. An edge detection algorithm can then be used to count the rings.

Figure 8 explains the implementation of methodology steps for the first version of the app. The second stage is to use image-processing techniques to read the tree rings through images. After counting the number of rings, an algorithm is developed, which takes into consideration the different parameters that can affect the formation of a ring within a standard timeline that is one year. Subsequently, the app displays the tree age estimation.

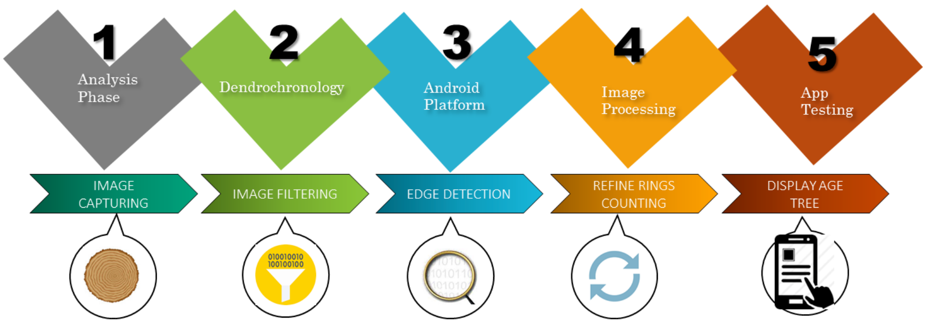

Fig. 8. Dendroarchaeology Mobile App Development steps

5 Discussions

As part of any archeology study, researchers must process the samples in the lab, clean them and ensure that there is no impurity on them that may affect the age measurement. Then, they burn the sample and submit it to a totally disinfected vacuum system as gas of carbon dioxide. The gas, afterwards, passes through additional purifying techniques. Subsequently, the gas is kept in an apparatus isolated by Mercury and Lead, to reduce the probabilities of radiations from the atmosphere that may affect the sample. Once a C14 atom disintegrates, sharp tools notice the action, control panel emits light flashes, and a counter sums the number of decomposing atoms. This technique allows scientists to determine how many atoms decay for a specific period. Mobile technology can waive archeologists from this tedious task. However, archeology has its unique concerns that impede the use of information and communication technology (ICT). For instance, the archaeologists' usage of computer applications to record their data is quite different from software developers' perception that developed these solutions. In general, developers' approaches do not usually fit academicians' expectations, and the development of academic insightful principles has been moderate and poorly engaged in the applications requirements. It is time to conduct more interdisciplinary researches; despite obstacles such as the disparate interest of scientists from different disciplines. Notwithstanding the prominence of computers and digital devices to archaeology, still few scientists are using the power of computers for the benefit of archeology. Even though researchers have raised this concern for more than 3 decades [38, 39], yet there is not enough interaction between experts in information technology concerned with the archeology field advancement and "traditional" archeologists. Such concern is diminishing with the use of mobile apps, since developing such applications is no more restricted to software developers. Another problematic issue may arise with the information abundance and the expansion of databases usage. Once archeologists utilize digital devices to view information as opposed to study the archeological items themselves, they may lose partial insight of the items that can be generated from manual examinations. However, once the field will can remedy the digital divide, it will cope better with the post-device era. Hence, the human aspect of the archeology filed will be less affected since, in this era, the digital infrastructure will be more "hidden!".

Mobile phones are ever-present in almost all human being activities. Its growth, as illustrated below (Figure .9), went beyond expectations.

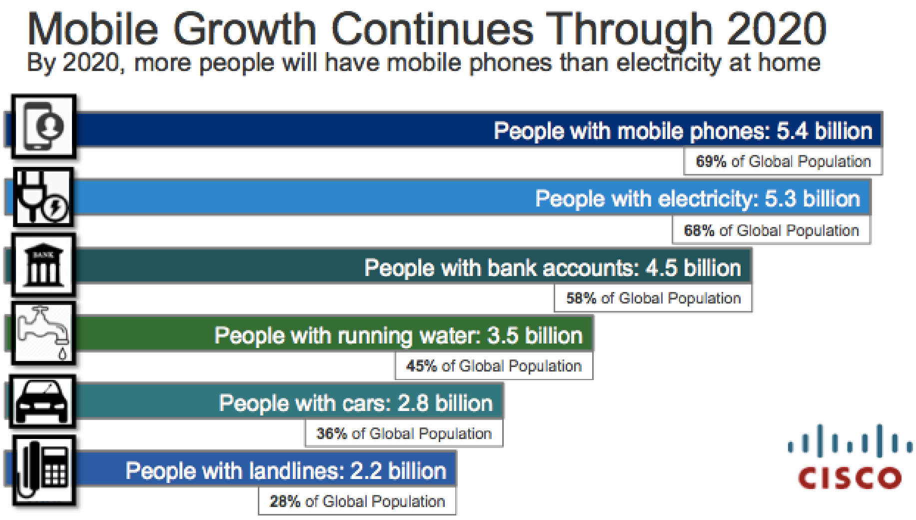

Fig. 9. Mobile Phone Growth [40]

Mobile phones have abundant advantages when it comes to data collection and analysis, as outlined below.

Pocket size and great versatility: Being handheld devices, smartphones can record, process and store an extensive range of data, such as video, audio, image and text, making them extremely versatile, which can release the archeologist from carrying expensive and dedicated devices. Smartphones provide instant access to information through Internet that can replace going through voluminous manuals. Showing video tutorials, the delivered information can be more illustrative and engaging.

A way to demystify mobile technology for traditional archeologists: simple and intuitive mobile apps can encourage people to use more digital devices, even those who are reluctant towards digital technology.

Less Data Entry Errors: Data recorded manually are prone to contain more mistakes than computerized ones. Thus, with control on data entry and being digital machines, smartphones reduce the mistakes of these data transcriptions. For instance, the function of spelling check can correct errors without having a messy document that is difficult to interpret. Automatic data record can include auditing functions, such as mandatory fields and defined range data that enhance the data quality.

Reducing the time between data collection, analysis and dissemination: Smartphones transfer data through Internet, which means data analysis can be initiated instantly. Besides, data collected electronically are easier to migrate or integrate with other systems. Moreover, no need to bring the data from the archeological site to the lab, since the Mobile technology could send the data immediately, which in turn improves the pace of sharing data with external users. Sharing data with the archeology community enhances keeping momentum and enthusiasm in the archeological findings, and empowers people to take their own informed choices about asset usage.

Improving the communication among the community: Beyond information sharing, the community can use the mobile technology to request experts for data verification and information dissemination.

Including more people and raising more awareness about the usage of mobile technology in the archeology discipline: The technology engages its advocates, especially young people who might be outside the community. This enables establishing a dialogue between young researchers who are computer proficient and 'traditional' archeologists who are experts in the field. Smartphones have the potential to engage users, empowering them all to be aware of the archeology updates. Presently, the archeology filed cannot follow the pace of the Mobile Era, without the mobile technology involved, how can the field cope with the post-device era?

Radiocarbon dating has its own limitations. The levels of C-14 have been elevated since the atomic bomb testing has started. Therefore, the dates really need to be calibrated to get good results. The precision of this technique is sometimes biased [41]. It figured out remarkable disparities in the radiocarbon dating results of objects of known age. Those objects were sent to thirty-eight specialized labs all over the globe. Thirty-one labs provided unsatisfactory results as per the British group. The discrepancies might have occurred due to inadequate lab standards letting impurity of the samples.

The main reason behind these errors and inaccuracies is partially because the dates are calculated in a laboratory environment where chemical methods are used to determine the number of carbon isotopes in the sample. In addition, the C14 concentration may fluctuate in the atmosphere. It is time for the archeology community to go beyond the radiocarbon dating technique and rely on more computing approaches and digital devices to cater for the growing error rates in measuring the ages of archeological artefacts.

6 Conclusions and Future Work

The archeology field needs more deployment of mobile technology solutions to reach other domains' maturity related to the computing sector. The use of computing solutions is of meagre nature in the field. This study highlighted the need of a clear path to remedy this digital divide. This research presented a comprehensive methodology on how to develop mobile apps for the archeology filed and its sub-domains. The introduction of two mobile apps about epigraphy and dendrochronology in this study describes the practical steps of the research. It demonstrates the benefits of following the suggested roadmap, such as better data collection, processing and sharing. It can also improve the collected information precision and dissemination among the community. It helps the archaeology activities to be less destructive. Adopting the proposed roadmap allows the archeologists to perform many of their duties onsite using handheld devices. It may open new perspectives for scientists in the field and enables them to explore new approaches that go beyond the traditional ways of measuring archeological items. With the advent of the mobile technology, scientists in the field can explore the possibility of developing new approaches to precisely measure the age of archeological artefacts. Hence, as future research endeavors, more mobile apps can be developed that meet the archeologists needs during their work onsite. Improving the first versions of mobile apps can lead to more established discipline where more researches can be conducted to provide more accurate age telling tools.

An ultimate future work could be the exploration of developing mobile apps, in an interdisciplinary context, that measure the age of archeological items by few clicks and prepare the field for the forthcoming post-device era.

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